Dublin City University
Ollscoil Chathair Bhaile Atha Cliath
School of Chemical Sciences

The Development, Implementation and Evaluation of Alternative Approaches to Teaching and Learning in the Chemistry Laboratory

Orla Kelly

PhD 2005

Volume 2 of 2

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

By

Orla Kelly B.Sc. (Hons)

A thesis submitted to Dublin City University for the degree of

DOCTOR OF PHILOSOPHY

This work was carried out under the supervision of Dr. Odilla Finlayson, School of Chemical Sciences, Dublin City University

September 2005

Volume 2 of 2

CONTENTS **VOLUME-PAGE**

CHAPTER 4

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

EVALUATION & CONCLUSIONS

4.1: INITIAL PROFILE OF THE STUDENTS

This chapter presents the evaluation of the PBL module in terms of the students' experience, their approach to learning and their academic achievement. This includes an investigation into the student's likes and dislikes of the PBL module, their experience of a traditional laboratory, their approach to learning in comparison with the traditional students, and their performance in their formal end-of-semester examinations, as well as an informal assessment. Where possible, the results are compared and contrasted with the traditional students i.e. the students following the traditional chemistry laboratories. The chapter begins with a profile study of the PBL cohort, including their prior experiences in terms of chemistry, and their Leaving Certificate points.

Initial intake survey

At the beginning of each year, each student taking the PBL module was asked to fill out a survey. Students from the last three academic years 2002-2003, 2003-2004 and 2004-2005 completed the survey with a response rate of 96%, 74% and 92% respectively. The survey asked the students for their reasons for coming to DCU, and for choosing the Science Education course. Also, included was their performance in the Leaving Certificate (i.e. CAO points) and the grades that they had obtained in science subjects and mathematics. See Appendix 4.1 for the full survey.

Using combined data from the three years, Figure 4.1 shows the course choice i.e. the number of students whose first preference was the Science Education (SE) course (#33), another teaching course (#9) or another course (#23). The bar chart shows clearly that just over half of the respondents chose the Science Education course as their first choice. The mature students were excluded (as they did not indicate their choice on the survey). Most students reported a desire to teach and an interest in science as reasons for choosing the course. Other teaching courses indicated by the students as their first choice included PE teaching, Home-Economics teaching and Mechanical Drawing teaching. Other courses that students gave as their first choice included Arts and Science as well as science related courses such as Aeronautical Engineering, Forensic Science, Nutritional Science, Optometry, Occupational Therapy, Pharmacy, Physiotherapy, Radiography, Sports Science and Health. Students indicated that factors such as locality, family and friends in DCU and/or in Dublin, and wanting to come to DCU as factors for choosing the Science Education programme.

Figure 4.1: Students first choice on CAO (SE cohorts 02-03, 03-04 & 04-05)

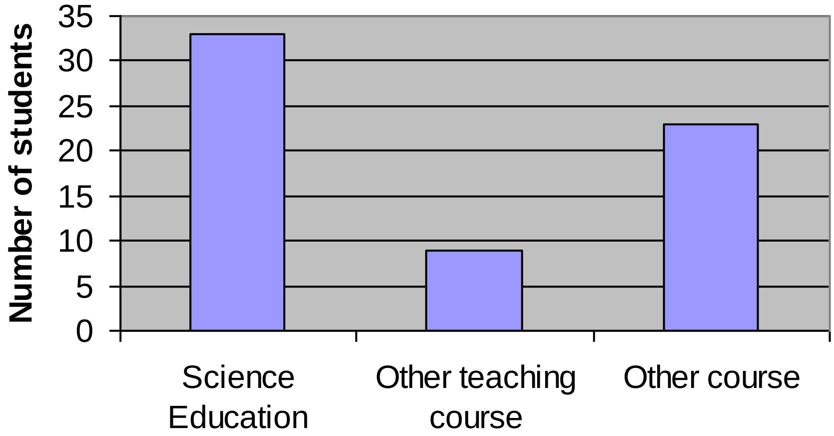
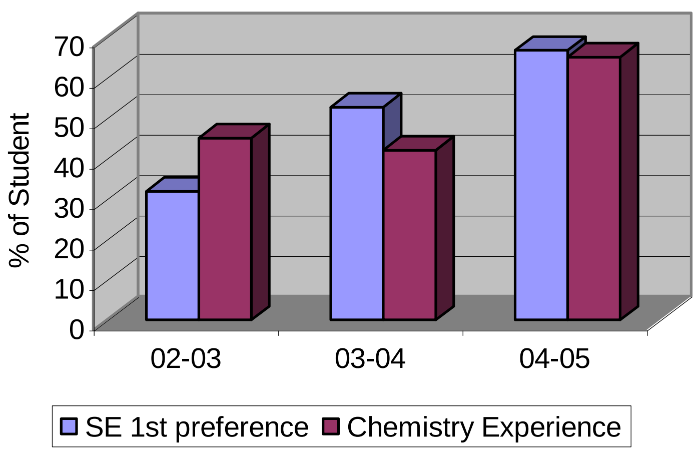


Figure 4.2 shows a comparison across the three cohorts in terms of the % of students from each cohort whose first preference was the Science Education degree. Further more the % of students who had prior chemistry experience (including Leaving Certificate Chemistry and other third level chemistry courses) is also shown. It is clear that the number of students who had given first preference for SE increased over the three years. This demonstrates that the majority of students (in 03-04 and 04-05 certainly) wanted to take this course, and suggests that they have an inherent interest in teaching and science, which may reveal itself in high motivation for the course. The CAO cut-off points for first round offers for this course over the last three years were 345 in 02-03, 330 in 03-04 and 400 in 04-05. Overall, the cohort from 04-05 scored significantly higher in their Leaving Certificate than either of the other two cohorts and also, has a significantly higher level of chemistry than students from 02-03.

Figure 4.2: Comparison of % of students who indicated Science Education as their first choice and % of students with chemistry in each cohort (02-03, 03-04 & 04-05)



4.2: STUDENT EXPERIENCE

Students taking the PBL module were asked to fill out various surveys to determine their experience of the module. These included surveys completed at the end of each semester and a survey comparing their experience of a traditional experiment in chemistry to PBL experiments. Semi-structured small group interviews were also conducted with ten students from the SE cohort from 2003-2004. The students selected were representative of the whole group in terms of gender, academic achievement in the PBL module and previous chemistry experience. A small number of students (10) from the traditional laboratory module were also selected to take part in similar interviews. The interviews were conducted by an independent person, who was given a series of questions which the students had to respond to. The interviewers encouraged the students to extend and elaborate on their answers, so as to get a real picture of their experiences. The interviews were held at the end of the second semester and reflected on the year long PBL module for the SE students and the year long chemistry module (CS151) for the traditional students. The results from the interviews are discussed in this section.

4.2.1: END OF SEMESTER 1

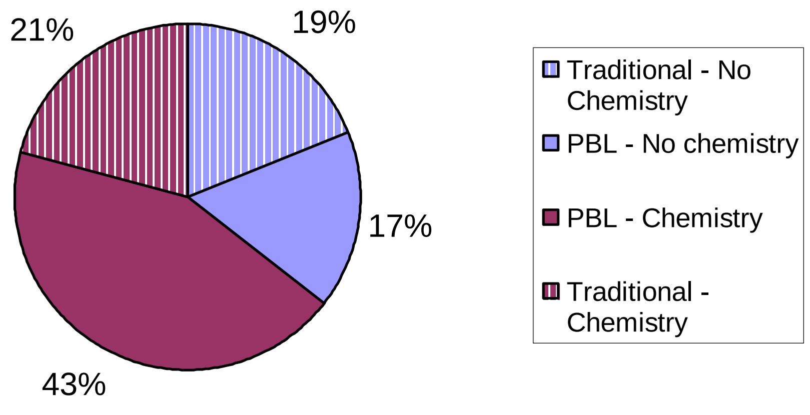
At the end of semester 1, the PBL cohorts were asked to complete a survey (Appendix 4.2) on their experience of the PBL module. This survey was carried out three times, at the end of semester 1 in the academic years 02-03, 03-04 and 04-05 with an overall response of 90.5%. The survey questioned the students on what they felt were the most and least beneficial aspects of the labs and asked them to list three things they liked and disliked about the labs. They also rated their experience of the chemistry labs with respect to six different factors – fun, learning experience, understanding, competency in techniques, calculations and tackling problems and indicated their preference for the PBL or traditional approach to lab work. They were also given space to suggest any changes and/or write comments.

At the end of semester 1, when each PBL cohort completed this survey, though they had not experienced the traditional approach in chemistry labs, they had experienced the traditional approach to labs in both physics and biology. In response to the question of which approach did they prefer, of the total number of respondents over the course of the three years (n = 67), 39% indicated a preference for a traditional method, whereas 61% were in favour of the PBL approach. The survey was adapted after the first year

(2002-2003) to allow students to indicate whether they had previously studied chemistry. This was to allow further in depth studies, for example to investigate if the preferences for either PBL or traditional were different overall for those who had and hadn't prior knowledge of chemistry before.

Since this adapted survey was only used with the last two cohorts (03-04 and 04-05) the sample size is reduced to 48. Figure 4.3 shows the breakdown for preference for each approach with respect to whether or not the students have studied chemistry before. The wine segments represent those who have studied chemistry before, whereas the blue segments represent the non-chemists. Secondly, the plain segments represent those with a preference for PBL, whereas the boxed segments represent the 'traditionalists'. This graph shows that a higher percentage of those who have studied chemistry before showed a preference for a PBL approach (43%) over a traditional approach (21%), whereas for the non-chemists the preference is fairly much 50/50. This may suggest that those who have done chemistry have a better experience with the PBL approach?

Figure 4.3: Breakdown of preference for each approach with respect to chemistry (SE cohorts 03-04 & 04-05)



A second study determined if there was a difference between the ratings for each of 6 factors – fun, learning experience, understanding, competency in techniques, calculations, and tackling problems between those students who showed a preference for PBL and those who didn't. For example, students were asked to rate themselves in terms of understanding on a scale of 1 to 5, with 1 meaning they understood nothing and 5 meaning that they understood everything or in terms of tackling problems, students who indicated a score of 1 meant that they ‘hadn’t a clue’ how to solve the problem, whereas 5 would indicate that they felt capable in tackling the problem. Table 4.1 shows the mean score and standard deviation for each cohort (i.e. those who indicated a preference for a PBL approach and those who indicated a preference for a traditional approach) for each factor, and the ‘t’ statistic, degrees of freedom (df) and significance (*p*). Remember, if the differences between the two means are significant, then the value for ‘*p*’ will be 0.05 or less for 95% confidence, or 0.01 or less for 99% confidence.

The results show that the mean ratings for ‘Fun’, ‘Learning experience’ and ‘Competency in techniques’ were no different for those participants who showed a preference for the PBL than for those who showed a preference for the traditional approach. In contrast, the mean ratings for ‘Understanding’, ‘Calculations’ and ‘Tackling problems’ were all significantly higher for those participants who showed a preference for the PBL than for those who showed a preference for the traditional approach. This shows that students who indicated a preference for the PBL approach felt they understood more, were better able to do their calculations and were better able to tackle the problem than those who indicated a preference for a traditional approach.

Table 4.1: Comparison of the mean scores for each factor against students’ preference for approach – Semester 1 (SE cohorts 02-03, 03-04 & 04-05)

FACTOR	PREFERRED APPROACH	MEAN	ST DEV	t	df	*p*
Fun	PBL	4.15	0.89	1.746	56	0.086
	Traditional	3.75	0.80			
Learning Experience	PBL	3.80	0.91	1.561	34	0.128
	Traditional	3.50	0.46			
Understanding	PBL	**3.85**	0.66	4.153	64	**0.000**
	Traditional	3.08	0.85			
Competency in techniques	PBL	3.82	0.76	0.958	66	0.342
	Traditional	3.64	0.70			
Calculations	PBL	**3.78**	1.00	4.563	64	**0.000**
	Traditional	2.62	1.02			
Tackling problems	PBL	**3.63**	0.54	2.712	64	**0.009**
	Traditional	3.15	0.87			

Analysing this data further showed there was a difference between the ratings for each of the 6 factors between those students who had done chemistry before and those who hadn't. Again since students' previous experience of chemistry was only asked in the last two years, this data represents only the SE cohorts from 03-04 and 04-05. The mean ratings for 'Fun', 'Learning experience' and 'Competency in techniques' were no different for those participants who have studied chemistry before than for those who haven't studied chemistry before. However, the mean ratings for 'Understanding', 'Calculations' and 'Tackling problems' was significantly higher for those participants who have studied chemistry before than for those who haven't, as shown in Table 4.2.

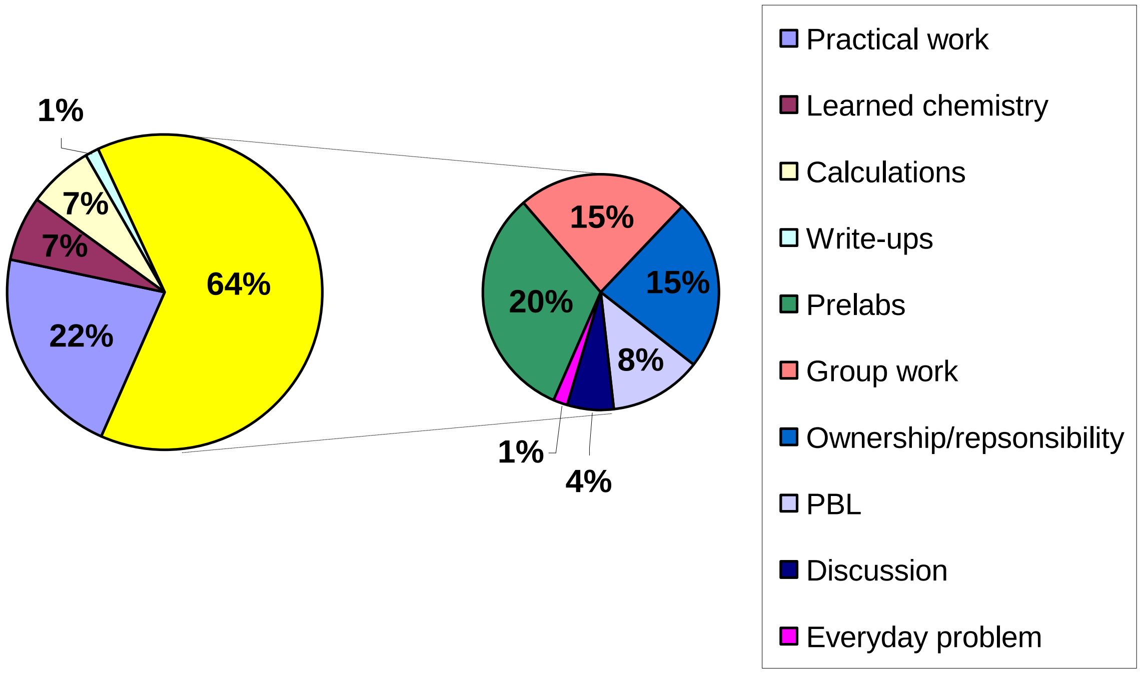
Table 4.2: Comparison of the mean scores for each factor against students' prior experience in chemistry – Semester 1 (SE cohorts 03-04 & 04-05)

FACTOR	CHEMISTRY	MEAN	ST DEV	t	df	*p*
Fun	Yes	3.97	0.93	0.446	40	0.658
	No	3.83	0.72			
Learning Experience	Yes	3.71	0.69	0.697	45	0.128
	No	3.63	0.72			
Understanding	Yes	3.71	0.90	2.520	45	**0.015**
	No	3.06	0.68			
Competency in techniques	Yes	3.97	0.90	1.808	43	0.078
	No	3.53	0.68			
Calculations	Yes	3.71	1.19	3.694	45	**0.001**
	No	2.44	0.96			
Tackling problems	Yes	3.68	0.79	3.395	45	**0.001**
	No	2.88	0.72			

Overall, understanding, ability to do calculations and tackling problems were identified as factors which those who have studied chemistry before rated higher than those who hadn't. Further analysis reveals that of those who have studied chemistry, those who indicated a preference for PBL rated only 'Calculations' significantly higher than those who indicated the traditional approach t(29) = 3.995, $\rho = 0.000$. Also, on analysis of the non-chemistry group, 'Understanding' and 'Competency in techniques' were revealed as the areas, which those who indicated a preference for PBL rated significantly higher than those with a preference for the traditional approach, t(14) = 3.489, $\rho = 0.004$ and t(13) = 2.257, $\rho = 0.042$ respectively. This suggests that for the non-chemists, those who indicated a preference for the PBL approach felt they understood more and were more competent in the techniques compared to the students who indicated a preference for a traditional approach. Furthermore, for the 'chemists', those who preferred the PBL approach felt they were better able to do the calculations compared to those who indicated a preference for a traditional approach.

In terms of the students' most beneficial aspect of the labs and their likes in contrast to their least beneficial aspects and their dislikes, fairly consistent results were seen over the three years. Cumulative data suggests that practical work, the pre-lab and other elements such as group work, and a feeling of ownership/responsibility were shown to be the most beneficial aspects of the labs. Figure 4.4 shows a summary of the beneficial aspects of the labs, with the yellow portion representing the PBL, this is then broken up into individual aspects of the PBL approach. Figure 4.4 shows that 64% of the students felt that one or other of the aspects of PBL were the most beneficial including the pre-labs (20% of the students) or group work (15% of the students). 22% of the students felt actually doing the experiments was the most beneficial.

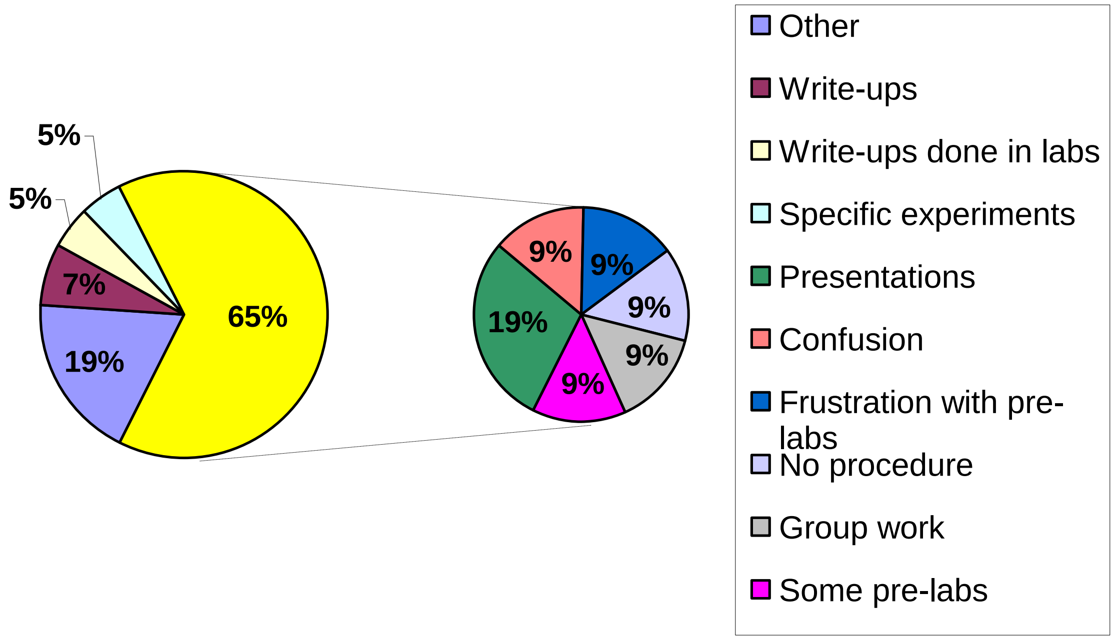
Figure 4.4: Pie chart of the most beneficial aspects of the labs (SE cohorts 02-03, 03-04 & 04-05)



In terms of their ‘likes’, ‘hands-on experience’, ‘group work’ and the ‘teaching and learning environment’ were the top three. These results have similarities with the beneficial aspects of the labs since the teaching and learning environment was defined mostly by the PBL approach, and obviously group work is an integral part of this approach too. Students also enjoyed actually getting hands on experience.

In contrast, ‘presentations’, the ‘fact that there was no procedure’, ‘difficulties with groups’, ‘frustration with pre-labs’ and sometimes ‘confusion’ at the start of labs were seen as the least beneficial aspects. Figure 4.5 shows a summary of the least beneficial aspects of the labs, with the yellow portion again representing the PBL, this is then broken up into individual aspects of the PBL approach. It is worth noting that the total number of least beneficial aspects listed was 43, in contrast to the 75 listed in the most beneficial aspect. Therefore, the percentages reflect a much smaller portion i.e. the 65% which felt that one or other aspect of the PBL approach was least beneficial in fact only represents 32 actual responses, in comparison to 48 responses which represents the most beneficial aspects of PBL. The calculations, and difficulties with calculations, the pre-lab work and the fact that the PBL group had more work to do than the other first year cohorts were listed as the factors, which were most disliked by the group.

Figure 4.5: Pie chart of the least beneficial aspects of the labs (SE cohorts 02-03, 03-04 & 04-05)



It is clear from both Figure 4.4 and 4.5 that there is overlap of some elements. For example, the benefit of pre-labs as recognised by these students is clear from Figure 4.4 but this is in contrast with students having a feeling of frustration with pre-labs (Figure 4.5). As one student commented:

> *'Sometimes even though a lot of pre-lab work can be done, sometimes you can have difficulty with calculations, in end losing marks – I think most marks should be given when there is adequate proof that pre-lab work was done!'*

However, to represent the other side of the argument, one student reports why pre-labs are the most beneficial aspect of the labs:

> *'Gave me as a student who hasn't done chemistry before an opportunity to get to grips with what I was doing before I went in.'*

The conflict between aspects that might be beneficial but not liked i.e. the prelabs, were summed up by the following two comments made during the interviews. The students were asked what aspects of the labs did you dislike:

> Student 1: *'Maybe the pre lab but I thought that was a good thing, so I'm contradicting myself'.*
>
> Student 2: *'I know what you mean but there were aspects of pre lab that bothered me as well even though I think it's a good idea'.*

Similarly, group work is factored into both the most and least beneficial aspects of labs. However, for those who reported a negative feeling toward group work this was due to one of two reasons:

a) Groups of three or more means less opportunity for hands-on experience
b) Within group conflict.

The latter point was made clear by one student who went on to suggest

> *'Let people select their own groups: after all, we are in college therefore responsible for ourselves, whether we work or not.'*

Results from this survey suggested that presentations were not seen as beneficial to many of the students, however this is in contrast to other results obtained through the interviews. Generally, the students that were interviewed commented very positively about the experience, as shown by the comments below from various students.

> *'They* (the presentations) *were enjoyable because you're trying to work out why and how am I going to use this result to make my point and all that kept everyone's interest'.*

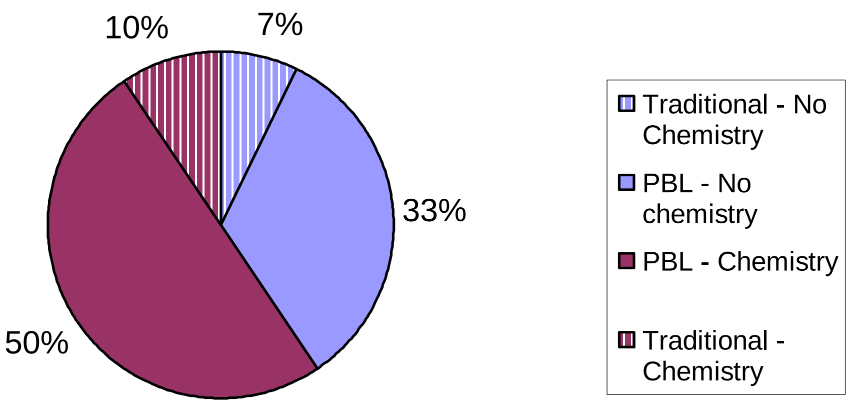
'There was loads involved in them (lab sessions) but you know, for the whole two or three hours you were down there you were really focused on what you were trying to get. You didn't want your results to be off because you were trying to argue your point with somebody. You were really working hard at the experiment'.

'It (the problem) *went on for two weeks and we had to make a presentation. That's actually one of the things I enjoyed most about the lab. I remember twice last semester we got to do that. We all used to have these big rows and it was a way of learning because we knew what we were talking about. We were able to learn from each other'.*

4.2.2: END OF SEMESTER 2

A similar survey was given to the students at the end of the 2nd semester. Since the 2nd semester PBL module was only run in the last two years, there is only two years of data available (2003-2004 & 2004-2005). The response rate was 85%, with a total population sample of 52. Initial analysis suggests that the PBL approach was more favoured at the end of semester 2, than at the end of semester 1. Figure 4.6 shows that overall 83% of students indicated a preference for a PBL approach over the traditional approach, in comparison to 60% at the end of semester 1 for the same cohorts. At this stage the students had carried out a traditional lab in chemistry as well as carrying out traditional labs in both physics and biology for the year.

Figure 4.6: Breakdown of preference for each approach with respect to chemistry



The reason for the decrease in number taking chemistry, from 64% at the end of semester 1 (Figure 4.3) and 60% at the end of semester 2 (Figure 4.6), is due to two reasons:

a) Each semesters' cohorts are slightly different as not every student filled out both surveys.
b) In 2003-2004 there was at least one student who dropped out during the 2nd semester.

Table 4.3 shows the results of a comparison of the mean rating for each factor between those who indicated a preference for a PBL approach and those who indicated a preference for a traditional approach. This shows that, overall, those who indicated a preference for a PBL approach rated their experience of labs in terms of the 'learning experience' and 'calculations' higher than their peers who indicated a preference for the traditional approach. This suggests that students, who indicated a preference for the PBL approach, felt they learned more and could do the calculations more successfully than those who indicated a preference for the traditional approach.

Table 4.3: Comparison of the mean scores for each factor against students' preference for approach – Semester 2 (SE cohorts 03-04 & 04-05)

FACTOR	APPROACH	Mean	Std. Dev.	t	df	ρ
Fun	Traditional	3.20	0.837	1.944	32	0.061
	PBL	4.10	0.976			
Learning experience	Traditional	2.86	0.690	3.040	40	**0.004**
	PBL	**3.63**	0.598			
Understanding	Traditional	3.00	0.816	1.443	40	0.157
	PBL	3.43	0.698			
Competency in techniques	Traditional	3.57	0.787	0.791	40	0.434
	PBL	3.83	0.785			
Calculations	Traditional	1.86	0.690	4.400	15	**0.001**
	PBL	**3.31**	1.207			
Tackling problems	Traditional	3.00	0.816	1.296	40	0.202
	PBL	3.51	0.918			

As before, a second study was done to monitor the differences between the experience of the 'chemists' and the 'non-chemists'. This time 'understanding', 'competency in techniques', 'calculations' and 'tackling problems' were all identified as factors that those who have studied chemistry before rated higher than those who hadn't. See Table 4.4. Further analysis reveals that of those who have studied chemistry and who indicated a preference for PBL rated 'Learning experience' and 'Calculations' significantly higher than those who indicated the traditional approach; t(23) = 3.118, $\rho = 0.005$ and t(23) = 2.937, $\rho = 0.007$ respectively. Interestingly, on analysis of the non-chemistry group, the t-tests show no significant difference between any of the factors for those who indicated a preference for PBL and those who indicated the traditional approach.

Table 4.4: Comparison of the mean scores for each factor against students' prior experience in chemistry – Semester 2 (SE cohorts 03-04 & 04-05)

FACTOR	CHEMISTRY	Mean	Std. Dev.	t	df	ρ
Fun	Yes	4.18	0.958	1.688	33	0.101
	No	3.62	0.961			
Learning experience	Yes	3.46	0.761	0.655	41	0.516
	No	3.59	0.507			
Understanding	Yes	**3.69**	0.549	4.250	41	**0.000**
	No	2.88	0.697			
Competency in techniques	Yes	**3.96**	0.662	2.093	41	**0.043**
	No	3.47	0.874			
Calculations	Yes	**3.46**	1.240	2.751	41	**0.009**
	No	2.47	1.007			
Tackling problems	Yes	**3.73**	0.874	2.607	41	**0.013**
	No	3.00	0.935			

Figure 4.7 summarises the most beneficial aspects of the labs according to the students. It is clear that the pre-lab, group-work and discussion, all aspects of the PBL approach, are among the top four mentioned, and the fact that they learned chemistry too! Figure 4.7 shows that 73% of the students felt that one or other of the aspects of PBL were the most beneficial aspect of the chemistry labs such as the pre-labs or group work. These

two aspects were also observed as the two most beneficial aspects within the PBL approach in the semester 1 survey showing consistency over the year.

Students' comments from this survey reflected the results above:

'Understanding what we were doing due to the pre-lab'

'Knowing what we were doing and the reason for it because of the PBL method'

Also, another student commented that the lectures and labs were more related than the previous semester.

'I felt the pre-labs were more connected to our lecture material'

Figure 4.7: Pie chart of the most beneficial aspects of the labs (SE cohorts 03-04 & 04-05)

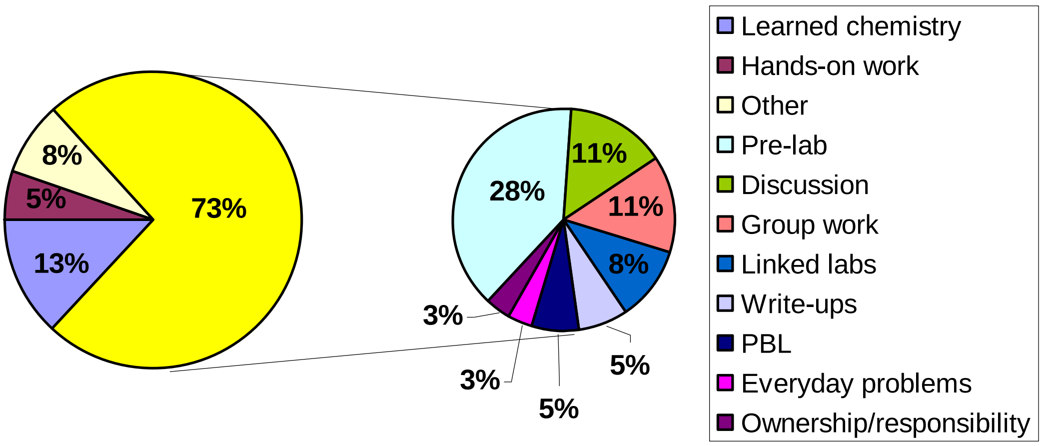
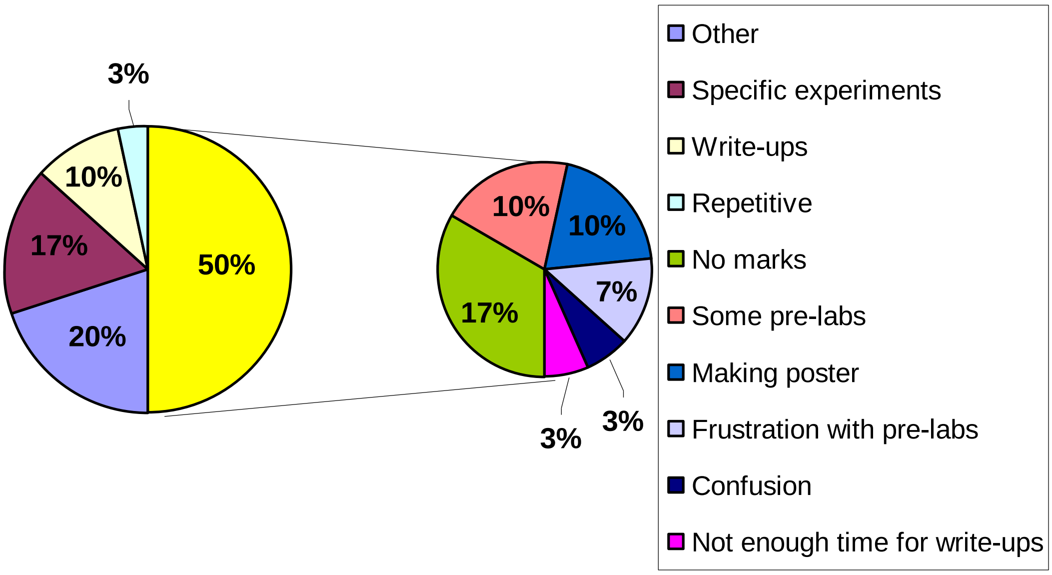


Figure 4.8: Pie chart of the least beneficial aspects of the labs (SE cohorts 03-04 & 04-05)



In contrast, students identified specific experiments as the least beneficial aspect of the chemistry lab module, as well as the fact that the students did not get regular marks. See Figure 4.8. Again the yellow segment reflects aspects of the PBL approach, and it is clear the fact that students felt that not being given regular marks was not beneficial. During semester 2, instead of giving students weekly marks for their lab reports, they were given written feedback on how they could improve their reports. They were then shown their marks at two stages during the semester in week 7 and week 12.

The background to giving comments only, with no marks, stems from research done by Butler[1] and Black[2]. Butler's research involved a controlled experimental study to determine the effects of three types of feedback – marks, comments, and marks and comments, with the study concluding that the learning gains were greatest when only comments were given. Black *et al.* studied various comments written by teachers and found that typical comments either stated a general evaluation or were geared to improving presentation. He suggests that these type of comments need to be replaced by 'others that informed students about what they had achieved and what they needed to do next'. Feedback by grades focuses students' attention on their ability rather than on the importance of effort whereas feedback which focuses on what needs to be done can encourage all to believe that they can improve, therefore enhancing learning through direct effort and indirectly through supporting the motivation to invest such effort. [2] For example, a student who receives a grade of 55% in their written report might be happy to have passed and therefore thinks the work they are doing is sufficient, however, if the same student is unaware of their actual mark and instead receives constructive feedback on their lab report, in theory they should strive to improve on this. However, it is clear from Figure 4.8 that students were uncomfortable with not receiving regular lab marks. Also, one student commented in the interviews that the effort put in on the part of the assessor, in terms of writing comments, was possibly not worth it.

> *'I don't know that the benefit to the student justifies the efforts on behalf of the teacher and I'm sitting here with a future teacher's hat on I honestly don't know whether it would but I think that the reviews that Orla did in the second semester quite possibly took more effort on her part than marking it saying 'yes, yes ok, five out of ten or fourteen out of twenty'.*

Finally, students also reported that certain pre-labs and doing the poster were other aspects of the PBL approach which they felt were not beneficial to the labs. The poster assignment in 2003-2004 was different to that in 2004-2005. The negative feedback about posters were from the cohort in 2003-2004. That year, students all did a poster on the aspirin problem (following the 3-week problem as described in Chapter 3) in pairs and presented their poster to other groups of students within the class. The obvious disadvantage was that there was repetition of the material over the whole class. However, some students still liked doing the poster as shown by the comment below:

> *Whereas with the other presentations we had no poster to make up. We just had to write up the results on the board. We had nothing to show for our work like. We went that extra little bit* (with the poster).

With relation to the pre-labs, one student commented in the interviews that they felt some pre-labs were pointless:

> *'I think some weeks pre labs had a reason behind them, then other weeks we were just getting pre labs for the sake of it, a lot of it I thought was kind of pointless'.* (Student from 03-04 cohort)

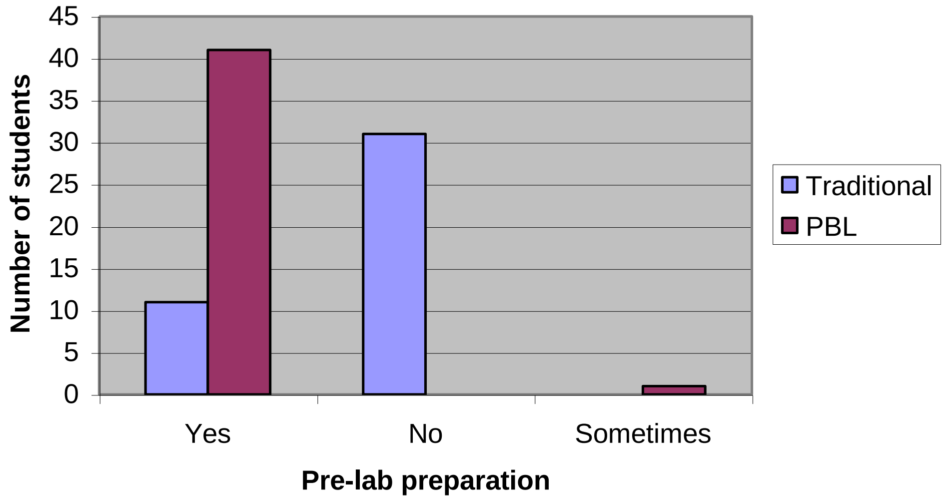
However, generally students found the pre-labs beneficial, even if they had mixed feelings on whether they liked them or not! Students reported pre-labs, the length of time spent on chemistry labs, the write-ups and finally the calculations as the least popular elements at the end of the second semester. It is worth noting again that the total number of least beneficial aspects listed was 30, in contrast to the 38 listed under the most beneficial aspects. Therefore, the percentages reflect a much smaller portion i.e. the 50% which felt that one or other aspect of the PBL approach was least beneficial in fact only represents 15 actual responses, in comparison to 28 responses which represents the most beneficial aspects of PBL.

4.2.3: COMPARISON OF THE STUDENTS' EXPERIENCE OF TRADITIONAL AND PBL LABS

At the end of the year long PBL module, the PBL cohort of students had the opportunity to do a traditional chemistry lab with the rest of the first year group. The following week, the PBL students were asked to complete a survey aimed at determining their attitudes towards the PBL and the traditional lab. See Appendix 4.3 for the survey. 19 of the 26 students (73%) completed the survey in 2003-2004, whereas 23 of the 26 students (88%) completed it in 2004-2005.

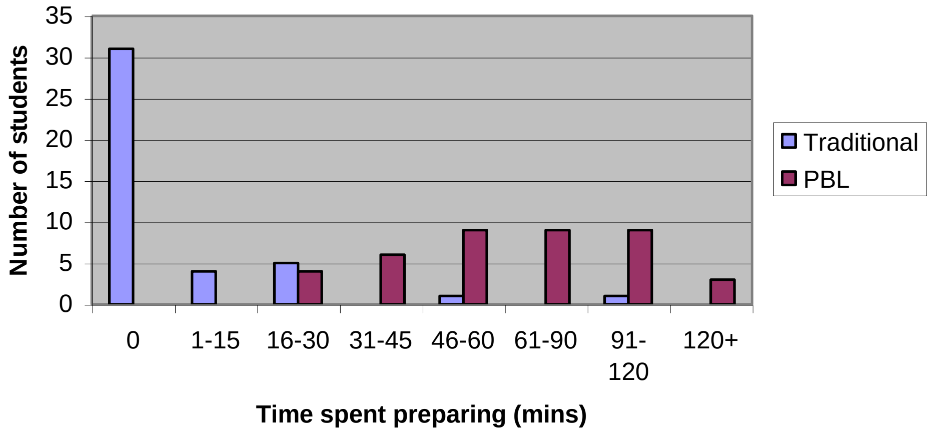
Students were initially asked if they prepared for the traditional labs, and if so, how much time did they spend? Secondly, they were asked the same questions in relation to the PBL labs. It is clear from Figure 4.9 that all of the students prepared for the PBL labs, in comparison to only 11 of the 42 who prepared for the traditional lab. A total of 31 people spent no time preparing for the traditional laboratory and those who did reported spending from 15 minutes (as long as it took to read the experiment) to 2 hours (Figure 4.10) Where as for the PBL labs, all students reported preparing for the labs, with the exception of one student who reported doing the pre-lab work only sometimes. On average, students spent approximately 70 minutes on their pre-lab work. Interestingly, the PBL cohort had spent all year doing pre-labs; however when they weren't being asked to do a pre-lab (i.e. not assessed) the majority of the students didn't prepare. Therefore it is necessary to give assessment marks for pre-lab work if we want students to take it seriously.

Figure 4.9: Comparison of the number of people who prepared for both types of lab



Students were asked to indicate which preparation was more effective – the preparation for the PBL labs or the preparation for the traditional lab. Though only 11 students reported preparing for the traditional labs, 20 students responded to this question. I suggest the extra 9 students were basing their answer on their preparation for other traditional labs such as in physics. Of those who did prepare for both, 17 of the 20 were in favour of the PBL preparation

Figure 4.10: Comparison of preparation times for both types of labs



Reasons for students indicating that the PBL preparation was more effective, as given by the students, are quoted below:

> *'I felt that I was working on something that would be of use in the lab.'*
>
> *'Because it was more of a problem that had to be solved so you had to understand what was going on.'*
>
> *'Techniques to be used had to be researched in order to understand them.'*
>
> *'We had to investigate the experiment ourselves instead of just reading briefly through a procedure, therefore we knew more about what we were doing.'*

In contrast, one student comments on why the traditional lab preparation was more beneficial:

> *'Your time is spent on the material rather than wasting time on guess work.'*

The next aspect of comparing the traditional and PBL labs was to determine:

- Which labs were easier to do from students point of view
- Which labs did they enjoy more
- Which lab did they feel they learned more from
- Which lab write-up was easier.

The results from these four questions are shown in Figure 4.11 (Figure 4.11a-d), with breakdown of students preferences in terms of either traditional, PBL or whether there was no difference (the same).

Figure 4.11a gives a breakdown of students' preferences in terms of which lab was easier. It shows clearly that the majority of the students found the PBL lab easier. Here are some of the explanations students gave for finding the PBL labs easier:

> *'I didn't know exactly what was happening in the traditional experiment, I was just following the procedure.'*
>
> *'Because it was easier to understand what we were doing.'*
>
> *'I just felt that the PBL made you think about what you were doing.'*

In comparison, students gave the following explanations for indicating that the traditional labs were easier:

> *'Procedure laid out – didn't need to think a lot.'*
>
> *'Because you are given a step by step method of how to conduct the experiment.'*
>
> *'Less work!'*

'Which lab did you enjoy more?' was the next question, and Figure 4.11b gives a breakdown of the results. Again, the majority of the students show a preference for the PBL approach. Two students quote there is no difference between the two approaches in terms of enjoyment, and another two are in favour of the traditional approach.

Some of the reasons given for students enjoying the PBL lab more include:

> *'Learned more, as with the traditional you're given the procedure don't have to really think about what your doing.'*
>
> *'When we had to present our results it was a bit of competition, good fun, also made us be more accurate.'*
>
> *'Because it made you think and it sometimes was a challenge. I like challenges.'*
>
> *'Gave the chance to learn why we were doing an experiment and research background to it. This allowed a proper understanding of the procedure rather than just following the manual.'*

In contrast, reasons cited for enjoying the traditional labs more include:

> *'Because didn't have to worry about pre-labs and lab reports outside lab times.'*
>
> *'The traditional lab was more enjoyable because I knew what I was doing during the lab.'*

The penultimate question was ‘Which lab did you feel you learned more from?’ and once again it was heavily in favour of the PBL approach, see Figure 4.11c. Similar explanations were given for preferring a PBL approach, including:

> *‘The PBL approach because (again) we usually had to look up the procedure before we came into the lab so therefore the experiments stuck in my head.’*
>
> *‘You get to relate it to life and what way the chemistry of the experiment relates to the world we live in.’*
>
> *‘By working out the procedure you understood exactly what you were doing.’*

The group was fairly divided on the final question ‘Which write-up was easier to do?’ with 20 students indicating that the traditional lab report was easier to do (see Figure 4.11d). Some of the reasons given for this include:

> *‘You could just copy straight from the lab manual.’*
>
> *‘Traditional lab is easier to do, but not of as much benefit.’*

The last part of the survey asked students

(a) ‘If given a choice, which approach would you choose to do?

(b) ‘If given a choice, which approach would you choose to do in 2nd year?

Of the 42 respondents, 36 and 35 respectively were in favour of the PBL approach in answer to (a) and (b) respectively, and therefore, 6 and 7 respectively in favour of the traditional approach showing that 83% of the group would choose to follow a PBL approach in second year despite the harder write-ups and the longer time spent outside the laboratory on pre-labs etc.

Figure 4.11: Breakdown of students' preferences in terms of…

Figure 4.11a: Which lab was easier

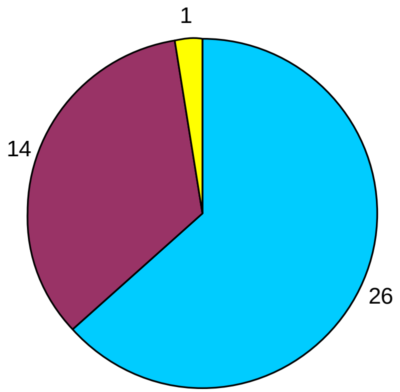


Figure 4.11b: Enjoyment of the lab

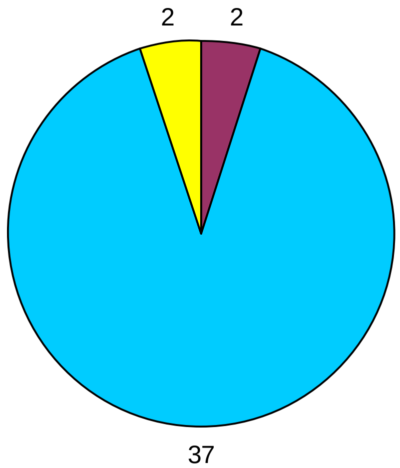


Figure 4.11c: Learning in the Laboratory

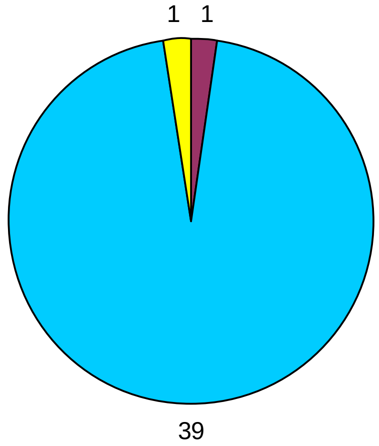
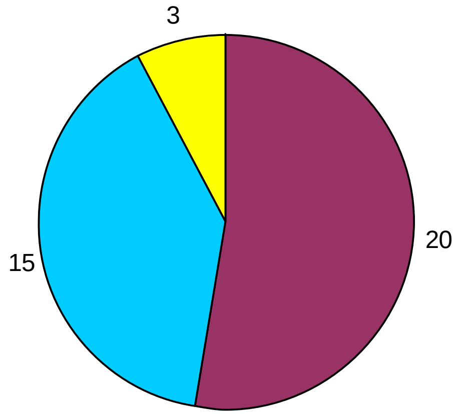


Figure 4.11d: Lab write-up



Legend: Traditional PBL Same

4.2.4: DISCUSSION OF OUTCOMES OF STUDENT SURVEYS

At the end of the second semester, 83% of the students indicated a preference for the PBL approach in comparison to 60% at the end of semester 1 (03-04 & 04-05 combined data). This is seen for both students who had previously studied chemistry and those who hadn't, suggesting that students seem to appreciate the PBL method more the longer they are doing it.

Students' ability to do calculations seems to be an important factor in whether they prefer the PBL or traditional approach. Students in both semester 1 and 2, who indicated a preference for PBL, rated their ability to do calculations higher than those who indicated a preference for the traditional approach. Other factors, which students reporting a preference for PBL rated significantly higher, were 'understanding' and 'tackling problems' in semester 1 and 'learning experience' in semester 2. Further analysing this data suggested that differences were observed between those who had and had not done chemistry previously. Table 4.5 shows an overall summary of the differences observed between the students who indicated a preference for the PBL approach and those who indicated a preference for the traditional approach in terms of whether or not they had done chemistry before. It shows clearly that in both semester 1 and semester 2 students who had studied chemistry before and who indicated a preference for the PBL approach scored their ability to do calculations in the labs much higher than those who had chemistry but indicated a preference for the traditional approach. The 'learning experience' was also rated higher for the students who preferred the PBL approach. In contrast, 'understanding' and 'competency in techniques' were rated by the students who had not studied chemistry before and preferred the PBL approach at the end of semester 1 in contrast to the students who also had no chemistry but indicated a preference for the traditional approach. By the end of semester 2 there were no observed significant differences between the ratings on each of the factors for the two cohorts. However, in all cases the cohort which indicated a preference for the PBL rated each factor higher, though often not significantly.

Table 4.5: Summary of the differences observed between the students who indicated a preference for the PBL approach and those who indicated a preference for the traditional approach in terms of whether or not they had done chemistry before.

CHEMISTRY	SEMESTER	FACTOR	PREFERRED APPROACH	> or =	PREFERRED APPROACH
Yes	1	Calculations	PBL	* > #	Traditional
	2	Calculations	PBL	* >	Traditional
		Learning experience	PBL	* >	Traditional
No	1	Understanding	PBL	* >	Traditional
		Competency in techniques	PBL	* >	Traditional
	2	All factors	PBL	=	Traditional

*Significantly higher >
For example, students, who had prior knowledge of chemistry and who preferred a PBL Approach, rated the factor 'Calculations' significantly higher than those with prior knowledge of chemistry who preferred a traditional approach.

Over the year, aspects of the PBL approach that were felt by the students to be most beneficial to the labs were the pre-labs and group work. However, pre-labs also featured in the least beneficial aspects and the dislikes. There is a definite element of contradiction here as outlined earlier in this section, though students may not have liked the prelabs, the majority did find them beneficial. Other dislikes included more work outside of the laboratory due to pre-lab work and the write-ups being done outside of the scheduled lab time. On a positive note, many students appreciated the friendly, relaxed, fun environment of the laboratory. Some student comments are shown below:

> *'No pressure to get everything right, just try what you think is right.'*
>
> *'We had more fun than the other classes – keep up the system.'*
>
> *'Really enjoyed the lab. Was the best part of the chemistry course so far! Thanks!'*

It was clearly shown from the survey comparing the PBL and traditional lab, that students felt they learnt more from the PBL labs and enjoyed them more too. The majority of students also found the PBL labs easier. However, the majority found the traditional lab write up easier, however, it is observed from the comments that this might be due to the fact that they can copy a lot from the manual. Furthermore, comments from the interviews suggest that the students actually have to understand what they are doing to write up their experimental conclusions in PBL and perhaps this is another reason why students find the traditional easier:

> *‘Conclusion takes time to do at the end even though calculations are pretty difficult but trying to think of something to write for a conclusion is hard because you basically have had to understand what you did.’*
>
> *‘Your conclusion kind of made you think of what you had learned’.*

The main message here is that despite the various dislikes and the negative aspects of the PBL experience as perceived by students, the majority – 83% - would choose to continue with a PBL approach if given the choice in second year, as one student commented:

> *‘I mean there were times that at the start when we would be giving out at the amount of work we had to do, but in hindsight it was worthwhile.’*

4.3: STUDENTS' APPROACH TO LEARNING

The main aim of this section is to determine the approaches to learning of the PBL students, to monitor any changes in their approach over time and to compare the PBL students to the traditional students in terms of their approaches to learning. The approach to learning of the students was determined using the Approaches and Study Skills Inventory for Students (ASSIST) as described in Chapter 2, which classifies learners as predominantly deep, strategic or surface.

An overview of the findings from the longitudinal work described in Chapter 2 is given below:

- Students adopt deep and strategic approaches over surface at the initial intake
- Students preferences for deep and strategic approaches decrease over time
- Students preferences for a surface approach increases over time

The survey was carried out at various stages during first and second year, over the course of three academic years as described for the main study in Chapter 2 (see Figure 2.5). The cohort beginning in 2002-2003 was sampled at three intervals, once at the beginning of semester 1 (Sampling Interval 1 – SI 1), again at the end of semester 1 (SI 2) and finally at the end of semester 3 (SI 3) in second year. The 2003-2004 cohort was sampled at four intervals, at the beginning of semester 1 (SI 1), the end of semester 1 (SI 2), the end of semester 3 (SI 3) and the end of semester 4 (SI 4). Finally, the 2004-2005 cohort was sampled twice, in semester 1 (SI 1) and at the end of semester 2 (SI 2). It is worth noting that the initial analysis of the 2004-2005 cohort, unlike the previous two years, was carried out after week 4 of semester 1, and not in week 1 as with the other years. An overview of the number of students from the PBL and traditional who completed the surveys at each sampling interval is given in Table 4.6.

Table 4.6: Number of students who completed the survey at each sampling interval

NO. OF STUDENTS	SAMPLING INTERVAL 1		SAMPLING INTERVAL 2		SAMPLING INTERVAL 3		SAMPLING INTERVAL 4	
Cohort	PBL	Trad.	PBL	Trad.	PBL	Trad.	PBL	Trad.
2002-2003	14	90	18	58	11	85		
2004-2005	20	129	16	64	8	34	15	59
2005-2006	17	60	23	93				

4.3.1: INITIAL PROFILE – COMPARISON OF PBL COHORT TO THE TRADITIONAL COHORT

Initial analysis involved determining the predominant approach to learning of the PBL and traditional cohorts from each year. Results from this analysis suggests that the first year students from all three years taking the PBL module are very similar to the traditional cohorts at the initial intake in terms of their approaches to learning. In 2002-2003 at the initial intake, both cohorts show a preference for deep and strategic over surface. In 2003-2004 similar results were found at the initial intake, with both cohorts indicating a preference for deep and strategic approaches over surface. Finally, in 2004-2005, which was the second year for the full PBL module to be tested, the PBL cohort once again showed preferences for deep and strategic over surface initially. However, the traditional cohort in this year showed no significant preference for any approach at the initial intake. See Figure 4.12 for the mean scores for deep, strategic and surface at the first sampling interval for each PBL cohort and Figure 4.13 for the mean scores for each approach at the first sampling interval for each traditional cohort. These show that the students generally showed the same trends, however, further analysis was needed to determine if there was any difference between the PBL and traditional cohorts mean score for deep, strategic and surface each year. This was carried out using independent t-tests.

Figure 4.12: Mean score for each approach for the PBL cohorts at the first sampling interval

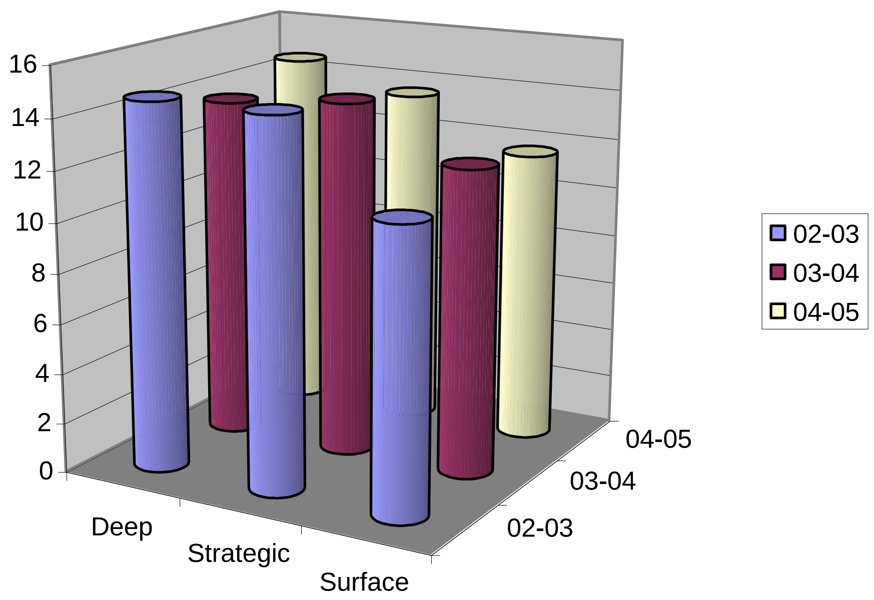
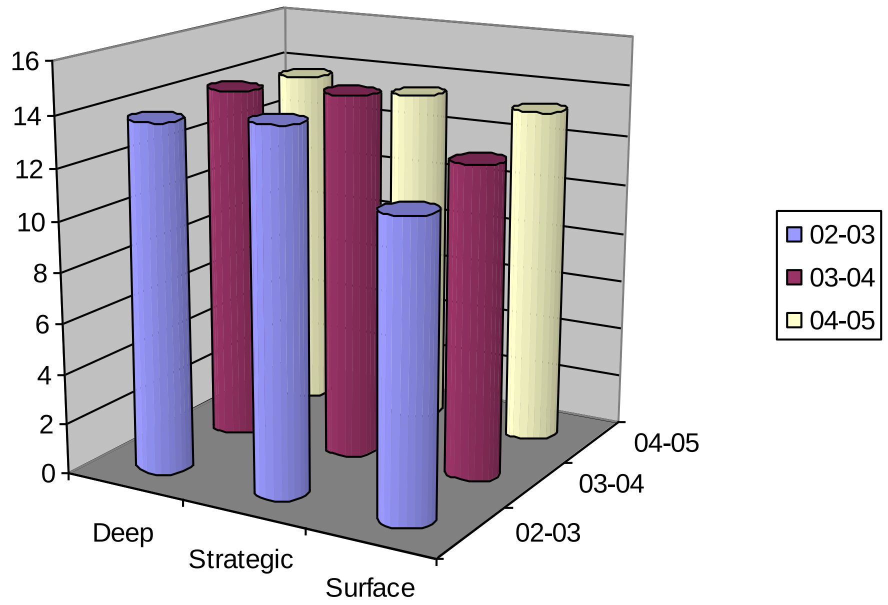


Figure 4.13: Mean score for each approach for the traditional cohorts at the first sampling interval



Independent t-tests between the PBL and traditional cohorts at the first sampling interval reveal that there is no significant difference between the PBL and traditional cohorts in either 2002-2003 or 2003-2004. In 2004-2005, the traditional students show a significantly higher preference for a surface approach at 95% confidence than the PBL students. This accounts for the fact that they show no preference for any approach, which was reported in the last paragraph i.e. because the mean score for surface is higher, the differences between the mean score for surface and strategic and between surface and deep are not significant. Table 4.7 shows the mean scores and standard deviation for each cohort, and the 't' statistic (t), degrees of freedom (df) and significance (*p*). Reminder, if the differences between the two means are significant, then the value for the significance will be 0.05 or less for 95% confidence, and 0.01 or less for 99% confidence.

Further investigation into the reported difference in the surface approach for the PBL and traditional cohorts in the academic year 2004-2005 reveals that the mean scores for the surface subscales 'unrelated memorising' and 'fear of failure' are significantly less for the PBL cohort than the traditional at 94% and 92% confidence respectively thus giving rise to the overall difference in the surface main scale (Figure 4.17c). Further studies of the subscales show that there are no significant differences in the mean scores for the deep or strategic subscales between the PBL and traditional cohorts in 2004-2005. There are also no significant differences in the mean scores of the subscales between the PBL and traditional students in 2003-2004. However, in 2002-2003 the PBL students score the two strategic subscales ‘Achieving’ and ‘Time management’ significantly higher than the traditional students (Figure 4.16a). However, this does not result in an overall significantly higher preference for a strategic approach.

Table 4.7: Comparison of PBL and Traditional at sampling interval one

YEAR	SUBSCALE	COHORT	MEAN	ST DEV	t	df	ρ
02-03	Deep	PBL	14.6	2.0	1.162	91	0.248
		Traditional	13.7	2.6			
	Strategic	PBL	14.6	1.8	0.611	91	0.542
		Traditional	14.2	2.4			
	Surface	PBL	11.3	3.0	-0.303	94	0.763
		Traditional	11.5	2.5			
03-04	Deep	PBL	13.7	2.9	-0.480	20*	0.637
		Traditional	14.0	2.3			
	Strategic	PBL	14.2	2.5	-0.296	143	0.468
		Traditional	14.4	2.5			
	Surface	PBL	12.2	3.0	-0.157	144	0.876
		Traditional	12.3	2.6			
04-05	Deep	PBL	14.6	2.2	1.057	75	0.294
		Traditional	13.8	2.9			
	Strategic	PBL	13.6	2.3	1.250	74	0.885
		Traditional	13.5	3.0			
	Surface	PBL	11.7	3.2	-1.993	73	**0.050**
		Traditional	**13.3**	2.8			

Similarly, the preferences for different types of courses and teaching reveal that overall students at the start of their college careers show a preference for teaching which ‘transmits information’ and not teaching which ‘supports understanding’. It is clear from Table 4.8 that the PBL and traditional cohorts have similar preferences at the start of the year, with no significant difference between the two groups over the three academic years for either preference.

Table 4.8: Comparison of PBL and Traditional at sampling interval one for preferences for different types of courses and teaching

YEAR	SUBSCALE	COHORT	MEAN	ST DEV	t	df	ρ
02-03	Supporting understanding	PBL	13.6	2.5	-0.1951	94	0.846
		Traditional	13.8	3.7			
	Transmitting information	PBL	16.7	3.8	-0.8293	95	0.409
		Traditional	17.4	2.7			
03-04	Supporting understanding	PBL	13.7	3.7	-0.5225	151	0.602
		Traditional	14.1	3.6			
	Transmitting information	PBL	17.9	2.1	1.29796	150	0.196
		Traditional	17.0	2.7			
04-05	Supporting understanding	PBL	13.1	3.1	-0.9615	77	0.339
		Traditional	14.0	3.5			
	Transmitting information	PBL	17.6	2.2	-0.4011	77	0.689
		Traditional	17.9	2.5			

The ASSIST inventory is used to investigate if changing the approach taken in one module can influence the overall approach to learning taken by the students. The next section reports on the changes in the PBL cohorts approach to learning and preference for teaching over time, in comparison to the traditional cohorts for each of the three academic years.

4.3.2: COMPARISON OF PBL AND TRADITIONAL COHORTS OVER TIME

Earlier in this section, the general trends in students' approaches to learning from the main study (Chapter 2) were presented. This showed that students from all three first year intakes generally show a decreasing preference for deep and strategic approaches and an increasing preference for surface approaches over time. This study aims to investigate if these observed changes in trends are the same for the PBL students and what are the differences in approach to learning of the PBL students in comparison to the traditional students. Figure 4.14 shows the mean scores for deep and surface approaches for both the PBL and traditional students for all three cohorts at each sampling interval. The strategic approach was not included as it distracts from the more conclusive trends for deep and surface since no differences were observed for the strategic approach.

Figure 4.14: Mean scores for deep and surface approaches for the PBL and traditional cohorts for each sampling interval for each intake

Figure 4.14a: 2002-2003 Intake

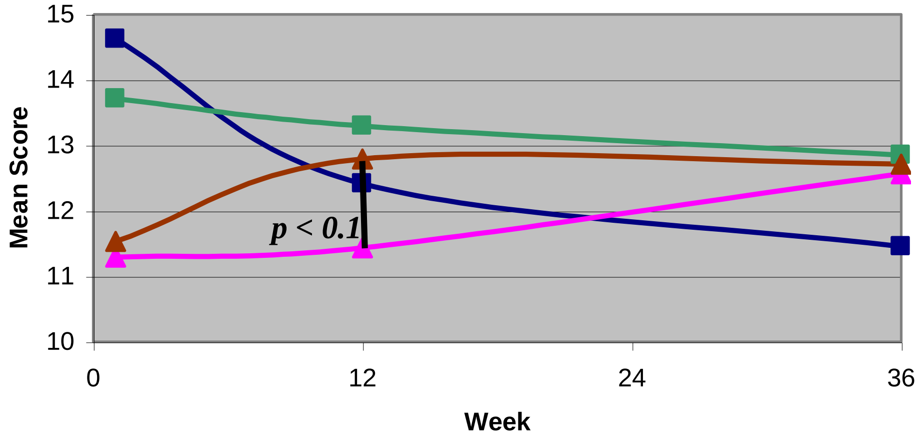


Figure 4.14b: 2003-2004 Intake

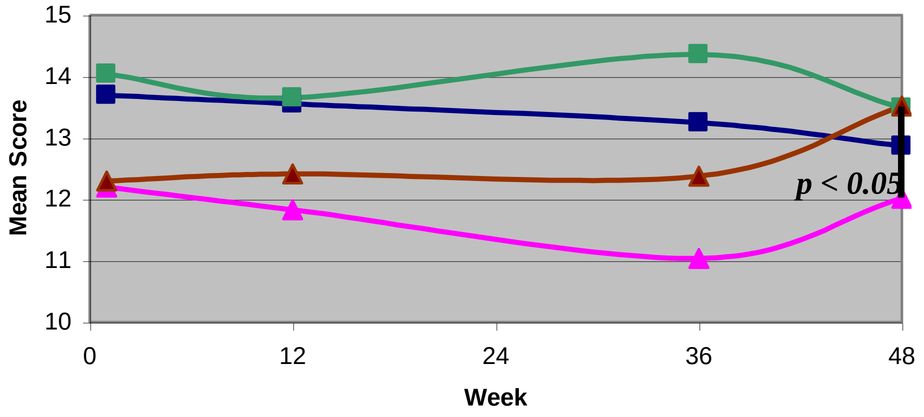
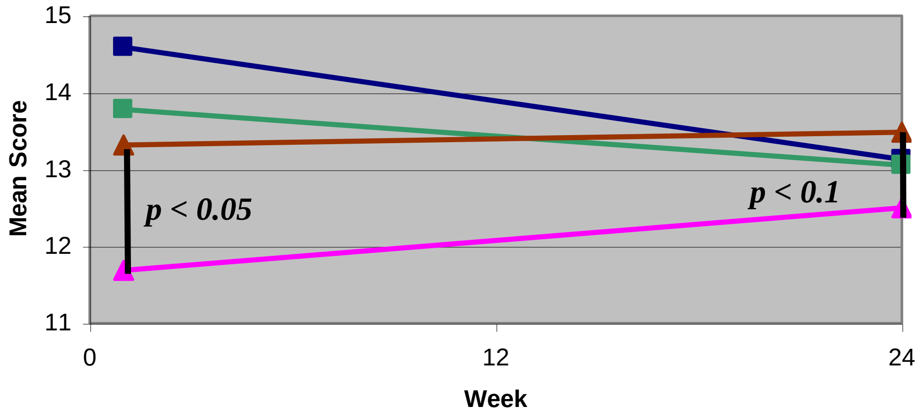


Figure 4.14c: 2004-2005 Intake



Legend: Deep PBL Deep Traditional
Surface PBL Surface Traditional

The graphs (Figure 4.14) also indicate where there are significant differences in the mean scores observed between the PBL and traditional cohorts. It is clear that in all three years, having completed the PBL module, the PBL students show a significantly lower preference for a surface approach i.e. in week 12 of 2002-2003 after one semester of the PBL module, in week 48 of 2003-2004 after the year long PBL module and in week 24 of 2004-2005 after the year long module. This suggests that the PBL students rely less on surface approaches and instead rely more on deep and/or strategic approaches. Furthermore, in two of the three years (02-03 and 03-04) the initial scores for a surface approach for both the PBL and traditional cohorts were very similar the graphs also show that the surface approach for the PBL students in consistently lower than the traditional students. To further investigate these observed differences and others each 1^{st} year intake will be discussed individually.

2002-2003

As highlighted in the previous section there was no significant difference between the PBL and traditional cohorts at the beginning of semester 1 in 2002-2003. Investigating the trend over time reveals that at the second sampling interval, the mean score for surface was higher for the traditional students (M = 12.789, SD = 2.4147) than for the PBL cohort (M = 11.433, SD = 3.1896), $t(64) = -1.773$, $p = 0.081$ as shown in Figure 4.14. This would suggest that the semester long PBL module was effective at keeping a surface approach to a minimum compared to the traditional approach. Further analysis shows that ‘syllabus-boundness’ and ‘fear of failure’ are the subscales, which give rise to this difference, with these subscales significantly lower for the PBL cohort at 93% and 90% confidence respectively than the traditional cohort. No other significant differences were observed at the second sampling interval. By the third sampling interval there is no difference between the two cohorts in terms of the overall approach. Interestingly, the traditional students score ‘Use of evidence’ and ‘Interest in ideas’ higher than the PBL students at the third sampling interval. A detailed overview of the mean scores of the deep, strategic and surface subscales for the PBL and traditional cohorts are given in Figure 4.15a, 4.16a, 4.17a. Where significant differences are identified between the PBL and traditional cohorts the level of significance is shown i.e. $p = <0.1$ indicates that the difference in the means are significant at 90% confidence. If no difference indicated, then there is no significant difference at 90% confidence or less.

Figure 4.15: Mean scores for the deep subscales for the PBL and traditional cohorts for each sampling interval for each intake

(PBL – Plain bar, Traditional – Spotted bar)

Figure 4.15a: 2002-2003 Intake

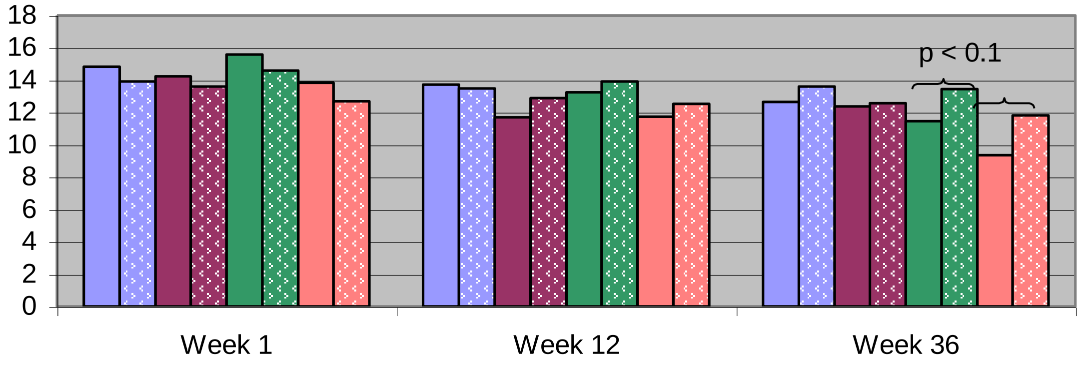


Figure 4.15b: 2003-2004 Intake

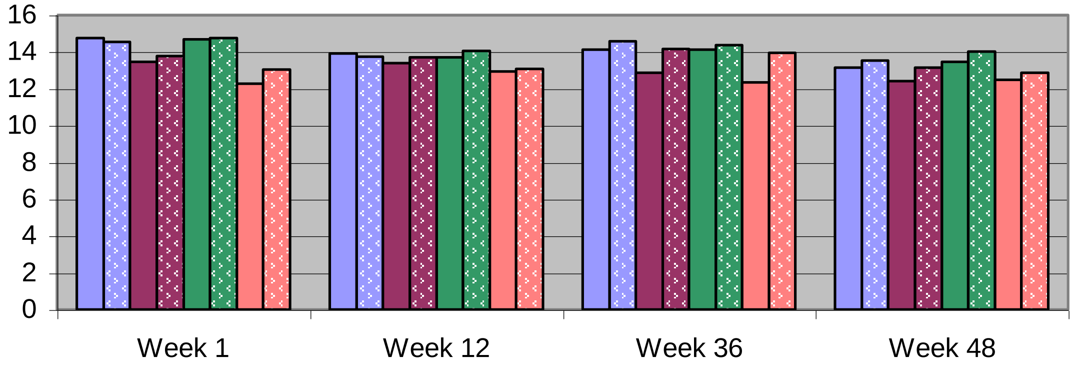
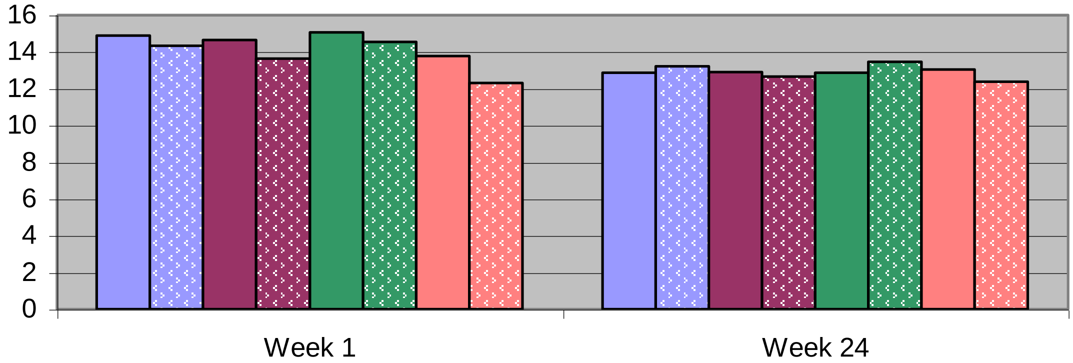


Figure 4.15c: 2004-2005 Intake



Legend: Seeking meaning, Relating ideas, Use of evidence, Interest in ideas

Figure 4.16: Mean scores for the strategic subscales for the PBL and traditional cohorts for each sampling interval for each intake
(PBL – Plain bar, Traditional – Spotted bar)

Figure 4.16a: 2002-2003 Intake

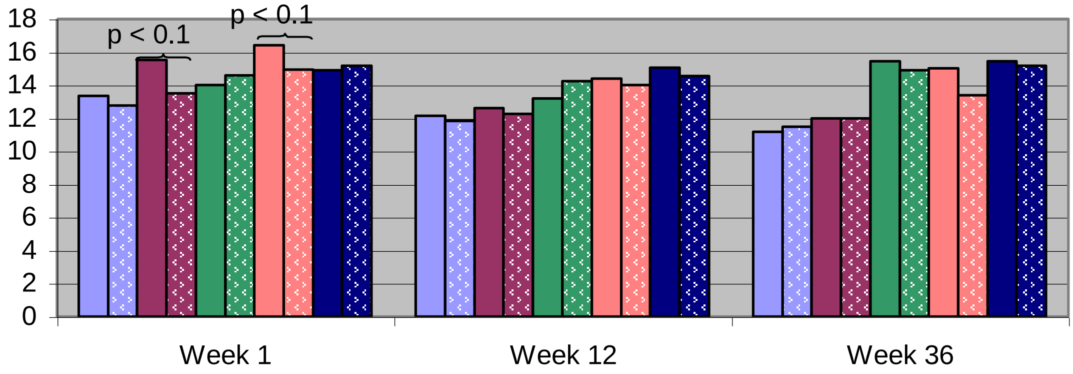


Figure 4.16b: 2003-2004 Intake

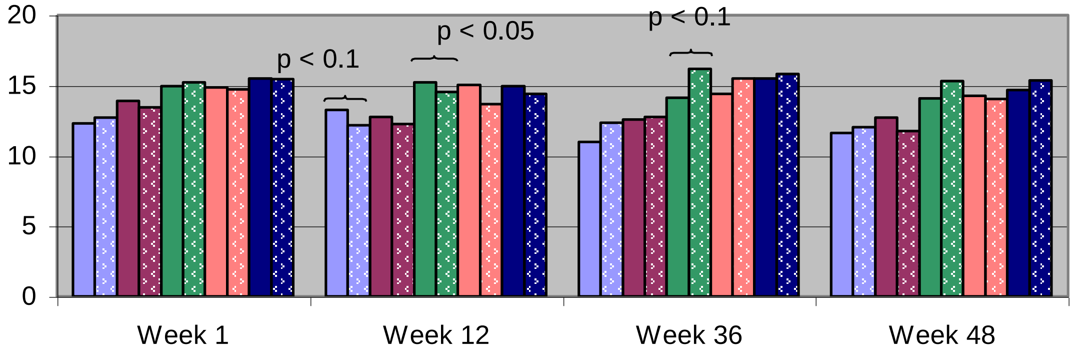
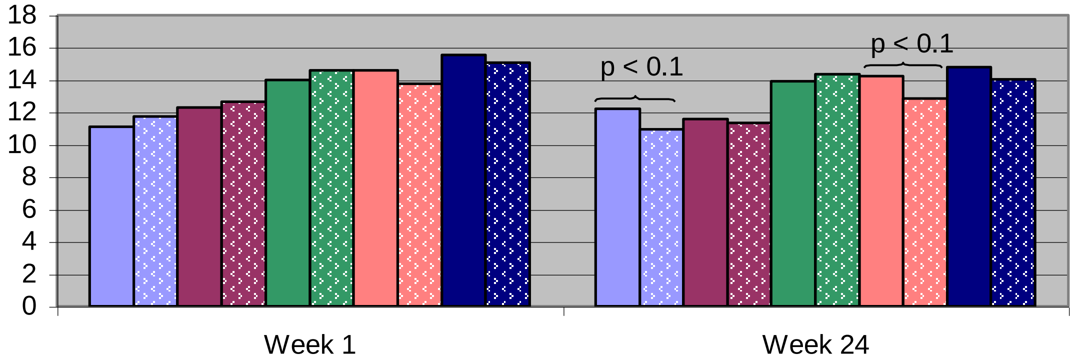


Figure 4.16c: 2004-2005 Intake



Legend: Organised studying, Time management, Alertness to assessment demand, Achieving, Monitoring effectiveness

Figure 4.17: Mean scores for the surface subscales for the PBL and traditional cohorts for each sampling interval for each intake

(PBL – Plain bar, Traditional – Spotted bar)

Figure 4.17a: 2002-2003 Intake

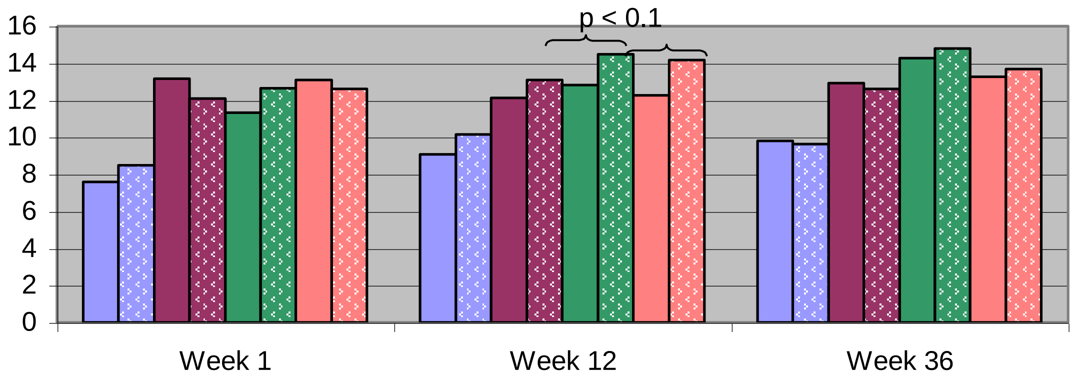


Figure 4.17b: 2003-2004 Intake

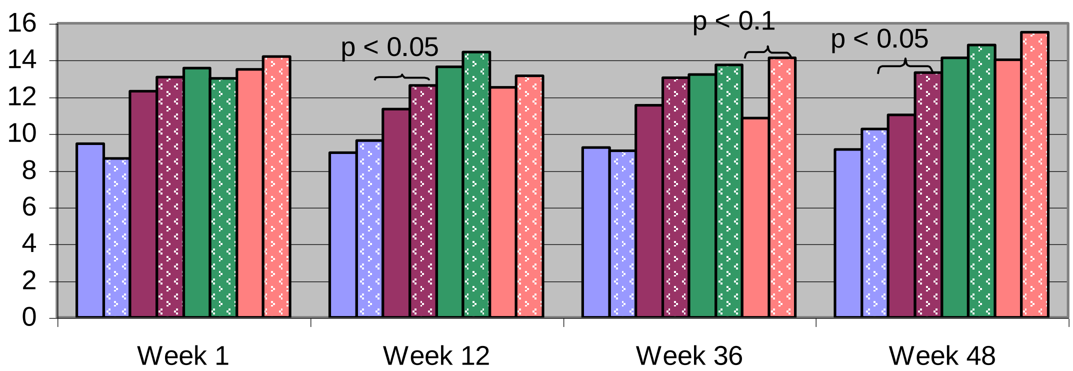
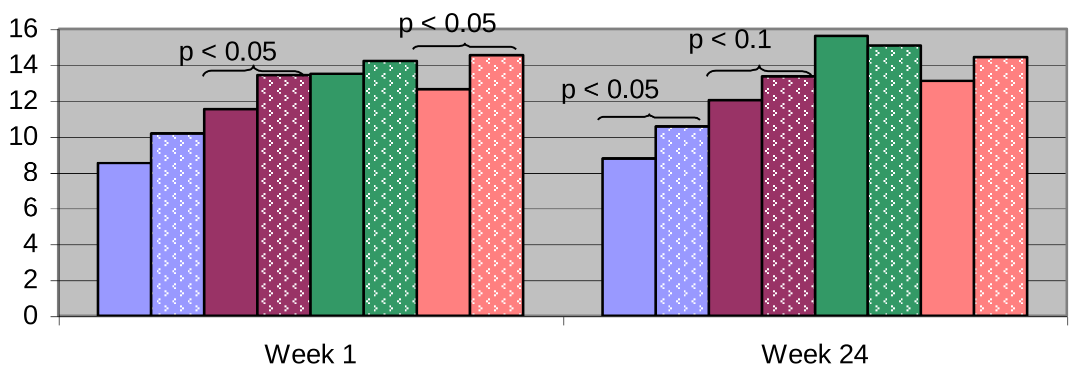


Figure 4.17c: 2004-2005 Intake



Legend: Lack of purpose; Unrelated memorising; Syllabus boundness; Fear of failure

It was discussed in Chapter 2 that the deep approach decreased over time for this cohort of first years, and it is clear from Figure 4.14a that the deep approach is decreasing for both the PBL (from 14.6 to 12.4 to 11.5) and traditional cohorts (from 13.7 to 13.3 to 12.8) over the duration of the trials. Since the students were not identified at the second sampling interval direct comparison is only possible between the first and third sampling interval. Paired t-tests reveal that both the PBL and traditional cohorts show a significant decrease for a deep approach over time, however the PBL cohort show a highly significant decrease at 99% confidence in comparison to the traditional cohort, which is only significant at 94% confidence. See Table 4.9. However, it is worth remembering that the number of students, from the PBL cohort, who completed both surveys was only 3 and therefore, the result is possibly not representative of the group. The trend is however confirmed by Figure 4.14a. Both groups also show a decrease in preference for a strategic approach from the first to the third sampling interval. See Table 4.9. This is also similar to the overall trend observed in the main study. The traditional students also show a significant increase in surface from the first to the third sampling interval, a similar increase is also seen for the PBL students but due to the low numbers the difference is not reported as significant.

Table 4.9: Comparison of each main approach mean between sampling interval 1 and 3 for the PBL and traditional students from 02-03

COHORT	SUBSCALE/WEEK	MEAN	ST DEV	t	df	ρ
PBL	Deep –Week 1	14.250	1.51383	6.481	3	**0.007**
	Deep – Week 36	12.500	1.19024			
	Strategic –Week 1	14.800	2.0000	2.640	3	**0.078**
	Strategic – Week 36	12.300	0.41633			
	Surface –Week 1	10.417	2.24072	-0.697	2	0.558
	Surface – Week 36	11.583	2.56580			
Traditional	Deep –Week 1	13.524	2.54760	1.944	41	**0.059**
	Deep – Week 36	12.857	2.79052			
	Strategic –Week 1	14.029	2.44318	2.149	40	**0.038**
	Strategic – Week 36	13.146	2.94619			
	Surface –Week 1	11.458	2.79531	-2.965	41	**0.005**
	Surface – Week 36	**12.655**	2.75136			

‘Time management’ and ‘achieving’ are two strategic subscales, which significantly decreased for both the PBL and traditional cohorts from the first to the third sampling interval, whereas the surface subscale ‘syllabus-boundness’ significantly increased for both. Fear of failure also was reported to increase significantly for the traditional cohort. Details are given in Table 4.10. No other significant changes in subscales are observed from the first to the third sampling interval.

Table 4.10: Subscales, which are significantly different from sampling interval one to three for both PBL and traditional cohorts (02-03)

SCALE	COHORT	MEAN DIFFERENCE WEEK 1 – WEEK 36	t	df	ρ
Time management	PBL	5.5	3.538	3	**0.038**
	Traditional	1.4	2.704	44	**0.010**
Achieving	PBL	4.5	15.588	3	**0.001**
	Traditional	1.6	3.441	45	**0.001**
Syllabus-boundness	PBL	-4.5	-3.781	3	**0.032**
	Traditional	-2.4	-3.586	44	**0.001**
Fear of failure	PBL	1.0	0.397	3	0.729
	Traditional	-1.0	-1.806	46	**0.078**

In terms of preferences for different types of course and teaching, the trend for both cohorts remains the same with both cohorts showing a highly significant preference for teaching which transmits information (TI) over teaching which supports understanding (SU). Table 4.11 shows the results for the paired t-tests for both the PBL and traditional cohorts at the second sampling interval. Also, both cohorts reveal that over time, their preference for teaching, which supports understanding, decreases significantly, similar to the trends observed in the main study (see Section 2.3.3.4). For example, for the traditional cohort, the mean decrease in their preference for teaching which supports understanding from the first sampling interval to the third sampling interval was 1.6667, $t(44) = 2.964$, $p = 0.005$. The traditional cohort also shows a simultaneous increase in their preference for teaching which transmits information, with a mean difference of –1.1304, $t(45) = -2.699$, $p = 0.010$.

Table 4.11: Paired t-test results for preferences at second interval for both cohorts

COHORT	PREFERENCE	MEAN	ST DEV	t	df	ρ
PBL	Supporting understanding	11.8125	2.61327	-4.421	15	**0.000**
	Transmitting information	17.0000	3.01109			
Traditional	Supporting understanding	12.4630	3.86915	-7.748	53	**0.000**
	Transmitting information	17.9074	2.32519			

2003-2004

The PBL cohort from 2003-2004 completed the ASSIST inventory at four intervals as discussed in the beginning of Section 4.3. It was reported earlier that there was no significant difference between the PBL and traditional cohorts at the initial intake in either the approaches or within the subscales. (See Figure 4.15b, 4.16b & 4.17b). Independent t-tests at each sampling interval for each approach between the two cohorts, PBL and traditional, reveal that the only significant difference is at the fourth sampling interval where the surface approach is significantly less for the PBL cohort (M =12.0179, SD = 2.3482) compared to the traditional cohort (M = 13.5212, SD = 2.3881), $t(71) = -2.1240$, $p = 0.037$. (Table 4.11). An analysis of the subscales for this interval and approach show that 'unrelated memorising' is significantly higher for the traditional cohort compared to the PBL cohort. There are no other significant differences at this sampling interval. It is worth noting that the PBL students, after the initial sampling, consistently report a lower mean score for a surface approach compared to the traditional students, though the difference is not statistically significant.

Though there are no overall significant differences in approach between the PBL and traditional cohorts at either the second or third sampling interval, analysis of the results indicates interesting differences in strategic and surface subscales. (Figure 4.16b & 4.17b). Strategic subscales, 'organised studying' and 'achieving' are observed to be significantly higher for the PBL cohort at the second sampling interval and furthermore, the PBL cohort also report a significantly lower score for the surface subscale 'unrelated memorising'. Considering that 'organised studying' was a serious concern for students in the longitudinal study described in Chapter 2, this may suggest that the PBL students are better able to manage their study. At the third sampling interval the traditional students report 'alertness to assessment demands' and 'fear of failure' significantly higher than their PBL peers. PBL students score lower on 'unrelated memorising' at the fourth sampling interval suggesting that generally they have a better sense of purpose to their learning, and are not just rote-learning material that has no meaning to them.

Table 4.11: Comparison of PBL and Traditional at each sampling interval for 2003-2004 cohort

APPROACH	SAMPLING INTERVAL	COHORT	N	MEAN	ST DEV	t	df	ρ
Deep	1	PBL	18	13.6944	2.9350	-0.4798	20	0.637
		Traditional	129	14.0407	2.3326			
	2	PBL	13	13.5577	2.8888	-0.1229	75	0.902
		Traditional	64	13.6563	2.5841			
	3	PBL	8	13.2500	2.8847	-1.0104	40	0.318
		Traditional	34	14.3603	2.7772			
	4	PBL	15	12.8667	2.8471	-0.8224	70	0.414
		Traditional	57	13.4868	2.5326			
Strategic	1	PBL	18	14.1778	2.4532	-0.2959	143	0.768
		Traditional	127	14.3638	2.5019			
	2	PBL	16	14.1875	1.7701	0.9760	77	0.332
		Traditional	63	13.5175	2.5905			
	3	PBL	7	13.3714	2.6794	-1.2167	35	0.232
		Traditional	30	14.5733	2.2802			
	4	PBL	15	13.4667	2.2369	-0.3710	72	0.712
		Traditional	59	13.7390	2.6059			
Surface	1	PBL	20	12.2000	3.0247	-0.1566	144	0.876
		Traditional	126	12.2996	2.5786			
	2	PBL	16	11.8281	2.3782	-0.8385	77	0.404
		Traditional	63	12.4127	2.5165			
	3	PBL	7	11.0357	3.3368	-1.0917	39	0.282
		Traditional	34	12.3750	2.8810			
	4	PBL	14	12.0179	2.3482			
		Traditional	59	13.5212	2.3881	-2.1240	71	**0.037**

To determine specific changes in the PBL students approach to learning over time a series of paired t-tests were carried out. Although 77%, 62%, 31% and 58% of the PBL cohort completed the survey at sampling intervals 1-4 respectively only 19% of the students successfully completed all four surveys. Therefore, a 'repeated measures ANOVA' analysis, to investigate the change over time, is not beneficial as the sample size is too small and not representative of the group. Figure 4.14b shows the trend for deep and surface for the PBL and traditional cohorts as each sampling interval. It is clear from the graph that the profile of both cohorts changes over time. However, paired t-tests between sampling intervals 1 and 2, 1 and 3, and 1 and 4 suggest that there are no significant changes in the PBL cohort over time. This may be due to the small sample size, and significant differences will only be noted for very large shifts in preferences. Figure 4.14b shows that the PBL cohort scores the surface approach consistently lower than the deep approach, and the strategic approach is also observed to be higher than the surface (though it is not shown on the graph). It is only at the fourth sampling interval that their preference for a surface approach increases to the same level as the traditional students. Unfortunately, the PBL cohort shows a consistent decrease in their preference for the deep approach over time, however, paired t-tests reveal that this decrease is not significant. In contrast to their traditional counterparts, the PBL students show very little change with regards the subscales with only 'time management' and 'achieving' showing significant decreases over time.

There is no significant difference between the traditional and PBL cohorts in terms of the preferences for different types of course and teaching over the course of the two years except at the fourth sampling interval where the traditional cohort has a statistically higher mean (M = 18.1746, SD = 1.9637) than the PBL students (M = 17.0000, SD = 2.3905), $t(76) = 1.995$, $p = 0.05$ for teaching which transmits information.

2004-2005

The 2004-2005 cohort was sampled at two intervals, at the beginning and the end of their first year. This is in contrast with the previous two years groups, who were surveyed at the end of the first semester rather than the end of the second semester. Initial findings from Figure 4.14c suggest that while the PBL cohorts preference for a deep approach decreases over time their preference for a surface approach increases. However, it is worth remembering that this cohort showed a statistically lower preference for surface approach at the initial sampling compared to their traditional counterparts so were significantly less ‘surface’ than the majority of their peers from the offset. Comparison of the PBL and the traditional cohort at the second sampling interval shows no significant difference except for the surface approach, which is significant at 90% confidence. See Table 4.12. This shows the PBL cohort are still significantly less surface than their traditional counterparts, however, this difference is not as significant as it was at the beginning of the year.

Table 4.12: Comparison of PBL and traditional cohorts at the end of semester 2 for each main scale (04-05 cohort)

APPROACH	COHORT	MEAN	ST DEV	t	df	ρ
Deep	PBL	13.1304	2.37992	0.122614	110	0.903
	Traditional	13.0562	2.63870			
Strategic	PBL	13.4091	2.75437	1.226423	110	0.223
	Traditional	12.6889	2.39684			
Surface	PBL	12.5000	2.22004	-1.75655	113	0.082
	Traditional	13.4839	2.39389			

‘Lack of purpose’ and ‘unrelated memorising’ were the two surface subscales which gave rise to the difference in the traditional and PBL cohorts at the end of the year. See Figure 4.17c for differences in the surface subscales for the two sampling intervals. ‘Lack of purpose’ was higher for the traditional cohort (M = 10.5684, SD = 3.96703) than for the PBL cohort (M = 8.7727, SD = 3.23569) at the end of the year,, $t(115) = 1.974$, $p = 0.051$. ‘Unrelated memorising’ was also higher for the traditional cohort (M = 13.3617, SD = 3.03333) than for the PBL cohort (M = 12.0435, SD = 2.93069) at the end of the year, $t(115) = 1.3182$, $p = 0.063$. Analysis of the other subscales revealed that the strategic subscales ‘organised studying’ and ‘achieving’ were significantly higher for the PBL cohort than the traditional at the second sampling interval. See Figure 4.16c. These results are very similar to the 2003-2004 cohort, where at the end of the first semester the PBL students scored ‘organised studying’ and ‘achieving’ significantly higher and ‘unrelated memorising’ significantly lower than their traditional counterparts.

Paired t-tests reveal that there is a significant decrease in the PBL cohort's preference for a deep approach from the first (M = 14.69, SD = 2.182) to the second sampling interval (end of the year) (M = 12.875, SD = 2.553), with a mean difference of 1.8125, $t(15) = 2.889$, $p = 0.011$. Further analysis reveals that the three deep subscales 'seeking meaning', 'relating ideas', and 'use of evidence', are significantly less from the first to the second sampling interval with a mean difference of 2.500, $t(15) = 2.576$, $p = 0.021$, 2.500, $t(15) = 3.762$, $p = 0.002$, and 2.375, $t(15) = 2.657$, $p = 0.018$ respectively. The only other subscales which show a significant difference is the surface subscale 'syllabus-boundness', which shows a mean difference of –2.0667, $t(14) = -2.869$, $p = 0.012$ from the first to the second sampling interval, which can explain most of the increase in the surface approach. The strategic main scale shows no significant differences in any of the subscales. Details are given in Table 4.13.

Table 4.13: Comparison of each main scale and subscale for the PBL cohort from sampling interval 1 to 2 (Week 4 Sem 1 to Week 24 Sem 2)

SCALE	MEAN DIFFERENCE WEEK 1 – WEEK 24	t	df	ρ
DEEP	1.813	2.8894	15	**0.011**
Seeking meaning	2.500	2.5763	15	**0.021**
Relating ideas	2.500	3.7618	15	**0.002**
Use of evidence	2.375	2.6571	15	**0.018**
Interest in ideas	0.688	0.7190	15	0.483
STRATEGIC	0.133	0.2797	14	0.784
Organised studying	-0.867	-1.1478	14	0.270
Time management	0.438	0.5946	15	0.561
Alertness to Assessment	-0.250	-0.2692	15	0.791
Achieving	0.125	0.2505	15	0.806
Monitoring effectiveness	0.875	1.2387	15	0.234
SURFACE	-0.400	-0.5257	14	0.607
Lack of purpose	0.438	0.3698	15	0.717
Unrelated memorising	-0.063	-0.0657	15	0.948
Syllabus boundness	-2.067	-2.8695	14	**0.012**
Fear of failure	0.063	0.0606	15	0.952

Paired t-tests reveal that there is still a significant preference for teaching which transmits information over supporting understanding at sampling interval two for the PBL cohort. The mean difference between teaching which supports understanding and transmits information is –5.836, t(21) = -5.304, p = 0.000. A very similar result is also found for the traditional cohort, with a mean difference of –5.9574, t(93) = -10.874, p = 0.000. However, unlike the PBL cohort, the traditional students show a significant decrease in their mean score for teaching which supports understanding from sampling interval one to two, with a mean difference of 1.5263, t(37) = 2.411, p = 0.021. Table 4.14, however, shows that there is no significant difference between the two cohorts at the second sampling interval.

Table 4.14: Comparison of PBL and traditional cohorts at the second sampling interval for each teaching preference

PREFERENCE	COHORT	MEAN	ST DEV	t	df	ρ
Supporting understanding	PBL	11.7273	3.64080	-0.6831	114	0.496
	Traditional	12.3723	4.06132			
Transmitting information	PBL	17.6957	2.65321	-1.1803	116	0.240
	Traditional	18.3053	2.10912			

4.3.3: DISCUSSION OF STUDENTS APPROACHES TO LEARNING

An overview of the three years results suggests that the PBL students, having taken either the semester long or year-long module, indicate a significantly lower preference for a surface approach than their traditional counterparts. Furthermore, the PBL students also report use of 'organised studying' higher than the traditional students. See Table 4.15 for an overview of the differences between the PBL and traditional students at each sampling interval for each cohort.

Concerns were raised in Chapter 2 about students indicating low scores for basic study skills such as 'time management' and 'organised studying'. Here it is reported that the PBL students in the last two years report significantly higher scores on 'organised studying' having taken part in the PBL module. Furthermore, in all three years, the PBL cohorts score surface or surface subscales significantly lower than their traditional counterparts. This suggests that the PBL students are choosing deep and strategic approaches over surface approaches. Also, these trends were seen to remain with the students – even after the PBL modules was complete e.g. with the 2003-2004 intake, various surface subscales were reported lower for the PBL students than the traditional at sampling interval 2, 3 and 4 e.g. unrelated memorising at sampling interval 2 and 4. However, both the PBL and traditional cohorts have experienced different courses in their second year, which may also influence these trends.

Table 4.15: Overview of the significant differences between the PBL and traditional students in terms of the main approaches and subscales at each sampling interval

FACTOR	YEAR	WEEK 1	WEEK 12	WEEK 24	WEEK 36	WEEK 48
Approach	02-03	No difference	#Surface > for Trad.		No difference	
	03-04	No difference	No difference		No difference	Surface > for Trad.
	04-05	Surface > for Trad.		Surface > for Trad.		
Subscales	02-03	A, TM > for PBL	SB, FF > for Trad.		UE, II > for Trad.	
	03-04	No difference	OS, A > for PBL UM > for Trad		AA, FF > for Trad.	UM > for Trad.
	04-05	UM, FF, > for Trad.		OS, A > for PBL LP, UM > for Trad		

Key: UE: Use of evidence, II: Interest in ideas…Deep subscales
OS: Organised Studying, TM: Time management,
AA: Alertness to assessment demands, A: Achieving…Strategic subscales
LP: Lack of purpose, UM: Unrelated memorising, SB: Syllabus boundness,
FF: Fear of failure…Surface subscales

For example, in terms of the main approach to learning, in 02-03, there was no difference between the PBL cohort and the traditional cohort in week 1, while in week 12, the preference for the surface approach was significantly greater for the traditional students over the PBL cohort.

Newble & Clarke[3] as far back as 1986 reported on the approaches to learning of students in a traditional and in an innovative problem-based medical school both in Australia. In the PBL school, students completed a 5-year problem-based curriculum in which students learned by confronting selected clinical problems, which required them to acquire the relevant basic and clinical skills, with students working predominantly in small groups. Various assessment methods were used including essay type questions and with clinical skills being assessed by observation of patient interviews and examinations. The study used the Lancaster Approaches to Studying inventory[4] a predecessor of the ASSIST inventory. Studies were carried out with first, third and final year students at about two-thirds of the way through the year. Comparisons were made using t-tests. Results showed that overall the students from the PBL school rated themselves significantly higher for the 'meaning orientation', equivalent of the deep approach, in years 1 and 3 in contrast the students from the traditional school rated themselves significantly higher in all three years for the 'reproducing orientation', equivalent of a surface approach. Interestingly, fear of failure was almost identical in all years with a rising trend with seniority, showing that neither a PBL nor a traditional approach manages to relieve students of this negative feeling even after successfully completing years of medical school. In comparison to the Newble & Clarke[3] study, the results from this study are not as dramatic. However, it is important to remember that the students from the Newble & Clarke[3] study were taking part in a 5-year PBL course, not a one year long module.

4.4: ACADEMIC ACHIEVEMENT

In previous sections, we have examined the effect of a PBL approach on students approaches to learning in the laboratory. In this section, we want to determine if there are differences in academic achievement in the formal examinations between the PBL and traditional cohorts. The academic achievement in chemistry of first year students from both the PBL and traditional cohorts is assessed formally through two modes, through continuous assessment in the chemistry laboratory (CS151) and two end-of-semester written exams - Inorganic and Analytical Chemistry at the end of semester 1 (CS101) and Organic and Physical Chemistry at the end of semester 2 (CS102). Academic achievement in each of these areas is examined and correlated (a) to student group, either PBL or traditional, and to their approach to learning and (b) to the CAO points level at the initial intake.

Additionally, as the end-of-semester examinations are written papers designed to measure knowledge only, it was decided that we would try to devise an assessment to determine if their was a difference in the problem-solving abilities of those students who followed the PBL labs and those who followed the traditional labs. Furthermore, the assessment would investigate if students taking the PBL labs were equally competent in carrying out standard calculations and in laboratory skills as the traditional cohort. The assessment consisted of four sections: 8 short questions (8 marks), a calculation question (4 marks), 4 practical questions (4 marks) and a chemistry problem (4 marks), typical of the PBL module, with a total mark out of 20. See Appendix 4.4 for the assessment. The short questions were based on chemistry knowledge that both the PBL and traditional students had covered over the course of the first semester in their laboratory sessions, the calculation was a basic molarity one, the practical questions were based on experimental techniques which they had used over the course of the 12 weeks, and finally the problem was designed to assess their ability to apply the chemistry knowledge and techniques they had met over the semester.

At the end of semester 1 for the first years in 04-05, the PBL cohort and the traditional group who shared the same laboratory session were asked to complete the assessment during the laboratory session. The traditional group consisted of students following the Genetics and Cell Biology and Analytical Science programmes. The PBL cohort had a response rate of 65% (17 students) compared to 18 students from the traditional cohort. It can be assumed that students from both cohorts who did not complete the survey were more likely to be the weaker students who felt uneasy at doing an assessment despite the fact that it was stressed it was not for academic purposes. An analysis of the scores obtained by both cohorts as well as their approaches to learning will be discussed in the next section.

One advantage of the PBL approach as cited in Chapter 1 (Section 1.4) is that students can retain the knowledge that they gain by PBL over longer time since they are not using rote-memorising techniques. To test this, an assessment was devised similar to the one described above, and given to second year students – who had completed the PBL module the previous year. For comparison, it was also given to another group of second year students who had taken a traditional approach in first year. See Appendix 4.5. The response rate was unfortunately low, with only 53% of the class completing the assessment. 15 students from the traditional cohort also filled out the survey. The students who filled it out were in the same laboratory group as the PBL cohort in first year. They were 'Chemical and Pharmaceutical Sciences' and 'Chemistry with a Language' students. These results will also be discussed. A further measure of the problem solving ability of the PBL and traditional cohorts was to hold independently run interviews with the students. These were discussed in Section 4.2.

4.4.1: ANALYSIS OF FORMAL EXAM PERFORMANCE

In terms of their overall achievement at second level, the PBL and traditional cohorts are similar in terms of the CAO points. Table 4.16 shows the average CAO point scores for each cohort for the three academic years 02-03, 03-04 and 04-05, as well as the relevant data from the independent t-tests. It is clear that there is no significant difference between the two cohorts in 02-03, and 03-04. However in 04-05 the average points are significantly higher for the PBL cohort. In real terms, however, the first two traditional cohorts have higher CAO points than the PBL students.

Comparing their experience in Leaving Certificate Chemistry (Figure 4.18), shows the number of students who have honours, ordinary level chemistry or no Leaving Certificate chemistry. It clearly shows that in 02-03 and 03-04, a higher percentage of the traditional students have completed Leaving Certificate chemistry compared to the PBL students, with approximately 59% in 2002-2003 and 54% in 2003-2004 of traditional students having Leaving Certificate experience, compared to approximately 46% and 42% respectively of the PBL students. In 04-05 however, 65% of the PBL students have Leaving Certificate Chemistry, in contrast to 58% of the traditional students. This data shows that the PBL groups generally have less experience in chemistry and an overall lower number of CAO points. The 04-05 seems to be the exception. This is also observed in the large increase in the CAO points to the Science Education degree for that year in comparison to the previous two years. See Section 4.1.

Table 4.16:Comparison of PBL and traditional cohorts with respect to CAO points

YEAR	COHORT	N	MEAN (Max = 600)	ST DEV	t	df	Sig.
2002-2003	PBL	18	393	44.2	-1.089	130	0.278
	Traditional	114	407	53.3			
2003-2004	PBL	19	379	37.7	-1.452	131	0.149
	Traditional	114	396	49.2			
2004-2005	PBL	21	432	36	2.037	39	0.048
	Traditional	104	413	53			

Figure 4.18: Bar chart of the Leaving Certificate chemistry experience of each cohort expressed as % of each cohort of students

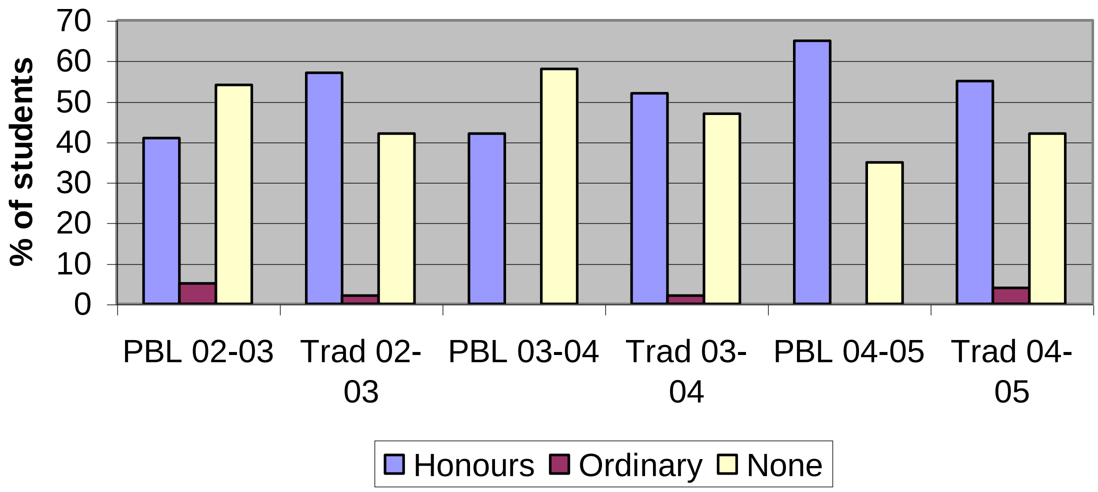


Table 4.17 compares the performance of the PBL cohort and the traditional cohorts in the first year formal examinations. An analysis of the performance of all three cohorts of first year students in their formal assessment reveals that there is no significant difference between the traditional and PBL cohorts in their achievement in either of the two written exams, CS101 or CS102, as shown in Table 17 except in the 1st semester

exam (CS101) for the 04-05 PBL cohort, which are shown to score significantly higher. This may be due the fact that they had a significantly higher level of chemistry and CAO points than their traditional counterparts at the initial intake. The PBL cohort is shown to have scored significantly lower than the traditional group in 2002-2003 in the laboratory module CS151. This may be due to the fact that the PBL module in this year lasted only for the first semester and the students then followed the traditional mode in the second and perhaps struggled with the different style of laboratory and write-up.

Table 4.17: Comparison of PBL and traditional for 1st year formal exams

YEAR	EXAM	COHORT	N	MEAN %	ST DEV	t	df	*P*
2002-2003	CS101	PBL	20	47	30.7	-0.030	22	0.976
		Traditional	121	47	22.1			
	CS102	PBL	21	46	26.1	-0.456	23	0.653
		Traditional	116	49	17.2			
	CS151	PBL	20	62	11.0	-3.018	139	0.003
		Traditional	121	69	9.0			
2003-2004	CS101	PBL	24	43	25.9	-0.456	143	0.649
		Traditional	121	45	21.7			
	CS102	PBL	23	34	21.2	-1.319	135	0.189
		Traditional	114	39	16.9			
	CS151	PBL	23	65	15.5	-0.431	141	0.667
		Traditional	120	67	11.3			
2004-2005	CS101	PBL	26	51	23.2	1.888	137	0.061
		Traditional	113	42	23.5			
	CS102	PBL	26	59	20.0	1.624	130	0.107
		Traditional	106	52	18.0			
	CS151	PBL	26	72	10.6	1.149	136	0.253
		Traditional	112	69	11.8			

These results suggest that the PBL module does not influence students' performance in their written exams – CS101 and CS102. Further investigation suggests that the CAO points are in fact a good predictor of performance in first year examinations. Table 4.18 shows Pearson's correlation coefficient between Leaving Certificate points and performance in CS101, CS102 and CS151 for the combined data for both PBL and traditional cohorts from all three years. Table 4.18 clearly shows that there is a highly significant correlation (p = 0.000 for all three correlations) between Leaving Certificate points and performance in the first year exams. Further more, independent t-tests between the students who had Leaving Certificate chemistry and those who didn't reveals that those students with prior chemistry experience did significantly better in all three modules (CS101, CS102 and CS151) than those with no Leaving Certificate Chemistry. Results found by Moran *et al.*[5] reported that the Leaving Certificate points were the best predictor of academic achievement of first years in University College Dublin regardless of whether they had studied the subject previously e.g. this relationship was also seen for students taking Psychology, which they would have had little or no prior experience of before entering college.

Table 4.18: Correlation of Leaving Certificate points and performance in the first year examinations (combined data from all three years)

		CS101	CS102	CS151
Leaving Certificate points	Pearson Correlation	0.479	0.534	0.339
	P	0.000	0.000	0.000
	N	381	364	379

So CAO points are shown to have a significant positive relationship with students' performance in their first year exams as well as prior experience in chemistry. However, are there any significant correlations between the approaches to learning taken by the PBL cohort and their achievement in their first year exams. Remember, the PBL approach should be encouraging and rewarding deeper approaches. The study has focused on the academic years 2003-2004 and 2004-2005 since the identifiable PBL sample size was very small at the first sampling interval (week 1, semester 1) for the 2002-2003 group. Table 4.19 shows the correlation figure, Pearson's rho, for each approach and assessment mark at sampling interval 1 and 2 for the 2003-2004 and 2004-2005 PBL cohort. Table 4.20 shows the correlation, Pearson's rho, for each approach and assessment mark at sampling interval 1 and 2 for the 2003-2004 and 2004-2005 traditional cohort.

It is shown that at sampling interval 1, there is a significantly negative correlation between achievement in the laboratory module CS151 and a surface approach, which is also observed at the second sampling interval for the 03-04 PBL cohort. Furthermore, this negative correlation is also observed in the 04-05 PBL cohort. This indicates a negative relationship between students' performance in CS151 and a surface approach. This suggests that the assessment of the module does not encourage a surface approach and students who did well were less inclined towards a surface approach, implying that those who didn't do well, were more inclined towards a surface approach. In contrast this result is not observed at either sampling interval for the traditional cohorts in either 03-04 or 04-05, implying that a surface approach was equally rewarded as a deep approach. See Table 4.20.

Table 4.19: Correlation of marks and approach at sampling interval 1 and 2 for the PBL cohorts 2003-2004 and 2004-2005

	SAMPLING INTERVAL 1			SAMPLING INTERVAL 2		
APPROACH	DEEP	STRATEGIC	SURFACE	DEEP	STRATEGIC	SURFACE
03-04 / N	17	17	19	13	16	16
CS101	+0.202	+0.285	-0.378	+0.315	+0.405	-0.590*
CS102	+0.239	+0.251	-0.320	+0.574*	+0.471	-0.470
CS151	-0.090	+0.087	-0.467*	+0.235	+0.377	-0.633*
04-05 / N	17	17	16	23	22	22
CS101	+0.537*	+0.099	+0.039	+0.108	+0.321	-0.219
CS102	+0.594*	-0.164	+0.047	+0.081	+0.309	-0.267
CS151	+0.420	+0.036	-0.380	+0.232	+0.407	-0.286

* Correlation significant at 95%

At the first sampling interval for the 04-05 PBL cohort and at the second sampling interval for the 03-04 PBL cohort, the students show a positive correlation between their performance in their written examinations and a deep approach. Thus suggesting that students who adopted a deep approach performed well in the module. A negative correlation is also observed between the module CS101 and a surface approach, thus indicating that students' who did well at this module, were less inclined toward a surface approach.

Table 4.20: Correlation of marks and approach at sampling interval 1 and 2 for the traditional cohort 2003-2004

	SAMPLING INTERVAL 1			SAMPLING INTERVAL 2		
APPROACH	DEEP	STRATEGIC	SURFACE	DEEP	STRATEGIC	SURFACE
03-04 / N	106	105	103	57	55	55
CS101	+0.092	+0.273**	-0.054	+0.114	+0.394**	-0.291*
CS102	-0.012	+0.201*	+0.141	+0.017	+0.150	-0.156
CS151	-0.061	+0.215*	-0.041	+0.153	+0.302*	-0.261
04-05 / N	59	58	58	83	84	88
CS101	+0.146	+0.069	-0.203	+0.200	+0.125	-0.279
CS102	+0.212	+0.175	-0.097	+0.325	+0.126	-0.283
CS151	+0.012	-0.052	-0.068	-0.047	-0.029	-0.036

* Correlation significant at 95%, ** Correlation significant at 99%

In contrast, the traditional students show a consistent positive correlation between their performance in their formal assessment and a strategic approach, particularly in 03-04. This suggests that those who did well in these modules scored high on the strategic approach, and vice versa. Interestingly, for the traditional students, there are no significantly positive correlations between their academic achievement and a deep approach, unlike the PBL students. This may suggest that the PBL students are more effective at using a deep approach to be successful in exams, whereas the traditional students use strategic approaches more effectively. This leads to another study where we ask – are students who adopt a deep approach rewarded in examinations and conversely, if they adopt a surface approach, are they equally rewarded?

4.4.2: ANALYSIS OF NON-FORMAL ASSESSMENT RESULTS FOR FIRST YEARS

This section describes the results from the non-formal assessment. This assessment as described earlier in Section 4.4, was completed at the end of semester 1 in 2004-2005 by the first years taking the PBL module and a sample of the traditional students in the same laboratory group. In terms of their prior experience, of the students that had completed the assessment, 62% of the PBL cohort had done chemistry before compared to 64% of the traditional cohort. An analysis of their academic achievement at Leaving Certificate showed that the groups were not significantly different in their CAO points.

However, the PBL cohort had a lower average of 438 CAO points compared to an average of 457 CAO points for the traditional cohort overall. This demonstrates that the groups are academically quite similar at the start of the year.

Independent t-tests were carried out to investigate the differences in the scores on the assessment between the PBL and traditional students. (Table 4.21). It is clear from the table that the PBL cohort scored higher than the traditional students in each of the four categories, and hence overall. The most significant difference was in the short questions, where the PBL group scored an average of 5.3 in comparison to the traditional students who scored an average of 3.0, $t(33) = 4.466$, $p = 0.000$. This suggests that in terms of the chemistry they had met in the lab sessions, the PBL students could recall more information compared to their traditional counterparts. This may be because of the engaging nature of the PBL problem, where the students are actively seeking the information themselves, rather than it all being given to them directly in a manual. In both the calculation and the practical questions there was no significant difference in mean scores for both groups, indicating that the PBL had gained sufficient knowledge in these areas. A criticism of PBL is that the students more time on less material and therefore don't master the whole course – this is shown not to be the case here!

Table 4.21: Comparison of PBL and traditional for end of semester 1 assessment

QUESTION (Max marks)	COHORT	N	MEAN	ST DEV	t	Df	*p*
Short (8)	PBL	17	5.259	1.7628	4.466	33	**0.000**
	Traditional	18	3.006	1.1815			
Calculation (4)	PBL	17	1.941	1.6382	1.623	33	0.114
	Traditional	18	1.056	1.5894			
Practical (4)	PBL	17	3.353	0.7859	1.231	33	0.227
	Traditional	18	3.056	0.6391			
Problem (4)	PBL	17	1.888	3.1424	1.795	33	**0.082**
	Traditional	18	0.500	0.9235			
Total (20)	PBL	17	15.082	13.4456	2.310	33	**0.027**
	Traditional	18	7.617	2.6578			

The PBL group also scored significantly higher in the 'problem' question in comparison to the traditional module, which is reassuring since problem solving is one area which the PBL module addresses directly. However, the difference is only significant at 91% confidence. This shall now be discussed further.

The problem given to them was:

> *How would you determine experimentally the rate of loss of vitamin C over time in a sample of orange juice stored at room temperature and open to the air?*

The type of solutions which students gave to the problem were varied. A selection of the answers have been chosen to represent the sample from both the PBL and traditional cohort in terms of those who scored high and scored low on this question.

For example, one of the PBL students who scored high on this question gave the following answer:

- *Every 24 hours, take a sample of the orange juice and titrate against NaOH to determine how much vitamin C is in it.*
- *After a week, plot a graph of vol. of vitamin C against time.*
- *Rate of decay of vitamin C = slope of line*

In contrast, one of the PBL students who scored poorly on the question wrote:

> *'Measure it every 4 hours for a day'*

As for the traditional students, below is an example of one of the better solutions:

- *Use labelled samples of the Orange Juice which have been left in the air for various lengths of time (eg 1min $\rightarrow$ 30mins etc)*
- *For each one, do a redox titration to find the amount oxidised*

In contrast, one of the weaker answers given by a traditional student was:

> *'Titrate orange juice against a base to find amount of citric acid in solution'*

Ability to use chemical knowledge in problem-solving was also evaluated in the independently conducted interviews, described earlier in Section 4.2. The problem given to them was the same as the one described in this section. Both PBL and traditional students were interviewed. It was clear that students from two of the three PBL groups were successful in providing a solution to the problem. Furthermore, students from both of the traditional groups were able to make very little progress. This suggests that the PBL approach is effective at improving students problem-solving skills, especially in group settings. For example, in the PBL interviews, the groups generally worked together to solve the problem, and showed good group dynamics by building on each others' comments to provide an overall solution. This demonstrated the benefits to students in terms of group working skills.

An extract of one of the solutions suggested by one the PBL groups is given below:

Student 1: *Because Citric acid is in there in the orange juice, doing the titration is not going to be all that straightforward. Is citric acid not possibly going to break down?*

Student 2: Well it's possible you might also do one of the more elaborate techniques like the UV absorption which will tell you which compound it is and how much of it is there but because there is ascorbic acid there too… I suppose you could run them through a mass spectrometer to find out which one is showing up more for instance. Leave it there for a while and then take the measurement maybe a couple of days later, divide the amount of time.

Student 1: *Maybe even hours later but yes, it would be a question of taking a series of tests starting and then going on with time to see how much you are losing. Yes. Anyway the rate of loss will be definitely monitored... a graph...against your concentration of Vitamin C and any particular point. That's right.*

Interviewer: Any particular type of titration you would do or are going to do a titration at all?

Student 3: I'm not sure but I think Vitamin C is possibly one that doesn't behave itself too straightforward. It's going to be a weak acid so strong base with it but it's also possible because it behaves itself in a peculiar way you might have to do back titration but I'm not sure.

Student 1: *To know which ph range would be suitable.*

Student 2: If it oxidises in air it'll stop being Vitamin C and it won't work for you.

An extract of one of the solutions suggested by one the traditional groups is given below:

Interviewer: So take your time there and read it (the problem).

Student 1: Have you any idea (One student to other)

Student 2: *I have no idea. I'll have to read it a bit more….*
I haven't got a clue now.

The other traditional group eventually suggested a titration, but did not suggest anything to titrate it with, or use of indicators etc. It is clear that the PBL students were more resourceful and were better able to cope with this type of problem. Furthermore, the PBL students referred back to other experiments they had done during the year, indicating a good recall considering the interviews were done at the end of the second semester and they were referring to work done in the first semester. The PBL cohort also referred to mass spectrometry, which is not a technique they would have come across in first year.

From Table 4.21 it is clear that overall the PBL cohort scored significantly higher than the traditional cohort at 95% confidence. On analysis of the approaches to learning of these specific students, the only difference is that at the second sampling interval the traditional students (M = 13.6875, SD = 1.9568) are more surface than the PBL students (M = 11.8571, SD = 2.1070), $t(28) = 2.466$, $p = 0.020$. 'Lack of purpose' and 'unrelated memorising' are shown to be the surface subscales which are significantly higher at sampling interval two for the traditional students. This suggests that the PBL students rely more on deep and strategic approaches to study in comparison to the traditional students, and may suggest why they have performed generally better in this assessment.

4.4.3: ANALYSIS OF NON-FORMAL ASSESSMENT RESULTS FOR SECOND YEARS

A study to investigate retention of knowledge and understanding from the first year chemistry practical module was carried out with a group of second year students as previously discussed in Section 4.4. A number of students who took the chemistry module, either the PBL or traditional approach, in the academic year 2003-2004 were assessed. This was completed near the end of their second year, almost a year after completing the first year labs. The details of the results are given in Table 4.22. Independent t-tests were carried out to investigate the differences between the PBL and traditional students in terms of their performance in the assessment.

Table 4.22: Comparison of PBL and traditional cohorts in assessment test – 1 year after 1st year lab module

QUESTION	COHORT	N	MEAN	ST DEV	t	df	*p*
Short	PBL	9	3.667	1.4841	-1.450	22	0.161
	Traditional	15	4.653	1.6843			
Calculation	PBL	9	2.000	1.7321	-0.374	22	0.712
	Traditional	15	2.267	1.6676			
Practical	PBL	9	3.333	0.5000	0.000	22	1.000
	Traditional	15	3.333	0.7237			
Problem	PBL	9	1.278	1.0929	-1.487	22	0.151
	Traditional	15	1.900	0.9297			
Total	PBL	9	10.278	3.4996	-1.361	22	0.187
	Traditional	15	12.153	3.1273			

It can be seen that there is no significant difference between the two groups, however the traditional cohort scores consistently higher than the PBL cohort. This comparison group are not really akin to the PBL cohort. The PBL cohort is 2nd year are taking approximately half of the chemistry that the other group take. Also, the groups were not matched in terms of their prior experience. It is worth noting that all but two of the students in this traditional cohort had taken chemistry for Leaving Certificate in contrast to only approximately half of the PBL cohort. Also examining individual students in the two cohorts, the traditional students had higher CAO points to the PBL cohort on entry to their respective course (Table 4.23) and scored higher in the first year exams – CS101 and CS102. However, these differences are not significant. This suggests that the PBL cohort, despite having less experience in chemistry, perform as well as their traditional counterparts. This is of particular note since the traditional students were from the 'Chemical and Pharmaceutical Sciences' and 'Chemistry with a language', predominantly chemistry focused courses.

On analysis of the approaches to learning of these specific students, the only difference is that at the fourth sampling interval the traditional students (M = 13.6923, SD = 1.9769) are more surface than the PBL students (M = 11.1875, SD = 1.9168), $t(19) = 2.851$, $p = 0.010$. As with the assessment group from 04-05, 'lack of purpose' and ‘unrelated memorising’ are shown to be the surface subscales which are significantly higher at sampling interval two for the traditional students.

Table 4.23: Comparison of academic achievement for the PBL and traditional cohorts from 03-04

	COHORT	N	MEAN	ST DEV
LC Points	PBL	8	394	39.3
	Traditional	13	428	64.7
CS101	PBL	9	60	25.8
	Traditional	12	64	23.2
CS102	PBL	9	52	16.5
	Traditional	12	57	17.1
CS151	PBL	9	74	11.5
	Traditional	12	71	6.8

4.5: CONCLUSIONS AND RECOMMENDATIONS

The aims of the PBL module, as well as addressing the typical aims of laboratory work, are to engage students with the content through interesting, relevant problems and to encourage deeper thinking. The students also have to opportunity to develop life-long skills such as group work, communication and problem-solving skills.

Despite the unfavourable aspects of the PBL module perceived by the students, and the dislikes such as extra work compared to the traditional course, these students would still choose to follow a PBL approach over a traditional approach if given a choice. This shows that students are willing to put in the extra time, do the extra work as they feel it is beneficial in the long run. Furthermore, the students seem to appreciate the PBL method more the longer they are doing it. This was reflected in the results from the end of semester surveys. At the end of the second semester, 83% of the students indicated a preference for the PBL approach in comparison to 60% at the end of semester 1. A similar trend in seen in both students who have and haven't done chemistry before. Students confidence in calculations seems to be an important factor in whether PBL is a success or not, with students in both semesters 1 and 2, who indicated a preference for PBL, rating their experience of calculations significantly higher than those who indicated a traditional approach. Other factors, which students who indicated a preference for PBL rated significantly higher, were 'understanding' and 'tackling problems' in semester 1 and 'learning experience' in semester 2. These factors show that students who prefer the PBL approach are more engaged with the whole process, either being better able to tackle the problems and/or feel they are learning more.

This study also suggests that students who have studied chemistry before, are better able to cope with the demands placed on them in this PBL module, in terms of calculations, their understanding and their ability to tackle problems. This was supported by the many comments students made regarding those who hadn't studied chemistry previously.

> *'More help is needed with people who didn't do chemistry: maybe a separate tutorial could be set up in relation to the labs'.*
>
> *'I think it would be better for those who haven't done chemistry to do traditional labs for the 1st semester then we would have some grounding and would cope better with PBL in the 2nd semester'.*
>
> *'Pair someone that has done chemistry with someone who hasn't'.*

However, in response to this, I would argue that this material is covered in lectures and tutorials already and so provided there is a match between labs and lectures, this would alleviate this problem. Also, it is not uncommon for tutorials to be poorly attended by students anyway during the year. Furthermore, I would suggest that similar comments could be made about any chemistry module i.e. students who have studied chemistry before are more likely to find it easier.

The benefit of the 'pre-lab' is evident from the students' responses in various surveys and this again demonstrates students' willingness to spend more time on their chemistry labs outside of the normal scheduled time. This supports the notion that PBL engages students with their learning, as students are interested in solving the pre-labs and problems. Over the year, the 'pre-lab' and group work were consistently seen as two of the most beneficial aspects of the module.

An interesting observation is that where students indicated dislikes or negative aspects of the PBL, it was often coupled with a counter argument to support the fact that though they might not like it, it was beneficial in the long run. Posters and giving oral presentations were not favoured by some students, however, I feel that these are important and integral aspects of the module. Skills developed from such activities are highly desirable and students comments indicated strongly that they were highly engaged with the problem when there was a presentation aspect to it. Difficulties with group work were also reported, and this is in itself a learning opportunity as students learn to work alongside people who either don't want to do any work or want to do all the work! Furthermore, those students who felt the pre-lab wasn't beneficial or disliked it perhaps have two reasons for indicating this:

- It required more effort i.e. work and time, on their part to prepare for the labs, instead of just reading the lab manual
- The pre-lab was often seen to the students to be too vague, and students were unclear what was expected of them.

With regards to the second point, this is definitely an area which can be improved on in the future, with more attention to the instructions as given to the students. Write-ups, another unfavourable aspect of the PBL module, are a 'necessary evil', since the students must learn how to document their experiments appropriately and it also helps to refocus them on what they have done and what they were trying to achieve. However, some students would rather not have to do them. In particular, as mentioned in Chapter

3, the PBL write-up required students to state very clearly their aims and to discuss and conclude their experiment/problem. Although more than half the group agreed that the traditional write-up was easier, they also appreciated that it is not as beneficial as they could 'just copy straight from the manual'. Students also stated that the conclusions were difficult as they actually had to think about what they had done to make a relevant conclusion. This again demonstrates students' engagement with chemistry.

What about the second aim of the PBL module i.e. to encourage deeper thinking? Similar to the traditional students, the PBL cohort shows an overall preference for deep and strategic approaches over a surface approach at the initial intake stage. Also, both cohorts show a preference for teaching, which transmits information as opposed to teaching which supports understanding. Perhaps this is because it is this style of teaching that students are more familiar with and hence more comfortable with. In all three years of the analysis, at various stages, the PBL cohort are shown to be significantly less surface than their traditional counterparts. Also, for the 03-04 cohort the traditional students are shown to have a higher preference for teaching which transmits information over the PBL students at the end of their second year. Similarly, the traditional students from 04-05 have a lower preference for teaching which supports understanding by the end of first year. Overall, this suggests the PBL module may play a role in helping students engage more fully with the learning, relying less on surface approaches and preferring teaching which supports their understanding.

In terms of the academic achievement of students the PBL module, as supported by the Albanese & Mitchell[6] review of the effects of PBL on medical students, did not give rise to an increase in student academic achievement. Overall, in the three years reviewed, the PBL cohorts performed as well as the traditional students in their formal written exams, CS101 and CS102. For the first years in 2002-2003, the PBL students scored significantly lower in their laboratory module course, CS151, than the traditional students. However, the PBL lab is assessed differently and so this is not comparing like with like. Furthermore, the CS101 and CS102 examinations are based on lecture material and this is not directly related to the labs.

An investigation into the relationship between academic achievement and approach to learning revealed that, for the PBL cohort, there was at certain stages a negative correlation between a preference for a surface approach and academic achievement, and a positive correlation between a preference for a deep approach and academic achievement. This suggests overall that students who adopted a surface approach scored less on their formal tests, whereas those who adopted a deep approach scored better on their formal tests. This suggests more successful use of deep approaches to support studying and learning. In contrast, for the traditional students, there are strong positive correlations between a strategic approach and academic achievement. With negative correlations between laboratory module CS151 and a surface approach at both sampling intervals 1 and 2 for the PBL cohorts, it is proposed that the assessment of the PBL module does not support a surface approach. In comparison, a positive correlation between laboratory module CS151 and a strategic approach at both sampling intervals 1 and 2 for the traditional cohort, suggests that the traditional students who adopt a strategic approach are more likely to be successful in this module.

The second analysis of achievement in chemistry showed that the PBL students significantly outscored their traditional counterparts in the end of semester 1 assessment. Students from both the PBL labs and traditional labs completed an assessment based on general chemistry, basic calculations, laboratory skills and problem solving. This was reflected in both the short questions, based on the semester 1 laboratory experiments, and the overall score, with the PBL students also able to tackle the 'problem' better at 90% significance. This further shows the effect of the PBL module in terms of students engaging with the content. However, when the assessment was repeated with PBL and traditional students from a 2nd year group, nearly a year and a half after these topics were covered, both groups scored equally in spite of the fact that the PBL cohort were doing half the chemistry as the traditional students.

Finally, a summary of the study shows that despite the students recognising the greater effort and time that is required for the PBL module, as well as the various aspects which some students find difficult to cope with, overall students get more used to PBL the longer they are doing it, with 83% of students indicating a preference for adopting a PBL approach in second year. The PBL discourages a surface approach and students do as well as their traditional counterparts.

Recommendations for the future include adapting various aspects of PBL to promote deeper thinking on the part of the students, such as, changing the pre-lab to give more concise, clear instructions and adapting the storylines for some of the problems to ensure that students engage with the problems. Also, for better running of the module, the open source virtual-learning environment, Moodle (similar to WebCT and Balckboard), should be used. This gives students an opportunity to discuss the problems in groups prior to the prelab, to allow them direct access to the problems as they become available and possibly to do weekly prelab assignments and postlab tests to monitor their understanding and/or misconceptions in chemistry.

References

[1] Butler, R; *British Journal of Educational Psychology* (1998) Vol. 58 Pg 1

[2] Black, P., Harrison, C., Lee, C., Marshall, B. & Wiliam, D.; *Assessment for Learning, Putting it into practice*, Maidenhead, Open University Press (2003)

[3] Newble, D.I. & Clarke, R.M.; *Medical Education* (1986) Vol. 20 Pg 267

[4] Entwistle, N.J., Hanley, M. & Hounsell, D.J.; *Higher Education* (1979) Vol. 8 Pg 365

[5] Moran, A., Bates, U., Coleman, U., Egan, A., Guerin, S. & O'Sullivan, C.; *Summary of 'Learning Support Unit Project – Evaluation a Learning Skills intervention for First Year Students in UCD*'. Paper presented at the Learning Support Unit Confernce, UCD, Dublin (October 2004)

[6] Albanese, M.A. & Mitchell, S.; *Academic Medicine* (1993) Vol. 68 Pg 52

CHAPTER 5

MICROSCALE TECHNIQUES FOR LEAVING CERTIFICATE CHEMISTRY:

DEVELOPMENT & EVALUATION

5.1: MICROSCALE FOR LEAVING CERTIFICATE CHEMISTRY

Introduction

Chapter 1 discussed the benefits of microscale chemistry, which many practitioners have found at both secondary and tertiary level. These benefits included reduced cost, increased safety, less time spent preparing and actually carrying out the experiments, as well as the potential for increased student learning. Microscale is also particularly useful and suitable in development of a Problem-Based Learning approach. This has been discussed earlier in Section 1.3.2.4. This Chapter describes the development and evaluation of microscale experimentation for Leaving Certificate Chemistry. Initially, problems within practical work are identified, with microscale promoted as a potential solution to some of these problems. The next section describes the results which can be obtained using the microscale procedures described in this research, and finally an evaluation of some of these experiments is discussed. A microscale manual for teachers of chemistry has been produced with clear and concise experimental notes, procedures, sample results/workings and description of apparatus required, as well as student worksheets. See Appendix 5.1 for an extract from the manual.

5.1.1: PRACTICAL WORK IN LEAVING CERTIFICATE CHEMISTRY

The Department of Education and Science recommend approximately 180 hours of class contact over a two-year period for the Leaving Certificate chemistry course, and note that teachers should provide for practical work in their teaching[1] with school management timetabling at least two forty-minute periods together per week to allow the students sufficient time to carry out the necessary practical work[2]. However, it has been reported that while half of the Leaving Certificate students do experiments each week, 10% never work with materials or apparatus[3]. This was also seen in Chapter 3 of this research, where 22% of the Science Education 1st year students, from 2002-2003 and 2003-2004 intakes, who took chemistry for Leaving Certificate were doing practical work less than once a month. Studies of schools with high take-up of physical sciences suggest a number of strategies for increasing take-up, including an emphasis on practical work, with a student survey confirming the positive impact of practical work[4]. The schools which had a high take-up of the physical sciences, were reported to have a lower student to laboratory ratio than the schools with low uptake, making experimental work more accessible to the students and teachers. Furthermore, the Report on the Physical Sciences revealed that levels of laboratory provision are generally lower in

Ireland than elsewhere[3], meaning that there are higher ratios of students per laboratory in Ireland than other countries. According to the case study commissioned by the Taskforce of the Physical Sciences on schools successful in science, the teachers stated they spent approximately half of their time doing practical work at Junior Certificate level[4]. This shows that practical work is an important aspect for the student, and is one of the factors that may influence student choice in continuing with physical science subjects at Leaving Certificate.

There are 28 mandatory experiments in the higher-level Leaving Certificate syllabus and 21 in the ordinary-level syllabus and the students are expected to carry out these experiments themselves over the two-year period, in tandem with teacher demonstrations and other simple experiments. The mandatory experiments are examined in a practical section on the Leaving Certificate written paper. The objectives of the chemistry syllabus in terms of practical work as given by the Department of Education and Science are shown below. Students should be able to [1]

- Follow instructions given in suitable form;
- Perform experiments safely and co-operatively;
- Select and manipulate suitable apparatus to perform specified tasks;
- Make accurate observations and measurements;
- Interpret experimental data and assess the accuracy of experimental results;
- Report experimental procedures and results in a concise, accurate and comprehensible manner.

These objectives will only be met if students are routinely doing practical work, getting hands-on experience in small groups or individually.

However, chemistry teachers at secondary can find it hard to provide for practical work in chemistry for a variety of reasons including safety issues, lack of time and resources. Often the lab layout is not conducive to practical work and in the absence of laboratory technicians, laboratory management can be difficult, especially when teachers are sharing the resources and facilities[5]. Lack of financial support is also a problem.

5.1.2: POTENTIAL EFFECTIVENESS OF MICROSCALE LABORATORIES

By using microscale, some of the problems associated with practical chemistry can be combated. More practical work can be carried out since microscale chemistry is time efficient. Lack of resources can be combated using microscale since a lot of the apparatus used are cheap, easily replaceable, plastic materials, and in the case of the microburette constructed using pieces of general laboratory apparatus. The cost of chemicals is greatly reduced also. However, it has been shown that the cost of the apparatus needed to carry out the Leaving Certificate mandatory experiments on a microscale is only slightly lower than the normal scale but significantly lower costs for chemicals are observed[6]. This is due to the high cost of glassware such as the apparatus needed for the organic preparations where regardless of the substantially smaller size the cost is only slightly less. Teachers can cope better with the laboratory environment with microscale since experiment preparation, and clean-up is much easier, the general storage and up-keep of the laboratory is more manageable, and the overall safety of the laboratory is improved[21]. Therefore, teachers are in a better position to provide real, hands-on experience for the students, in a context where the provision of laboratory assistants is a long way off. Also, microscale provides an opportunity for students to do experiments on their own, due to the increased safety and less strain on materials and chemicals. This gives them the chance to take complete control of the whole experiments. Microscale experimentation also allows for the objectives of practical work in chemistry, as set by the Department of Education and Science, to be met.

The use of microscale techniques for schools is not a novel idea however, and has been used in Ireland before, presented as a 'kit' – a set of apparatus sold as a unit. The most researched one was the BASF 'Minilab'. BASF introduced a 'Minilab' to Ireland over a decade ago and though very positive responses were received from teachers it was not as successful as hoped. The following case study takes a closer look at this kit.

Case Study - BASF Minilab

The Minilab is described as a 'laboratory in a suitcase' and it contains small-scale glassware, all contained in a metal case, which can be used to carry out a variety of science experiments (mainly chemistry). It was introduced to the ISTA (Irish Science Teachers Association) in April 1991 at the AGM by BASF Ireland in an effort to support, promote and enhance the study of chemistry and other sciences. The continued need for resources and reduction of costs, increase in safety, environmental awareness and the desire for 'hands-on-experience' made Minilab an attractive alternative to large scale experimentation[7].

The Minilab had been co-developed by Prof. Michael Schallies, of the Heidelburg University, and BASF scientist, Joerg Redeker. There was a manual to go along with it which was in German, and relevant to the German syllabi. BASF, having received a positive response from teachers after a presentation at the ISTA AGM, set about further developing the manual to suit the Irish curriculum. Five teachers came onboard, and having attended a training course in Heidelburg, they adapted and developed experiments to suit the Irish school curriculum. The experiments suit Leaving Certificate Chemistry and Biology, Transition Year Science and Junior Certificate Science. (See Appendix 5.2 for overview of the experiments). Shaw Scientific Ltd.[8] were the only distributors at the time and the kit was available at a reduced cost of approx. £300 (Irish punts). Since then Lennox Laboratory Supplies Ltd.[9] came onboard. The current cost in 2005 is approximately 660euro(VAT inclusive).

The five teachers who developed the experiments then trained other science teachers in Ireland on how to use the Minilab. In general, teachers responded well to the Minilab. There was a lot of commitment from the teachers, who also wanted to promote chemistry, and help the failing image of the subject. The Minilab had many advantages:

- User friendly;
- Compact and durable;
- Safer (due to hotplate use rather than open flame);
- Waste disposal less of an issue (which was becoming more of a problem for teachers due to legislation being introduced to schools regarding disposal of hazardous chemicals);
- Running costs very cheap;
- Small parts cheap, and easy to replace (e.g. glass fittings);
- Time saving.

Overall, the feedback from teachers and students was very positive, with students reporting that they enjoyed doing experiments at this scale. The margin of error was low and mistakes could be rectified quickly and easier. However, after 3-5 years of intensive promotional work from BASF, the project was still not a big success[10].

Why not? There are a variety of reasons but the main one was lack of funding. At the time, there was a boom in the computer industry, which meant any money schools had was going towards computer facilities and not equipping chemistry labs. There was also a similar product on the market from AGB Scientific Ltd[11] which should have made microscale chemistry even more accessible. However, Minilab has been very successful in other European countries, with it being most successful in Austria. Germany and Britain also have had relative success. The Minilab was introduced to some universities but the response was poor. Maynooth commented, at that time, that the scale was too small for use at university level.

Sales of the Minilab are very low today for both Shaw Scientific Ltd. and Lennox Laboratory Supplies Ltd. However, microscale as a potential technique for use in school laboratories has recently seen a new drive. This is in part due to the introduction of dataloggers, which naturally lend themselves to small-scale experimentation. The desire for more hands-on, investigative experience at Junior Certificate Science level, and the afore mentioned revised Leaving Certificate Chemistry syllabus, means that there is a high level of interest in novel and alternative approaches to laboratory work. Most school suppliers have now made microscale apparatus available in Ireland, however, these are in the form of ‘kits’. In-class Educational Ltd. have also launched a ‘microscale science’ kit suitable for the Junior Certificate Science syllabus. Some schools are using microscale techniques and at least one school is still using the BASF Minilab regularly[10]. Universities are also moving towards a microscale, with many 1st, 2nd and 3rd year chemistry laboratory experiments carried out on a microscale in the School of Chemical Sciences, Dublin City University.

This research, however, promotes the use of microscale as a technique, without the use of a ‘kit’ using apparatus which can be easily obtained from regular school suppliers at a similar or lower cost than the normal scale or adapting simple pieces of apparatus to make novel equipment. Conventional glassware is predominantly used but it is just smaller than the normal school-laboratory size. In this research microscale is used to describe smaller scale experiment compared to the normal scale used at Leaving Certificate. In some contexts, microscale refers to smaller than μg quantities!

5.2: DEVELOPMENT OF LEAVING CERTIFICATE EXPERIMENTS

As highlighted earlier, there are 28 mandatory experiments on the Leaving Certificate syllabus and 22 were successfully microscaled. The experiments that are not microscaled fall into two categories, those that are not suitable for microscale, because they are already carried out on a small-scale (Experiment 1.1, 7.7, and 9.1), or those that have proved difficult so far to be reduced satisfactorily to a smaller scale (Experiment 1.2, 7.3 and 7.6). Table 5.1 shows the title and code for the mandatory experiments as per the Leaving Certificate syllabus[1]. 19 of the experiments will be discussed in detail in this section.

Table 5.1: Mandatory Experiments for Ordinary and Higher Level Chemistry[1]

CODE	EXPERIMENT TITLE
1.1	Flame Test (Li, Na, K, Ba, Sr and Cu only).
1.2	Redox reactions of group VII elements: halogens as oxidising agents (reactions with bromides, iodides, Fe^{2+} and sulphites). Displacement reactions of metals (Zn with Cu^{2+}, Mg with Cu^{2+}).
2.1	Tests for anions in aqueous solutions: chloride, carbonate, nitrate, sulfate, phosphate, sulfite, hydrogencarbonate.
3.1	Determination of the relative molecular mass of a volatile liquid (conical flask or gas syringe may be used).
4.1	Preparation of standard solution of sodium carbonate.
4.2	Standardisation of a hydrochloric acid solution using a standard solution of sodium carbonate.
4.2A	*A hydrochloric acid/sodium hydroxide titration, and the use of this titration in making the salt sodium chloride.*
4.3	**Determination of the concentration of ethanoic acid in vinegar.**
4.4	**Determination of the amount of water of crystallisation in hydrated sodium carbonate.**
4.5	**A potassium manganate(VII)/ammonium iron(II) sulfate titration.**
4.6	**Determination of the amount of iron in an iron tablet.**
4.7	**An iodine/thiosulfate titration.**
4.8	**Determination of the percentage (w/v) of hypochlorite in bleach.**

Table 5.1 continued

5.1	Determination of the heat of reaction of hydrochloric acid with sodium hydroxide.
5.2	Preparation and properties of ethyne [combustion, tests for unsaturation using bromine water and acidified potassium manganate(VII) solution].
6.1	Monitoring the rate of production of oxygen from hydrogen peroxide, using manganese dioxide as a catalyst.
6.2	Studying the effects on the reaction rate of (i) concentration, and (ii) temperature, using sodium thiosulfate solution and hydrochloric acid.
7.1	Recrystallisation of benzoic acid and determination of its melting point.
7.2	Preparation of soap.
7.3	Preparation and properties of ethene [combustion, tests for unsaturation using acidified potassium manganate(VII) solution and bromine water].
7.4	Preparation and properties of ethanal [properties limited to reactions with (i) acidified potassium manganate(VII) solution, (ii) Fehling's reagent, and (iii) ammoniacal silver nitrate
7.5	Preparation and properties of ethanoic acid [properties limited to reactions with sodium carbonate and magnesium].
7.6	Extraction of clove oil from cloves (or similar alternative) by steam distillation.
7.7	Separation of a mixture of indicators using paper chromatography or thin-layer chromatography or column chromatography.
8.1	Simple experiments to demonstrate Le Chatelier's principle.
9.1	Colorimetric experiment to estimate free chlorine in swimming-pool water or bleach (using a colorimeter or comparator).
9.2	Determination of total suspended and total dissolved solids (expressed as ppm) by filtration and evaporation respectively. Determination of pH.
9.3	Estimation of total hardness using ethylenediaminetetraacetic acid (edta). (Balanced ionic equation required.)
9.4	Estimation of total dissolved oxygen by redox titration.

Note: Experiments in 'bold' are higher level only. Experiments in 'italics' are ordinary level only. Otherwise all the students to the other experiments.

In terms of the number of experiments, the volumetric analysis section (experiments 4.1-4.8) make up 29% of the experiments and if the two titrations from the environmental section (experiments 9.3-9.4) are included this means that 10 of the 28 experiments involve preparation of standards and/or volumetric analysis by titration. Titrations are described in Section 5.2.1. The organic experiments (experiments 7.1-7.7) make up another significant part of the syllabus, especially when the preparation of ethyne is included (experiment 5.2). The development of these experiments is described in Section 5.2.2. Section 5.2.3 deals with the rates of reaction experiments, taking into account the effect of concentration, temperature and catalyst on the rate of reaction. Finally, other experiments, which do not fall into a particular category, are dealt with in Section 5.2.4.

5.2.1: TITRATIONS

Typically in a school laboratory, titrations are carried out using a burette that is 25 or 50ml. On a microscale a micro-burette is used. There are various ways of constructing a micro-burette. The one described here was one developed within the School of Chemical Sciences, DCU. All that is needed is a 2.00mL graduated pipette, 4-5cm long piece of rubber, 5mL plastic syringe, a yellow automatic delivery pipette tip and a 2cm piece of Teflon tubing (see Figure 5.1 and 5.2). As a class activity students can construct their own micro-burette. This is fun and easy. The micro-burette was the only piece of apparatus that was different in this set of experiments. Otherwise, it was standard glassware, just on a smaller scale. Table 5.2 gives a comparison of the typical size of the glassware used on the normal scale and what was used in the microscale experiments.

Table 5.2: Typical size of glassware used in the volumetric analysis experiments

GLASSWARE	VOLUME OF GLASSWARE	
	NORMAL SCALE (mL)	MICROSCALE (mL)
Burette	25	2
Pipette	20	1 or 2
Volumetric flask	250	25
Conical flask	250	25

Figure 5.1: Unconstructed Microburette

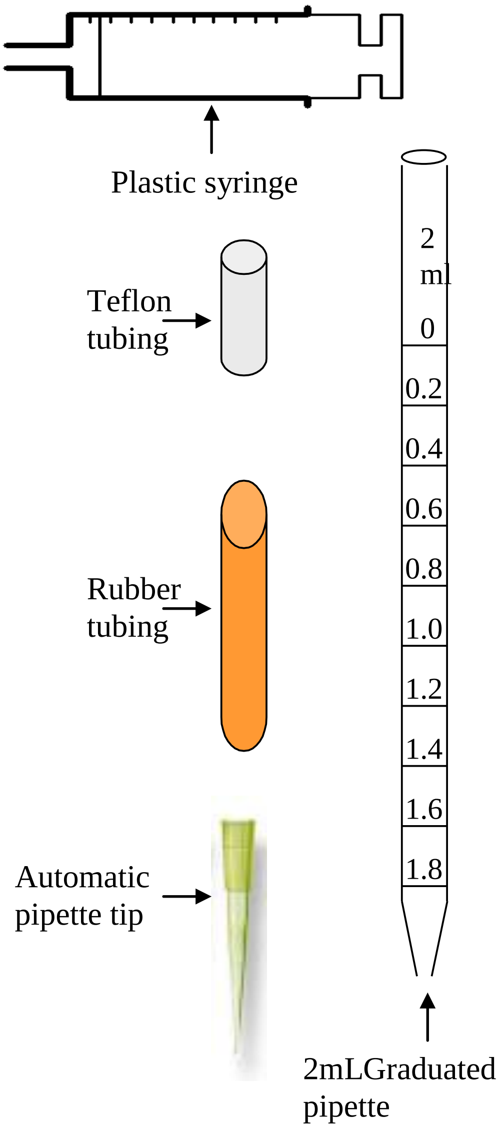
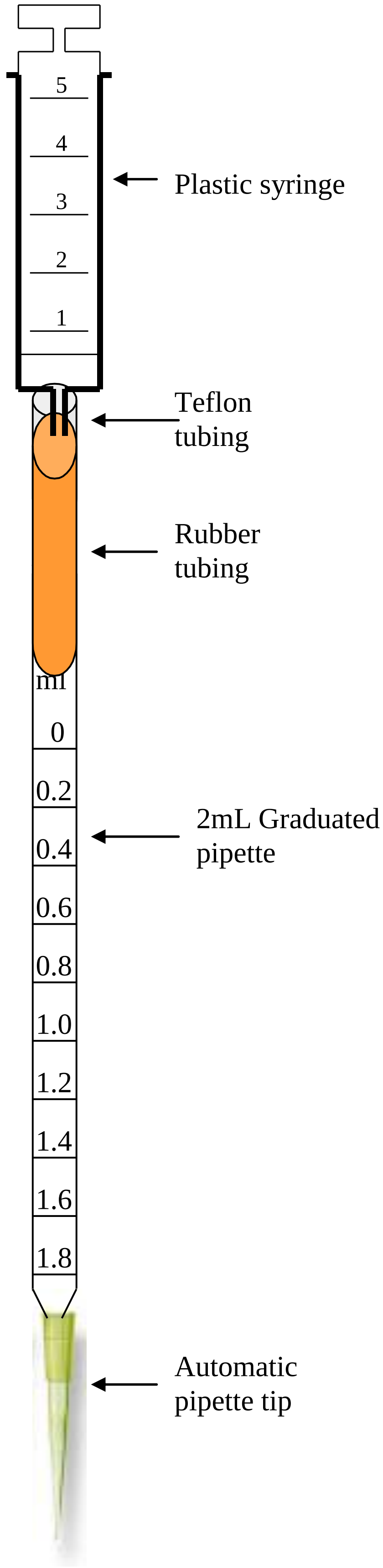


Figure 5.2: Microburette (Not to scale)



All of the titrimetric analysis were carried out both at the typical/normal scale given in the main Leaving Certificate Chemistry textbooks[12-13] and at micro-scale, which was based on an approximate 90% reduction of the normal scale. In Tables 5.3 and 5.4, the % difference between the experimental results I obtained using the normal scale and microscale apparatus are shown for the various volumetric and environmental experiments. The relative standard deviation of the titre results is also given, which was calculated using the standard formula[14]:

$$RSD = \frac{100 \times S}{\bar{x}}$$

where $\bar{x}$ is the arithmetic mean of the sample and

S is the standard deviation calculated using the formula:

$$S = \sqrt{\frac{\sum\left(x - \bar{x}\right)^2}{n-1}}$$

The relative standard deviation gives a measure of precision, giving an indication of the repeatability, or within run precision, of the measurement. Typically, a %RSD of about 2-3% is highly acceptable for analytical analysis, and 5% acceptable[15]. The % difference gives a measure of the magnitude of the difference between the normal scale result and the microscale result and was calculated using the formula shown below:

$$\frac{\left(\overline{x_M} - \overline{x_N}\right)}{\overline{x_N}} \times 100,$$

where $\overline{x_M}$ = average for microscale and $\overline{x_N}$ = average for normal scale

This formula is similar to the formula used to determine % relative error, however the relative error is determined against a true or accepted value, which there isn't in this case and instead the experimental value (microscale) is compared to the value obtained using the normal scale.

In the majority of the experiments, an average of 16 titrations were carried out for each scale. See Appendix 5.3 for the actual titre results for each experiment described in this section. In some cases, the precision/accuracy of the burette and pipette were the focus of the experiments, therefore the same solutions were used for both scales. However, in other cases, the whole experiment was completed on a microscale, including sample preparation, providing an overall picture of the accuracy of the technique.

In Tables 5.3 and 5.4 the first column gives the number of the mandatory experiment, and the second column shows what the variable to be determined was i.e. concentration of Hydrochloric Acid. The 'Average' refers to, for example, the concentration that was obtained when the titre values for that experiment were averaged and used in the determination of the concentration. The %RSD is the relative standard deviation of these titre values. Finally, as described earlier, the % difference is a measure of the difference between the value obtained for the normal scale and microscale.

Table 5.3: % difference between the result obtained for each volumetric experiment on normal and microscale (Mandatory experiment 4.1-4.8)

EXP.	OUTCOME	NORMAL SCALE		MICROSCALE		% DIFF
		AVERAGE	% RSD	AVERAGE	% RSD	
4.1	mols/L HCl	0.2007	0.2	0.1967	1.1	-1.99
4.2	mols/L HCl	0.2415	0.6	0.2441	1.2	+1.07
4.3	%w/v CH_3COOH	5.11	1.3	5.20	1.0	+1.76
4.4	X moles H_2O	10.04	0.5	10.15	1.7	+1.10
4.5	mols/L $KmnO_4$	0.0205	0.3	0.0203	1.7	-0.98
4.6	mg iron/tablet	38.05	1.8	37.42	3.1	-1.65
4.7	mols/L $Na_2S_2O_3$	0.1002	0.6	0.1006	0.5	+0.40
4.8	%w/v NaOCl	3.62	0.6	3.57	0.9	-1.38

For the environmental titrations (9.3 & 9.4) various water samples were used to test robustness of the methods with real samples. A Ballygowan Still Water (No. 1) was used to determine hardness (ppm $CaCO_3$) as well as a distilled water sample spiked with Calcium Carbonate (No. 2) for further comparison. Secondly, a sample of tap water (No. 3) was used to determine dissolved oxygen (ppm O_2).

Table 5.4: % difference between the result obtained for two environmental experiments on normal and microscale (Mandatory experiment 9.3 & 9.4)

EXP.	NO.	OUTCOME	NORMAL SCALE		MICROSCALE		% DIFF
			AVERAGE	% RSD	AVERAGE	% RSD	
9.3	1	ppm $CaCO_3$	318.88	0.9	320.29	3.1	+0.44
9.3	2	ppm $CaCO_3$	1059.39	0.6	1061.56	1.3	+0.21
9.4	3	ppm O_2	10.55	0.8	10.62	0.8	+0.72

From both Tables 5.3 and 5.4 the average relative standard deviation is 0.75% for the normal scale compared to 1.5% for the microscale. This shows that overall both techniques are within accepted specification in terms of repeatability of measurement, however, the normal scale is shown to be more precise overall. The results obtained for the % difference were all between ± 2%, this shows that there is a very small deviance in the results obtained between the two techniques showing a good level of precision and accuracy between them.

An overview of all these titrations at a microscale, shows that the benefits from microscale are plentiful. First of all, preparation time for teachers is much less since much smaller volumes of solutions are required. A decrease of at least 90% for all starting materials was used. The microburette is much easier to use, and fill, without students having to climb on stools! The accuracy and precision of both the micro-burette and the overall microscale method has been shown to be as good as the normal scale. The time taken to complete a titration is shortened and so more time can be spent on understanding the chemistry behind the experiment, and any applications there might be. Finally, it is possible for each student to do the experiment themselves, since chemical usage is low.

In terms of the micro-burette, the cost of buying commercially available microburettes for large number of students may prove costly. However, as can be seen from the results above the constructed micro-burette is both accurate and precise. Singh *et al.*[16], who use a similarly constructed microburette, report many advantages of this microburette over other micro devices. The advantages include the formation of more uniform drops at its micro tip, and a much higher degree of accuracy. Advantages of the micro-burette over the standard burette are also reported i.e. it is easy to fill, easy to control, is much less expensive and the titration requires much less time. Accuracy of the microburettes are quoted at ±1μl. Singh *et al.*[17] also carried out a comparative study of microscale and standard burettes. It concludes that considering the ease of performance, cost effectiveness, time saving and analytical rigor described above, the environmentally friendly microburette is of great value to the instructional laboratory.

5.2.2: ORGANIC EXPERIMENTS

The organic chemistry section is probably one of the most difficult to master for the students to understand and for the teachers to teach. Coupled with the difficulty of completing the mandatory preparation experiments (particularly 7.2, 7.4-7.6) within an 80 minute laboratory session, these experiments are often demonstrated by the teacher to the class[5]. There are 7 experiments in the organic section, of which five can be carried out on a microscale using small-scale glassware. Of the seven experiments, the two which have yet to be microscaled are 7.3 and 7.6 namely Preparation and Properties of Ethene, and the Extraction of Clove Oil from Cloves by Steam Distillation. These two experiments are successfully microscaled through the use of the 'BASF Minilab' described in an earlier section by using specialised glassware. However, the purpose of the microscale described in this research is to use apparatus that is already available or readily available to schools i.e. not having to purchase expensive kits. The preparation of ethene, on a microscale, has also been described by Mattson Creighton[18]. This is a bit more complex however (and in my opinion unsuitable for Leaving Certificate chemistry) than other gas preparations described on this website such as the production of oxygen and ethyne which shall be further discussed later.

Another two experiments in the organic section are the recrystallisation of benzoic acid and the determination of its melting point (exp 7.1) and separation of a mixture of indicators using paper chromatography (exp 7.7). These two experiments are both already on quite a small scale, especially 7.7, based on the methods given by Mullally[12] and Kennedy[13]. However, the recrystallisation can be microscaled by a further 75%, based on the amounts suggested in Mullally[12]. This yields enough recrystallised product to carry out a melting point. The apparatus used is the same as on the normal scale but smaller in size i.e. replacing the 250mL beakers suggested by 25mL beakers.

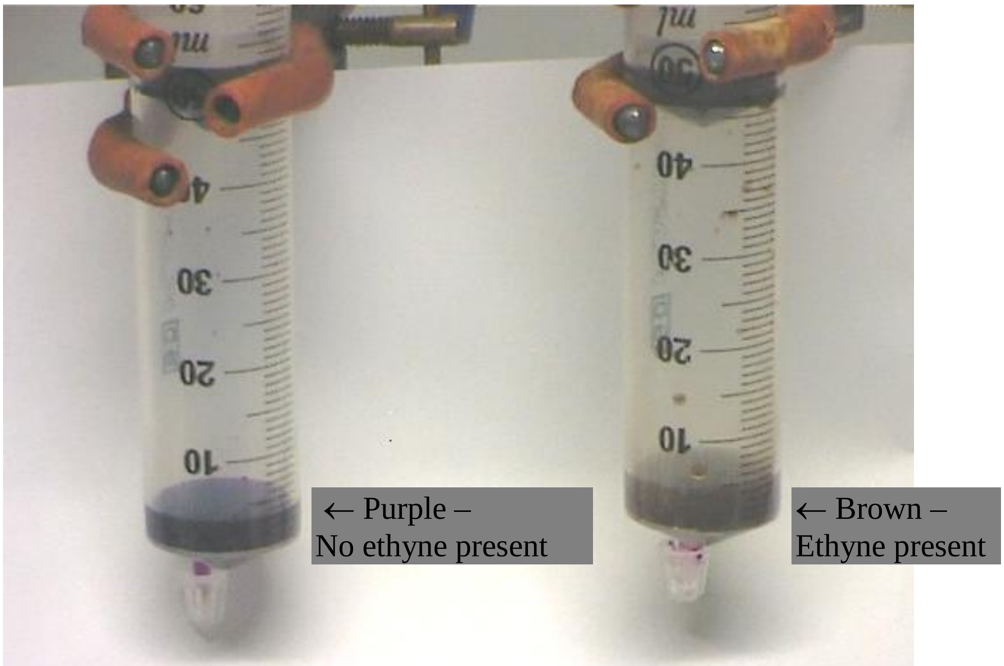
On a microscale, various heating methods have been promoted. Joling *et al.* [19]describe a low-cost and timesaving electric heater, and others[20,21] promote the use of Bunsen burners and microburners, provided certain precautions are observed. However, it is the use of a magnetic-stirring hot plate, which is most widely used at a microscale. The hot plate can be used with either an aluminium block or sand bath and it is the sand bath, which is the preferred method of heating in this work. This arrangement allows stirring and heating to be used simultaneously. It also provides a non-flammable source of heat, which increases safety. The sand is usually contained in a glass crystallising dish or metal container, in this case a metal soup bowl! Since small magnetic stirrers can be lost easily, a method to construct a magnetic stir bar has been devised[20,20]. This involves sealing a section of a paper-clip in a section of a long-tip Pasteur pipette and sealing both ends with a micro-burner.

This section looks at the preparations of soap, ethanal and ethanoic acid on a microscale and discusses the yields produced and the ease of use etc. Before that however, the production of ethyne gas and testing its properties is discussed.

Preparation and properties of ethyne

This gas preparation is carried out normally using a large bulky apparatus, and a sizeable amount of calcium carbide[12,13], a highly pyrophoric substance. On a microscale, the procedure used is one which is described on the Mattson Creighton website[22], whereby the reaction and gas collection all takes place within a 60mL plastic syringe. Calcium Carbide (0.02g) and 5mL of water are required to produce enough gas to fill a 60mL syringe. The production of ethyne is relatively fast and it typically takes 15 seconds to fill a syringe. Carrying out the characterisation tests are also very easy and quick. To test for unsaturation, potassium permanganate is used. This involves introducing a few mL of dilute, aqueous permanganate into the syringe. The typical purple colour of the potassium permanganate will disappear on shaking of the plastic syringe, turning the solution a brown colour when ethyne is present (See Figure 5.3).

Figure 5.3: Testing ethyne and air for unsaturation using permanganate



It is also possible to test for unsaturation using aqueous bromine. 3-5mL of the bromine solution is poured into a test tube and stoppered. The ethyne filled syringe is equipped with latex tubing and about 20-mL of the gas is transferred into the test tube, discharging the gas just above the surface of the bromine solution. On shaking the re-stoppered test tube, the red colour of bromine will disappear when ethyne is present. Overall, this techniques allows students to complete the experiment on their own, with increased safety due to less quantities of calcium carbide being used. Furthermore, the technique, with practice, is easy to do and much faster than the normal set-up for gas preparation.

Preparation of soap

Experiment 7.2 is the preparation of soap, and this works very well at microscale. The traditional method involves refluxing, using a liebig condenser, a mixture of lard, sodium hydroxide, ethanol and water, then distilling off the ethanol, and to precipitate out the soap, the soap is mixed with a saline solution and filtered. At a microscale, 5 or 10mL reaction flasks are used compared to 50mL or 250mL at a normal scale. The typical yields of soap on a microscale are 0.2-0.3g. Figure 5.4 below shows a modification of the traditional method to prepare soap. Instead of using a liebig condenser, an air condenser is used and this gave similar yields of soap as with the liebig condenser. All the soap produced showed the expected properties.

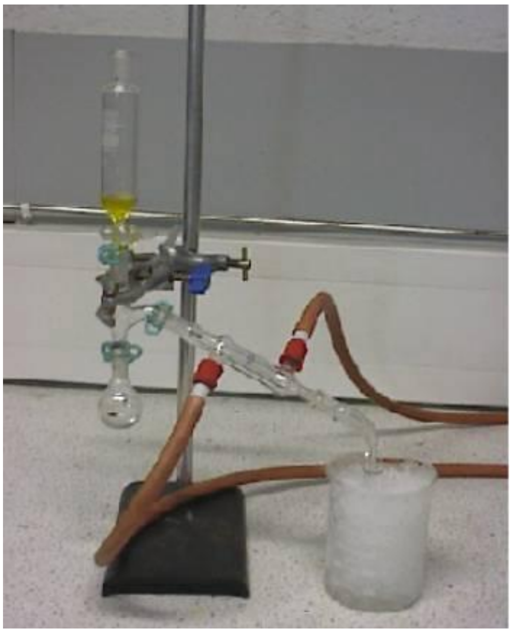
Figure 5.4: Air condenser for the preparation of soap on a microscale

The advantage of using the air condenser is that there is no need for water tubing and so it is easier to use in the laboratory. Overall, this technique is quicker and easier to use than the normal scale and more accessible for students to do on their own.

Preparation and properties of ethanal

The experimental set-up for the production of ethanal (Experiment 7.4) is shown in Figure 5.5. Use of a 10mL round bottom flask over a pear shaped flask is recommended to ensure contents are uniformly heated in the sand bath. Typical yields of 2-3mL of ethanal can be obtained, which is enough to carry out the characterisation tests on a microscale. Advantages such as less use of hazardous chemicals e.g. dichromate and less bulky apparatus mean a generally safer laboratory environment. Furthermore, reaction times are reduced and so allow students to easily complete the experiments in the typical 80minute laboratory class. Also, students are more able to assemble this smaller apparatus on their own compared to the normal apparatus.

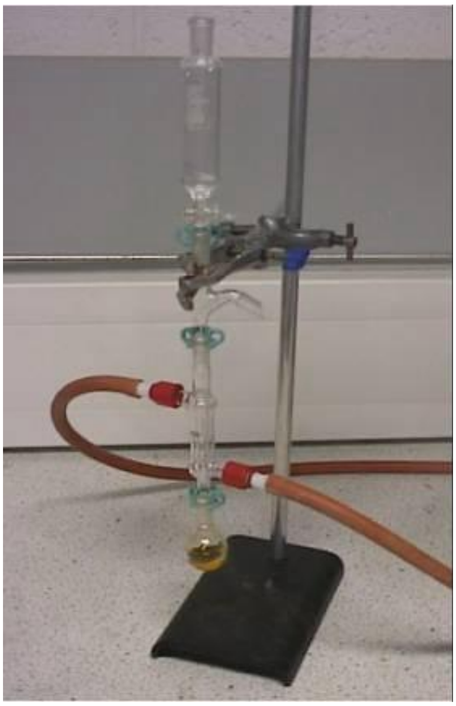
Figure 5.5: Preparation of ethanal on a microscale



Preparation and properties of ethanoic acid

The production of ethanoic acid (experiment 7.5) involves two steps, refluxing and distilling. The reflux step, on a microscale, is shown in Figure 5.6. Typical yields are 2-3mL of aqueous ethanoic acid. Similar advanatages are noted here, with use of less hazardous chemicals e.g. concentrated sulphuric acid and dichromate, fast reaction times and ease of assembly of apparatus.

Figure 5.6: Preparation of ethanoic acid (Reflux stage)



The benefits of microscale are very obvious in the latter four experiments particularly due to the use of less chemicals.

- Dichromate is irritating to eyes, respiratory system and skin and is difficult to dispose of
- Concentrated sulphuric acid causes severe burns and reacts explosively with water
- Calcium carbide also reacts explosively with water and is irritating to eyes, nose and skin[23]

So minimising the use of these materials, particularly in a school chemical laboratory would increase safety. In this work, a reduction of at least 50-80% on the typical quantities is used[12,13]. Table 5.6 gives the amount of the various reagents used in one set-up for the preparation of ethanoic acid as recommended by Mullally[12] and Kennedy[13], and as used in these trials on a microscale.

Table 5.6: Reagents required for one set-up of the preparation of ethanoic acid

Scale	Mullally[12]	Kennedy[13]	Microscale
Dilute sulphuric acid	$10cm^3$		$2cm^3$
Concentrated sulphuric acid	$2cm^3$	$3.5cm^3$	$0.4cm^3$
Sodium dichromate	10g	5g	2.4g
Ethanol	$5cm^3$	$1.5cm^3$	$1cm^3$

It is clear that the amount of chemical usage is much less, and therefore the amount of hazardous waste decreased. Also, the use of a sand bath and hot plate are much safer than gas burners and since there is much less chemical usage, the risk of fire is reduced. The setting up of these experiments on a normal scale can take two people in a school environment, whereas on a microscale, students would be able to do it themselves. Also, such large bulky set-ups are a risk in any teaching laboratory – taking up much space on benches and can be knocked against etc.

5.2.3: RATE OF REACTION

The effect of catalysts, concentration and temperature on the rate of reaction is studied in this section. In one experiment (Experiment 6.1) the production of oxygen from the decomposition of hydrogen peroxide is monitored using manganese dioxide as a catalyst. Another experiment (Experiment 6.2) uses the sodium thiosulfate/hydrochloric acid reaction to study the effect of concentration and temperature on the rate of reaction.

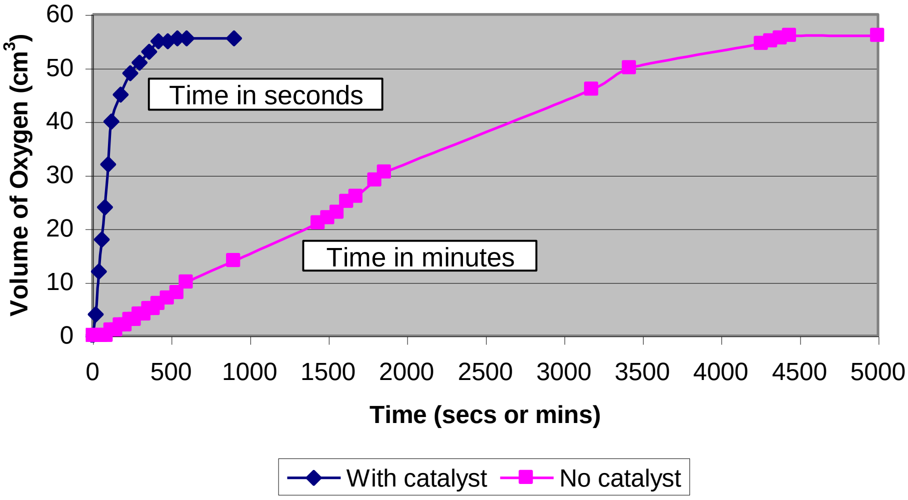
Effect of catalyst on rate of reaction

The decomposition of hydrogen peroxide to form oxygen is monitored in this experiment using manganese dioxide as a catalyst. The 'traditional' method for monitoring the production of oxygen is using an inverted graduated cylinder in a trough of water and measuring the displacement of water in the cylinder, due to oxygen production, in the cylinder relative to time. It is possible to use a similar technique using smaller amounts of hydrogen peroxide and manganese dioxide and smaller glassware but it can also be done on a microscale using a graduated plastic syringe. This technique is described on the Mattson Creighton website[24] and is similar to the one used in the earlier section for the preparation of ethyne. The aim of this experiment is to monitor the production of oxygen over time due to the decomposition of hydrogen peroxide according to the following equation:

$$2H_2O_{2(aq)} \rightarrow 2H_2O_{(l)} + O_{2(g)}$$

The use of the catalyst, manganese dioxide, increased the rate of the reaction significantly. This is clearly demonstrated in Figure 5.7. Two plots are shown, one which shows the volume of oxygen produced against time (in seconds) when the catalyst was used and the second plot shows the volume of oxygen produced against time (in minutes) when there was no catalyst present.

Figure 5.7: Graph of volume of oxygen produced over time with/without catalyst



The shape of the plot where the catalyst was used shows that the reaction is fast initially, indicated by the steep rise in the curve. However, as the reaction proceeds, the production of oxygen becomes slower, indicated by the almost flat curve, with the graph eventually levelling off when the decomposition of the hydrogen peroxide is complete. In contrast, the pink plot, showing the production of oxygen when no catalyst was present, indicates that the decomposition continues at a steady rate and is also much slower than when the catalyst was used. For example, it took approximately 7 minutes for $55cm^3$ of oxygen to be produced when the manganese dioxide was present, where as it took nearly 72 hours for the same volume to be produced when there was no catalyst present! The average rate for the reaction for the production of oxygen with the catalyst is $1.0x10^{-1}cm^3/s$ in contrast with $2.1x10^{-4}$ cm^3/s when there was no catalyst present.

In the school laboratory students typically only do the experiment with the catalyst, rather than doing it without the catalyst as well. I suggest the reason for this is:

(a) It is not prescribed on the syllabus

(b) It requires a long time to monitor the reaction without the catalyst

The benefit of doing both experiments is clear since students can see the real effect of using the catalyst. Using this microscale technique, the experiments are done more readily. Since the reaction takes place in a plastic syringe it is much more portable and student could even take it home and monitor the change in volume over time! Or the syringe could be left in the laboratory and students monitor it at various intervals during the school day. This also encourages students to really engage with the experiment.

Effect of concentration and temperature on rate of reaction

In the reaction between sodium thiosulphate and hydrochloric acid, sulfur is formed which can be seen as a dense yellow colour, according to the equation:

$$Na_2S_2O_{3(aq)} + 2HCl_{(aq)} \rightarrow 2NaCl_{(aq)} + SO_{2(g)} + S_{(s)} + H_2O_{(l)}$$

In these experiments (Experiment 6.2) an 'X' is marked under the reaction flask and this is clearly visible at the beginning of the reaction. As the reaction proceeds the sulfur is formed resulting in a dense yellow cloud forming in the reaction flask. The time taken for the 'X' to disappear is measured, this gives a measure of the rate of the reaction.

The use of well-plates and pasteur pipettes are very effective in carrying out this experiment at a microscale. Addition of small volumes is necessary in these experiments and can be added using pasteur pipettes or burettes. As well as using the pipettes to deliver a volume of liquid, it is also used to deliver a number of drops. An evaluation was done by Ealy and Pickering[25] on drop counting as a valid volume measurement. After evaluation of various apparatus, the best device for drop delivery was found to be the burette, and that plasticware, such as the pasteur pipettes were not as good in terms of precision. They note however that precision increased the more drops in a set but over 30 drops would lead to obvious human error, i.e. losing count! For ease of use, however pasteur pipettes have been used in the following experiments.

The first part of this experiment studied the effect of concentration on the reaction rate. A well-plate was used as the reaction flask and the concentration of sodium thiosulfate was varied by adding different number of drops of solution. The reactants were at room temperature. Table 5.7 shows the number of drops of sodium thiosulfate (0.2M) and water added to each well and a constant amount of hydrochloric acid (2M) was then added (2 drops).

Table 5.7: Details of the volumes of solutions used in experiment 6.2 (i)

Well	Drops of $Na_2S_2O_3$	Drops of H_2O	Drops of HCl
A1	20	0	2
A2	16	4	2
A3	12	8	2
A4	8	12	2
A5	4	16	2

Using this microscale approach, the aims of the experiment are met, with students observing the relationship between concentration and time (See Figure 5.8 – two trials shown), and then verifying the linear relationship between the rate of the reaction (1/t) and concentration (See Figure 5.9). It is also shown to be highly accurate. The experiment is very quick and students can carry it out numerous times with very little use of chemicals. Furthermore, since only well plates and pasteur pipettes are required students could easily do this experiment on their own or in pairs with one student monitoring the 'X' and the other student recording the time.

Figure 5.8: Graph of time against %concentration of sodium thiosulfate

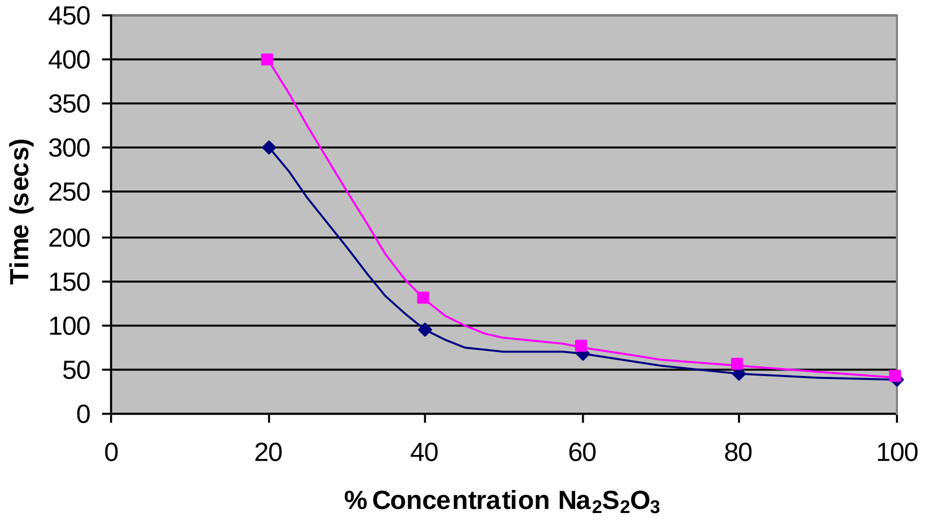
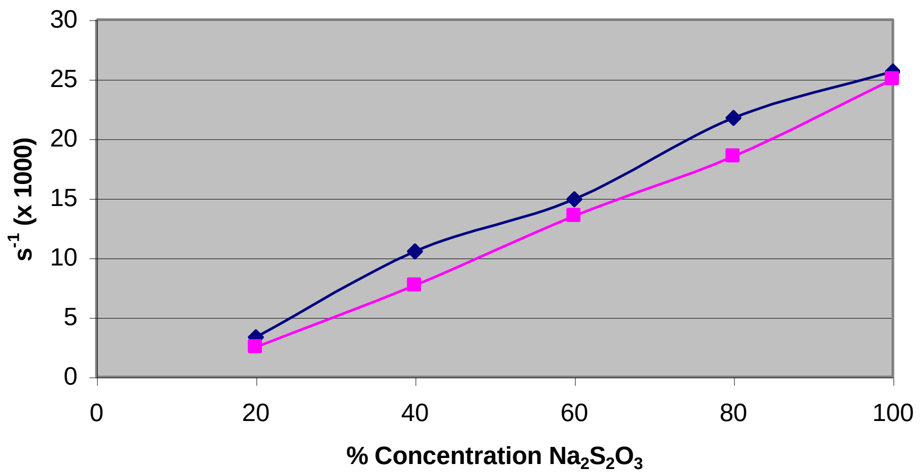


Figure 5.9: Graph of 1/time against % concentration of sodium thiosulfate



Effect of temperature on rate of reaction

Studying the effect of temperature is quite similar to the set-up to measure effect of concentration on rate but in this experiment, the concentration of the sodium thiosulfate is kept constant (0.1M) and instead the temperature of the sodium thiosulfate altered in a range of 20 to 90°C. The hydrochloric acid was kept at room temperature and a concentration of 1M used. The thiosulfate was heated to the appropriate temperature and 2cm^3 added to a well containing 0.5cm^3 drops of hydrochloric acid, the time taken for the 'X' to disappear was measured. It is necessary to take the temperature of the solution in the well during the reaction as there will be some cooling due to mixing with the room temperature hydrochloric acid, the plastic container and surroundings. The hydrochloric acid was not heated as the reaction would be too fast. Table 5.8 below shows the volumes and temperatures for the different solutions.

Table 5.8: Table 5: Details of the volumes of solutions used in experiment 6.2 (ii)

Well	$Na_2S_2O_3$ (cm^3)	HCl (cm^3)	Initial Temp of $Na_2S_2O_3$ °C
A1	2	0.5	20
A2	2	0.5	40
A3	2	0.5	55
A4	2	0.5	70
A5	2	0.5	90

In the previous experiment it was easier to get a range of concentrations of thiosulfate using drops rather than volumes therefore drop measurement was used. In this experiment volumetric quantities are used i.e. 2mL rather than 20 drops etc. This is because the volumes are not altered during the experiment and though 20 drops is approximately equal to 2mL I felt it was easier for students to measure 2mL rather than 20 drops. The other benefit is that it is quicker to dispense a measured volume than to count out drops. This is very important in this experiment since every second counts in terms of loss of heat from the thiosulfate solution! 0.5 and 2mL are accurate markings on the pasteur pipette.

This experiment is successful in demonstrating the relationship between temperature of reactant and time (see Figure 5.10 – two trials shown) and verifying the relationship between rate of the reaction and temperature (see Figure 5.11). It is also a very quick and easy experiment to do and as before students can easily do it on their own or in pairs. Also waste disposal is much easier as large quantities of sulfur are normally produced in the normal scale apparatus.

Figure 5.10: Graph of time against temperature of sodium thiosulfate

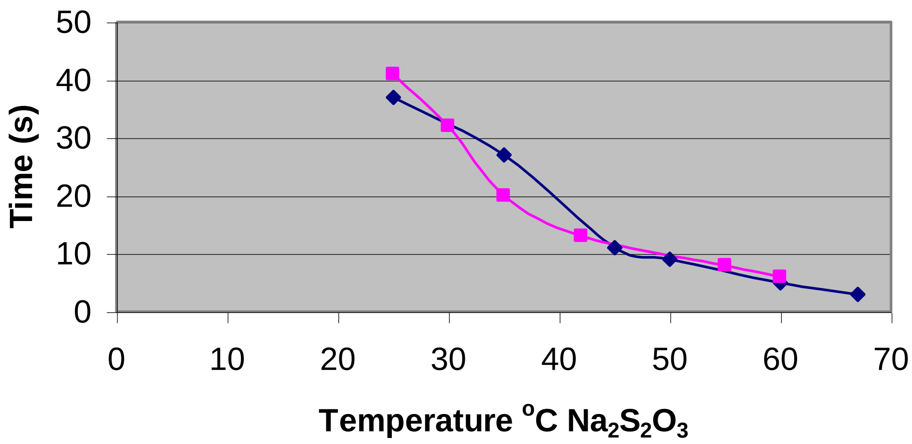
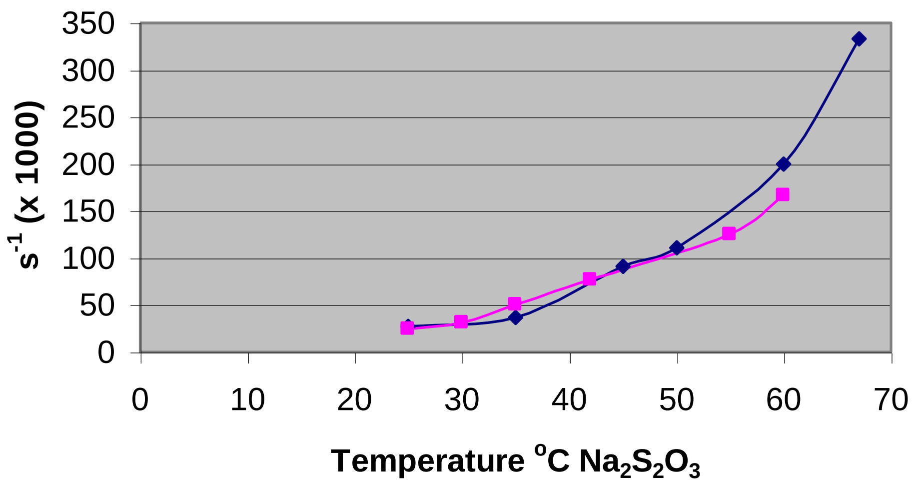


Figure 5.11: Graph of 1/time against temperature of sodium thiosulfate



5.2.4: OTHER EXPERIMENTS

Three experiments, the test for anions (Experiment 2.1), the heat of reaction (Experiment 5.1) and Le Chatelier's principle (Experiment 8.1) are dealt with in this section.

Tests for anions

There is one mandatory experiment in this section and it is the testing of anions in aqueous solutions. Most of the tests can be carried out effectively in well-plates (apart from the initial testing of carbonate and hydrogencarbonate, and the 'Brown Ring' test for nitrates, both of which involve the use of small test-tubes). Table 5.9 contains details to carry out tests for various anions in a well-plate.

TABLE 5.9: DETAILS OF WELL-PLATE TESTS FOR VARIOUS ANIONS

Anion	Carbonate	Hydrogen carbonate	Chloride	*Sulfate*	*Sulfite*	Phosphate
Well	A1	A2	A3	*A4*	*A5*	A6
Add* Test sol	10 of CO_3	10 of HCO_3	10 of Cl	*10 of SO_4*	*10 of SO_3*	10 of PO_4
Add*	10 of $MgSO_4$**	10 of $MgSO_4$ **	5 of Silver Nitrate	*10 of $BaCl_2$*	*10 of $BaCl_2$*	10 of $BaNO_3$ **
Add*			15 of NH_3 **	*10 of HCl* **	*10 of HCl* **	

* Number of drops of solution ** Confirmatory test

For example to test for sulfates or sulfites, 10 drops of the test solution is added to a well, then 10 drops of barium chloride added. If the solution turns cloudy, and a white precipitate is formed this shows the presence of either barium sulfate or barium sulfite. To confirm the presence of either the sulfate or sulfite, 10 drops of hydrochloric acid are added. Barium sulfate is insoluble in hydrochloric acid, where as barium sulfite is soluble. This allows for confirmation of the presence of either sulfate or sulfite ions.

This experiment has many benefits when done on this scale. First of all, having the solutions side by side in the wells makes comparison and observations much easier and clearer to see. Also, since such small amounts are required at this scale, the experiment can be repeated with very little extra time or chemicals required. An obvious advantage from this, is that the experiment can be made into a more investigative one, with unknown solutions. This will give the students a more thorough appreciation and understanding of these tests. Furthermore, using simple equipment such as the pasteur pipettes and well plates makes this a very easy experiment for students to do. Finally, using hazardous compounds, such as ammonia, and expensive compounds (in terms of initial purchase and disposal), such as silver nitrate, the obvious reduction at source, is both a financial and environmentally friendly option.

Heat of reaction

A calorimeter is used to determine the change in temperature when substances react. Calorimeters can come in many shapes or forms from the Bomb calorimeter, a strong cylindrical steel container with a tightly fitting screwed lid, through which an inlet tube for oxygen and a pair of electrical wires pass[26], to the use of double-nested expanded polystyrene cups, which are reported to have excellent insulation for thermometric measurement[27]. Here a plastic sample holder was used for the microscale thermometric measurement of the heat of reaction, where the temperature change was monitored against time on reaction of hydrochloric acid and sodium hydroxide. In this experiment, the heat of neutralisation of hydrochloric acid and sodium hydroxide is determined. The initial temperature of each solution is measured and the average initial temperature recorded. The solutions are then added to the calorimeter and the changes in temperature observed and recorded.

Since the reaction between hydrochloric acid and sodium hydroxide is also a neutralisation reaction, the molar heat of neutralisation for either hydrochloric acid or sodium hydroxide can be determined. The heat of reaction is determined by the formula below:

$$\Delta H = -mc\Delta T$$

where m = mass of reactants
c = specific heat capacity, (J $kg^{-1}K^{-1}$)
ΔT = change in temperature in K

To then calculate the molar heat of neutralisation of hydrochloric acid, for example, ΔH is divided by the number of moles of hydrochloric acid used in the reaction. The specific heat capacity of a substance is the amount of heat required to raise the temperature of 1kg of the substance by 1K. The specific heat capacity of dilute solutions is approximated as the same as that of the pure solvent, which in this case is water[28]. Water has a specific heat capacity of 4184 J $kg^{-1}K^{-1}$. A series of experiments were carried out and data from four of these is given in Figure 5.12 and calculations for the molar heat of neutralisation are given in Table 5.10. The reason for monitoring the temperature change over a long time after the initial large increase, is to allow for correct approximation of the maximum temperature reached. By drawing the plot back to the start of the reaction, the real maximum temperature can be obtained. A number of assumptions are made in calculating the heat of reaction. These include assuming that all the heat generated is going to raise the temperature of the solution and that none is absorbed by the plastic container or lost to the surroundings. Secondly, it is assumed that the density of the solution is the same as the density of water, e.g. 1g cm^{-3}.

Figure 5.12: Graph of temperature against time

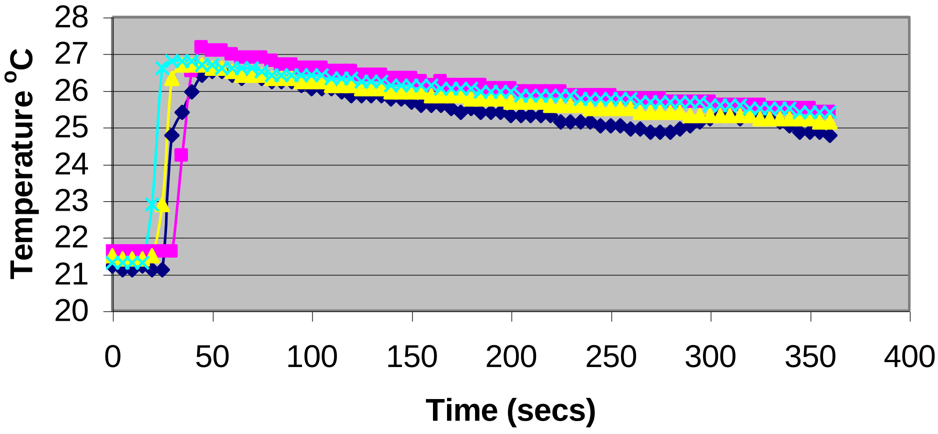


Table 5.10: Determination of molar heat of neutralisation (microscale)

MICROSCALE	TRIAL 1	TRIAL 2	TRIAL 3	TRIAL 4
Volume of 1M HCl	3 cm^3	3 cm^3	3 cm^3	5 cm^3
Volume of 1M NaOH	3 cm^3	3 cm^3	3 cm^3	5 cm^3
Weight (kg) NaOH and HCl	0.006	0.006	0.006	0.01
c (J kg^{-1} K^{-1}) H_2O	4184	4184	4184	4184
T°C Initial	21.21	21.6	21.41	21.31
T°C Final	26.51	27.16	26.7	26.79
Difference in T (°C/K)	5.3	5.6	5.3	5.5
Heat generated (J)	-133.05	-139.58	-132.80	-229.28
Number of moles of HCl	0.003	0.003	0.003	0.005
Molar heat of neutralisation (kJ)	-44.4	-46.5	-44.3	-45.9

The molar heat of neutralisation of hydrochloric acid is given as -57 J kg^{-1} K^{-1} [13], therefore there is a large error associated with this less than robust method, with an average of 45.3 J kg^{-1} K^{-1} obtained using the microscale method. However, using larger volumes of solutions and similar apparatus did not result in a significantly higher value of ΔH_M. See Table 5.11 for details.

Despite these large discrepancies between the theoretical value and the observed value, this microscale experiment can give rise to good discussion with students such as on how the experiment could be improved, such as modifying the calorimeter used and therefore giving students a sense of ownership and engaging them in the whole process. It also gives rise to discussion on errors and, for example, what adjustments could be made to determine more accurately the maximum temperature etc. Student will also enjoy the hands-on nature of making their own calorimeter from plastic containers and other insulating material!

Table 5.11: Determination of molar heat of neutralisation (normal scale)

NORMAL SCALE	TRIAL 1	TRIAL 2
Volume of 1M HCl	10 cm^3	10 cm^3
Volume of 1M NaOH	10 cm^3	10 cm^3
Weight (kg)	0.02	0.02
c (J kg^{-1} K^{-1}) H_2O	4184	4184
T°C Initial	21.21	21.6
T°C Final	26.51	27.16
Difference in T (°C/K)	5.3	5.6
Heat generated (J)	-443.504	-465.261
Number of moles of HCl	0.010	0.010
Molar heat of neutralisation (kJ)	-44.4	-46.5

Le Chatelier's Principle

The aim in this experiment (Experiment 8.1) is to demonstrate Le Chatelier's Principle, that when a disturbance is imposed on a system, the system will react so as to minimise the effect of the disturbance. Three different reactions are investigated each chosen because they have clear colour changes. The colour observed in each of the reactions depends on how far the reaction has gone to either the products or the reactants. Two of the reactions can be performed in well-plates, using a pasteur pipette as a dropper, and the third reaction is done in small test-tubes as heating is required. One of the reactions is to demonstrate the effect of concentration changes, using the reaction below :

$$2CrO_4{}^{2-}{}_{(aq)} + 2H^+{}_{(aq)} \leftrightarrow Cr_2O_7{}^{2-}{}_{(aq)} + H_2O_{(l)}$$

Table 5.12: Details of well-plate amounts for the reaction of chromate and acid

Well	A1	A2	B1	B2
1. No of drops	15 of chromate	15 of chromate	15 of dichromate	15 of dichromate
2. No of drops	10 of dil HCl	10 of dil NaOH	10 of dil HCl	10 of dil NaOH

Table 5.12 describes the details for the demonstration of the effect of concentration on the equilibrium. The yellow chromate and the orange dichromate are very distinct. In this case of addition of acid to the chromate, the reaction will shift to the right, and cause the formation of the orange dichromate. Similarily, the addition of base to the dichromate will shift the reaction to the left, and cause the formation of the yellow chromate. As before, having the wells side-by-side allows for comparison and observations to be made easily and clearly. There are a few hazardous chemicals used in this experiment. As well as the chromate and dichromate, concentrated acid is also required, therefore the minimisation of the use of these chemicals is a priority. Using such small amounts, means safety in the laboratory is improved and hazardous waste greatly reduced.

Finally two other experiments are also possible on a microscale (Experiment 3.1 and Experiment 9.2). The latter is the determination of total suspended and dissolved solids in a water sample and the former determination of the Relative Molecular Mass of a volatile liquid. However it is not necessary to describe them in detail since the procedures on a microscale are exactly the same just using smaller quantities and smaller apparatus.

Overall, it has been demonstrated that the aims of the mandatory experiments can be met using the microscale techniques described in this work. Furthermore, the advantages in terms of safety, less chemical usage and time have been discussed. Also, potential areas for further engagement of students with their practical work has been suggested such as assembly of the microburette and calorimeter.

5.3: EVALUATION OF THE USE OF MICROSCALE IN SECOND LEVEL SCHOOLS

For evaluation purposes, a number of the microscale experiments were carried out with 5th year students from four different schools. The schools selected were chosen because there were 3rd year undergraduate Science Education students, from DCU, on teaching practice at the time, thus providing a direct link with the chemistry teachers. Schools in which the student teachers were directly teaching or supporting the teacher in a 5th year Leaving Certificate class were targeted. Location of the schools and the timetables/schedule of the practical classes were also considered. This resulted in four schools getting involved doing a total of twelve of the Leaving Certificate experiments, with some duplication. Table 5.13 below shows the experiments carried out in each school.

Table 5.13: Details of experiments carried out in each school

EXPERIMENT\SCHOOL	1	2	3	4
An iodine/thiosulfate titration	■			
Determination of %w/v hypochlorite in bleach	■	■		
Total hardness by ethylenediaminetetraacetic acid			■	■
Total dissolved oxygen by redox titration			■	
Rate of production of oxygen from hydrogen peroxide	■	■		
Effect of concentration and temperature on rate on reaction	■	■		
Preparation of ethyne	■		■	
Preparation of soap			■	
Preparation of ethanal			■	
Preparation of ethanoic acid			■	
Le Chatelier's principle	■			
Determination of chlorine by colorimetry			■	

School 1 was an all-boys school in north Dublin with a chemistry class of 16 students. The second school was an all-girls school also in north Dublin with a chemistry class of 20 students. The third school was a mixed school in Kildare, with a chemistry class of 13 students. Finally, the fourth school was another all-girls school also in north Dublin with a chemistry class of 10 students. All the schools were non-fee paying secondary schools.

The format of the visits to the school was as follows:

- The teacher was provided with the procedures and all apparatus needed
- The teacher was given guidance on use of new techniques/equipment prior to the experiment being done with the class
- The teacher took the class as normal
- During the class, the students addressed questions on the experiment to the teacher
- If difficulties arose, the teacher discussed them with me and then proceeded with the class giving appropriate guidance to the students if needed
- Generally, my role was to simply observe the students
- Finally, after each experiment I asked students to share their experimental results with me and to give written feedback on the 'microscale' experience. This will now be discussed in more detail.

The following sections describe the actual experimental results from a selection of the experiments, as well as an analysis of the feedback from both students and teachers. The former allows a real analysis of the hands-on accuracy, precision and ease of use of the techniques by typical students. The feedback and comments from the students were gathered either by structured questionnaires which the students completed but in most cases, the students were simply asked to give feedback on the experiments, taking into account factors like 'ease of use', 'safety' and 'time'. As well as written feedback, evidence of students' usage of the techniques was gathered by video, thus giving further evidence of students' experience of the microscale approach. Teachers comments were also recorded by both written comments after the trial had been completed or through informal discussion.

5.3.1: SAMPLE RESULTS FROM SCHOOLS

As already mentioned, as part of the evaluation an analysis was carried out on the actual experimental results obtained by the students. In the case of the titrations, results from three of the schools are given. For the rates of reaction, the results from two schools are given. Finally, for the organic preparations, a discussion on the experience of the students, from observations made by the researcher, is given.

Titrations

The %RSD was calculated using the formula described previously in Section 5.2.1. The % difference was calculated by using a formula similar to the one described earlier, but each value obtained by the students was compared to an average value obtained by finding the mean of all the students' results within the one class.

$$\frac{Average\ for\ each\ group - Average\ titre\ for\ all\ groups}{Average\ titre\ for\ all\ groups} \times 100$$

Tables 5.14-5.16 gives the titre values obtained by each student group (student groups varied in number from 3 to 1, at the discretion of the teacher). The average titre was typically based on 3-4 titrations. It is important to remember that the students had no prior experience with the micro-burette and therefore, just like with the normal burette, it took some students a while to get comfortable with using it.

The first set of results, from Table 5.14, shows clearly that it is possible for students to obtain precise results, even with very limited practice with the micro-burette. Five of the ten results are within the accepted 2-3% relative standard deviation. However, it is also clear that some student were not precise at all. Also, there is a wide spread in their calculated answer for 'Dissolved oxygen' as shown by the % difference.

Table 5.14: Results from School 3 for the 'Estimation of total dissolved oxygen by redox titration'

GROUP	AVERAGE TITRE (cm^3)	% RSD	% DIFFERENCE
1	0.14	11.2	70
2	0.29	**2.0**	36
3	0.48	**1.2**	-6
4	0.34	18.3	24
5	0.53	6.6	-17
6	0.46	10.6	-2
7	0.63	**2.9**	-41
8	0.71	**1.8**	-58
9	0.61	9.3	-36
10	0.29	**2.8**	36

Table 5.15 again shows that students are capable of obtaining precise results, with half of the groups having a % relative standard deviation of less than 1.5%. And again, there is a wide spread in their calculated determination of the % w/v of hypochlorite in bleach as shown by the high % differences. This shows a less than desirable level of reproducibility.

Table 5.15: Results from School 2 for the 'determination of the percentage (w/v) of hypochlorite in bleach'

GROUP	AVERAGE TITRE (cm^3)	% RSD	% DIFFERENCE
1	1.15	5.3	-4
2	1.10	**0.5**	1
3	0.63	30.0	43
4	1.19	**1.3**	-8
5	1.30	**1.1**	-17
6	1.26	6.3	-14

Finally Table 5.16 generally shows both good levels of precision (%RSD < 6.1) and accuracy with % difference of ±3. It is worth mentioning that this school was an all-girls school and the student had previously carried out many normal scale titrations. See Figure 5.13 for student in school 1 carrying out a micro-titration on their own. It is interesting that there is such a wide diversity of precision, that some students can be highly precise with limited practice, whereas other students struggle with the new technique. Perhaps this suggests that these latter students have less developed manipulative and observational skills overall.

Table 5.16: Results from School 4 for the estimation of total hardness using EDTA

GROUP	AVERAGE TITRE (cm^3)	% RSD	% DIFFERENCE
1	2.36	3.1	2
2	2.42	6.1	0
3	2.35	**0.7**	3
4	2.50	4.0	-3
5	2.46	4.9	-2

Figure 5.13: Student from school 1 carrying out a micro-titration

Rates of reaction

The students' results were treated similarly as the data described in Section 5.2, by graphing the rate, 1/time, against concentration and temperature to investigate the effect of these parameters on the rate of reaction. Figure 5.14 shows a graph of 1/time against concentration for four of the groups' results. This shows that the students are capable of successfully demonstrating the correct relationship, which in this case is that the rate of the reaction is directly proportional to the concentration. In two of the four plots the near perfect straight line shows high accuracy. Though the other two plots are not as accurate, the linear relationship is still visible. Again, the equipment used in this experiment, which the students were not familiar with were the pasteur pipettes, both as a drop measure and a volumetric measure, and the well-plates.

Figure 5.15 shows the results obtained by two of the groups in School 1 for the experiment to monitor the effect of temperature on the rate of reaction. Again a plot of 1/time against temperature was graphed. The graph clearly shows that there is positive correlation between the rate and temperature, i.e. that as the temperature increases the rate of the reaction also increases. However, it is also clear that it is a non-linear relationship. This shape of graph is typical for this experiment.

Figure 5.14: Graph of 1/time against concentration – School 2

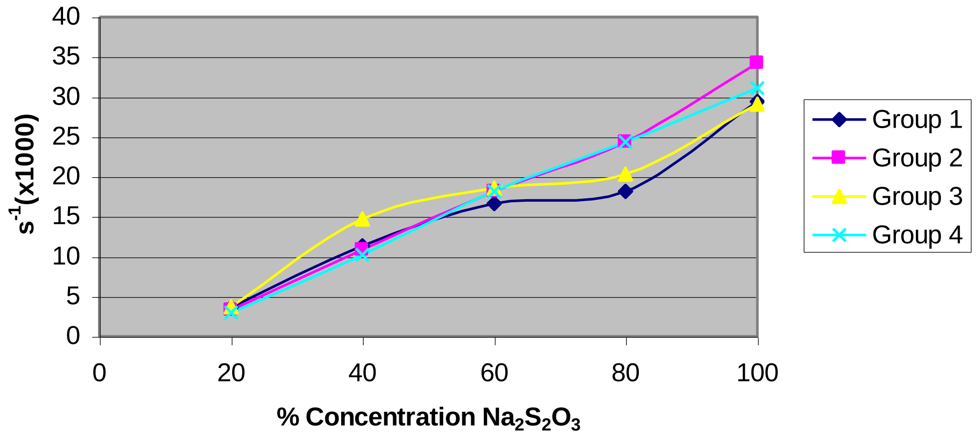
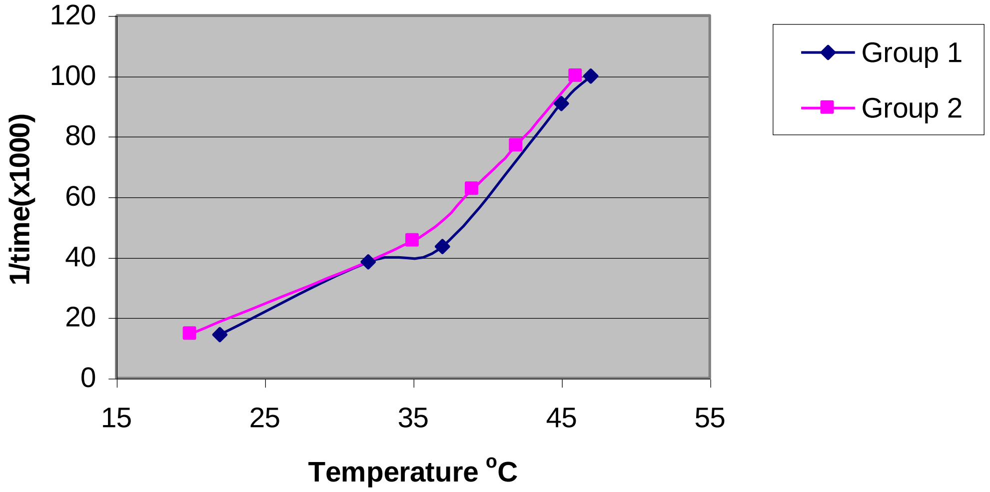
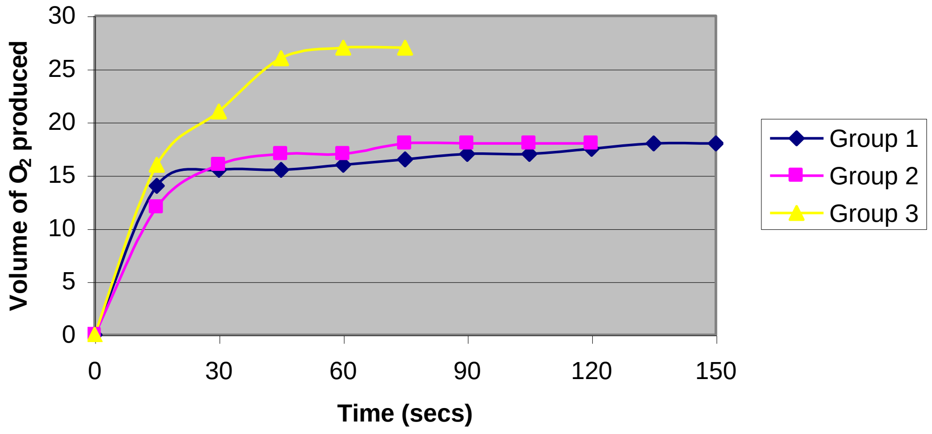


Figure 5.15: Graph of 1/time against temperature – School 1



The other experiment in this section looks at the effect of a catalyst on the rate of reaction. This is achieved by monitoring the production of oxygen from the decomposition of hydrogen peroxide using manganese dioxide as a catalyst. Results from three of the groups are shown. See Figure 5.16. The shape of the graph is once again typical of a catalyst enhanced experiment, with a steep initial increase with a levelling off due to the complete decomposition of the hydrogen peroxide. Group 3's graph (yellow plot) is shorter than the other two plots, this is because they monitored the reaction for less than a minute and a half! The students also got to test the oxygen they produced, adding an extra dimension to the experiment.

Figure 5.16: Graph of the volume of O_2 produced over time – School 2



Organic preparations

This area is one which teachers have difficulty teaching, mostly due to safety issues and laboratory resources, resulting in teachers either demonstrating the technique to the class, or large groups of students doing the experiments. Therefore, it was hoped that by using the microscale techniques students would be able to do the organic experiments either individually or in pairs. Furthermore, since on the normal scale reaction times are longer, it was hoped that students would be successfully able to complete the microscale preparation within the scheduled laboratory session.

Two schools did the preparation of ethyne experiment, with varying degrees of success. This was due to the difficulties that the students had with the 'in-syringe' technique for producing gases. This technique requires excellent manipulative skills. Students had difficulty in weighing the small amounts of calcium carbide and preventing the calcium carbide and water mixing prior to sealing the syringe. One school had some previous experience with the technique, since the students had carried out the experiment to monitor the production of oxygen, which uses the same technique. However, the other school had no prior experience of it. In both schools, most students were able to carry out the experiment, if not on their first attempt, by their second attempt.

Only one of the school had the opportunity to do the 'preparation of soap'. The students worked individually and everyone quickly set-up their apparatus. Two set-ups were possible within the one sand bath (see Figure 5.17). however, some of the hot-plates used were not effective as it took a long time to heat up the sand bath, and these students did not finish their experiment. However, those students whose hotplates were working correctly successfully prepared and tested the soap within the class time.

Figure 5.18: Student from school 3 monitoring reflux of soap

Again, only one school had the opportunity to do the 'preparation of ethanal' and 'preparation of ethanoic acid' experiments, with half of the class carrying out the preparation of ethanal and the other half doing the preparation of ethanoic acid (see Figure 5.19). The students did this experiment individually. The students who did the preparation of ethanal were very successful at getting their product. However, the students doing the preparation of ethanoic acid set up their experiments successfully but had difficulty with heating the sand baths enough, resulting in the temperature of the flask not reaching a high enough temperature to allow the ethanoic acid to distil off.

Figure 5.19: Student from school 3 monitoring distillation of ethanoic acid

5.3.2: STUDENT FEEDBACK

The experiences of the students are best described by the comments made having completed the experiments. School 1 and 3 both completed a structured questionnaire on the micro-titrations and an analysis of the results is given below. Written feedback was also obtained by asking students to write their comments on the microscale experiments. Comments, both positive and negative, on ease of use of equipment, safety, time etc in comparison to normal scale experimentation were obtained. This was done in two ways. All students were asked to write down their opinions immediately after completing a microscale experiment, having been given little guidance on what to write, for fear of biased comments (i.e. putting ideas in their heads!). In School 1 and 3, the students also completed a second guided feedback at the end of the school year, having done a series of microscale experiments by being asked to comment on their experience under the headings:

- Procedure/Written Instructions
- Assembly of Apparatus
- Time
- Safety
- Ease of Use
- Working On Your Own (School 3 only)

Structured questionnaire

The students were asked to respond to seven questions. The first five questioned if the students found a certain factor (e.g. observing the end-point) on a microscale easier or harder than the normal scale. Table 5.17 shows the frequency of response in terms of 'harder', 'easier' or the 'same' from the two schools, one an all-boys and the other an all-girls, thus allowing an analysis across gender.

Table 5.17: Frequency of response across gender for microscale over normal scale

FACTOR	GENDER	HARDER	EASIER	SAME
Microscale method	Male	5	2	0
	Female	0	14	1
Observing end-point	Male	4	2	2
	Female	3	7	5
Controlling accurate drop additions	Male	7	1	0
	Female	7	8	0
Filling burette/pipette	Male	1	6	1
	Female	0	15	0
Washing glassware	Male	0	7	1
	Female	1	14	0

It shows quite clearly that the female students generally found the method easier compared to their male counterparts, with 14 of the 15 female students saying the method was easier compared to only 2 of the 8 males. Some students seemed to have difficulty with observing the end-point, with again the female cohort preferring the microscale. The male group had the most difficulty controlling the burette. Sample comments:

> *'It was harder to control when getting small drops for the burette'*
>
> *'The burette was hard to stop on time at the point of colour change'*

However, some students did report a positive response to controlling the smaller equipment

> *'They (the small scale apparatus) were easier to use as they weren't so big and awkward e.g. it was easier to fill the burette'*

Both cohorts of students showed very positive attitudes towards filling the burettes and pipettes, which again was backed up the students' comments on the advantages, with 7 of the students commenting on the ease of filling the burette.

> *'It's easier to handle and fill the equipment'*

Finally, generally the students felt it was easier to wash the glassware after the experiment with the smaller equipment. Other advantages as highlighted by the students include:

- Less chemicals used
- Easier to fill
- Quicker
- Easier to handle

In terms of disadvantages, problems with controlling the burette as highlighted earlier and also problems with the actual microburette were the most common difficulties encountered. This was mostly due to the fact that the micro-tip on the burette often fell off, and meant the students had to restart the titration. This problem has now been addressed. By placing parafilm on the end of the pipette, the tip fits more securely on and is much less likely to fall off. Some students commented on the unfamiliarity of the techniques, thus leading to difficulties. However, the students typically recognised that with time, these difficulties would be overcome.

'Of course it will be difficult in the 1st couple of weeks but with time as we said we will be used to it'

Open feedback

Students were asked to give their comments/feedback on the microscale experience directly after doing the experiment, and in the case of two of the schools, School 1 and 3, the students also completed a second guided feedback at the end of the school year, having done a series of microscale experiments as described at the beginning of Section 5.3.2.

Titrations

With all four schools giving feedback on the micro-titration, an overall picture of the advantages and disadvantages/difficulties was easily obtained. As can be seen from the results in Table 5.18 some factors are listed in both advantages and disadvantages.

Table 5.18: Advantages and disadvantages of the micro titration method as described by the students

ADVANTAGES	DISADVANTAGES
Easier to set-up/assemble	Larger effect of errors on results
Quicker	Awkward
Easier to use	Visually difficult
Easier to control burette	Difficult to control burette
More space on the bench	Burette tap falling off
Easier to work on your own	More difficult to work on your own
Easier to clean-up afterwards	
Safer	

A selection of the positive comments are shown below:

'The titrations are very small so you can do them several times for more accurate results'

'Titration on the micro scale is much faster to carry out than on the normal scale'

'I found the micro apparatus much easier to use than the normal apparatus'.

It is clear that many students found the technique easy and quick to do. Also, for the most part, those students who did the experiment on their own, though initially may have found it a bit daunting, realised the benefit of doing it on their own.

> *'I didn't like doing it by myself at first but when I got used to it I liked it as I had a responsibility to do it myself and wanted it to work out.'*
>
> *'It also allows you to work on your own so you have to have a full understanding of what you are doing.'*

In contrast, some of the students found the technique difficult, especially trying to control the burette. This problem was also highlighted in the results from the structured questionnaires. Other students struggled with the visual aspects of the small scale, such as seeing the colour change at the end point and reading the scale on the microburette. Finally, students commented on the fact that on a microscale they had to be more accurate and have better skills. Some students commented on this disadvantage, as they realised that even a small error, could have large implications on their results.

> *'The small equipment resulted in having to have better skills with the burette as a firm push could result in an inaccurate result.'*
>
> *'Human error can have a huge effect on an experiment because of the precise amounts needed.'*

Organic experiments

The difficulties, which were encountered with the organic experiments, have already been outlined in Section 5.3.1. In terms of the student feedback, again there was both positive and negative feedback. By working on their own, the students learnt how to set up the organic apparatus for reflux and distillation, with students also realising that though it might be difficult on a micro scale, it would be much more so on a larger scale.

A comment reflecting the benefits of working on their own:

> *'Working on my own was good as I learnt how to set up the apparatus'.*

Students comments reflect the ease of use of the micro 'quick fit' apparatus:

> *'It was difficult to begin with but once it was shown to me it was fine. It was easy to change the apparatus from reflux to distillation'.*
>
> '*I found this easy as the diagrams were clear and easy to follow. The apparatus fitted well together with no problems'.*

Other comments confirm the benefits in terms of time for the preparation of ethanal:

> *'This experiment worked quite quickly on a small scale and was finished well within class time'*
>
> *'We had enough time to do this experiment in the double class'.*

Also, they found the preparation of ethyne to be much quicker and safer than on the normal scale as shown by the comments below:

> *'The experiment took a very short time to do'.*
>
> *'Very quick, a lot quicker than large scale method. Easier to collect the gas.'*
>
> *'It was very safe as none of the chemicals were near you during this experiment'.*

Some students also commented on the ease of use:

> *'It was much easier to make the gas on the syringe than set-up the whole apparatus as you would in a normal experiment'.*

The disadvantages students had included initial assembly of the apparatus and changing from reflux to distillation, and the length of time it took to complete the experiment. This was due to two reasons as recognised by the students:

- *It's a long experiment but the normal scale would probably take longer*
- *The hot-plates didn't work, resulting in much longer heating times*

For the ethyne preparation, students found it difficult to control the syringe, and to weigh the small amounts.

Rate of reactions

In terms of the effect of a catalyst on the rate of a reaction, students enjoyed seeing the plunger move up the barrel of the syringe as the gas is formed and then testing the gas by relighting a glowing splint.

> *'It was interesting and exciting to watch the plunger get pushed out and seeing the splint relight.'*
>
> *'It was very interesting using this equipment, as it was very different to everything else we've been using this year. It was interesting seeing how the oxygen was made.'*

Some students also found it easier and quicker to do:

> *'I think that is a lot easier and quicker.'*
>
> *'I think that using the micro scale makes it easier and quicker. It's better.'*

Students generally felt that the experiments to determine the effect of concentration and temperature on the rate of reaction were easier, quicker and accurate.

'Good experiments. Easy to do. Rapid reactions. Interesting.'

'I found it quicker, easy and more efficient. I found microchemistry a lot better. I thought it was better to use, as it was smaller and quicker to use'

The difficulties noted were weighing out the small samples and preventing mixing of the catalyst and hydrogen peroxide prior to sealing the reaction vessel for the in-syringe method for gas production. Finally, students again commented on the potential larger effect of errors on results.

I thought that the micro scale was harder to do than the large scale. You had to be a lot more careful as if you made a small mistake your results were a lot off. I prefer the large scale.

5.3.3: TEACHER OPINIONS

Of the schools who took part in the trials, two of the teachers gave feedback on the experience from their perspective as teachers and also in terms of benefits for the students.

Teachers stated the following as benefits from their management of the laboratory

- Lower cost of materials
- Easier storage of equipment in class quantities
- Less danger with the more hazardous chemicals

Benefits for the students

Student learning

Teacher A from School 3 stated that students had the opportunity to do practical work individually, where normally due to lack of resources they do experiments in pairs or threes. Because the students were responsible for each step themselves it meant that they had to pay more attention. This is highlighted in the comment below:

'I felt the students learnt a lot from the microscale. They understood more about what was going on at each step. They each had to pay more attention, work harder to make the experiment work – it was each persons' personal responsibility. With other scale they rely too much on others.' (Teacher A)

This was also recognised by the other teacher, however teacher B stated the importance of group skills in practical work and so would choose to do larger experiments as well.

'I think now that I would do the colour related investigations such as Le Chatelier and the Redox reactions on a micro scale and aim to have each individual do his/her own experiment. This gives practice and concentration training for individual work and micro.' (Teacher B)

Time saving

'All the experiments were completed in a shorter time scale. This meant I would have the time to recap on the theory at the beginning of the lesson and also discuss the results etc at the end of the experiment – all within the double lesson period. This last point is very important to give a sense of completion to the experiment on the day.' (Teacher A)

In the majority of cases, the students had more than enough time to do the experiment, the exception was when the students were doing the microscale preparations of ethanal and ethanoic acid, where some of the hot-plates were not working efficiently enough and the reactions took too long. However, the teachers recognised that shorter experiment times meant that they could use the extra time to go through the results of the experiment, or in some cases let the students repeat the experiment, which may not be possible on a larger scale due to lack or resources and/or time.

Safety

'Finally for the hazardous ones, and I include here some of the organic preparations I would probably look for micro methods. Some of these such as the preparation of ethanal and ethanoic acid I now do as a class exercise following some near misses with larger numbers of groups.' (Teacher B)

Both teachers recognised the benefits in terms of safety, both in terms of the laboratory environment and the safety for the students, as shown by the comment above.

Ease of use

There was conflicting feedback on the ease of use of the equipment, with Teacher B from the all-boys school, suggesting that it could be a gender issue that the boys, at times, found it hard to manipulate and control the smaller apparatus. However, this was not observed in the mixed school, where the boys did not seen to find the techniques any more or less difficult than their female counterparts, with their teacher commenting that *'They realised because the equipment was easy and quick to assemble they could repeat readings etc to get more accurate results'.* (Teacher A) Despite the difficulties noted by the teacher from the boys school, it was recognised that this is the very reason why microscale techniques should be employed to give them practice and training to improve their manual dexterity.

> *'Whether all students at this age, or certainly boys, have not developed their full hand-eye coordination, the students are less able to manipulate small scale. I don't recall girls I have taught having as much problems in this area, but that's going back some time. Nevertheless a strong argument may be that practice in this area is vital, given increasing use of small scales in the industry, and from this point of view some micro at least should be incorporated into our procedures.'*

Disadvantages

One teacher notes the downside of what he calls the 'demystifying of experiments' because of the very scientific approach to the experiments, that the students are not as motivated as they might be by the 'big bang' style of experiments. For example, he comments on the experiments which involve gas production:

> *'Experiments which have the extra dimension, to boys at least, of producing larger results – such as gas production – I would keep large scale.'*

Also, he comments that in the rate of reaction experiments, care must be taken to achieve useful results.

5.4: CONCLUSION

In terms of accuracy and precision of the microscale techniques discussed, in many cases the precision is on a par with the normal scale, and accuracy, in some cases, only slightly less favourable. However, the accuracy and precision is not as important as actually doing the experiment; if it's a choice between using expensive apparatus between 2-3 students and getting excellent results or each student doing the experiment themselves and getting good results, I'd go for the latter every time. It allows students to take ownership of the experiment and also makes them more aware of the importance of good experimental technique as they realise that very small differences, (not reading the burette as accurately as possible, or not reading the balance to as many decimal places as it allows, for example) can have very large effects on their results. Also, when compounds are produced, enough product is formed to carry out the characterisation tests. Why make large amounts of product, when only a small amount is required?

In terms of benefits for teachers, there are many. The preparation and clean-up time is reduced. The laboratory is a much safer place. Microscale provides a means for teachers to provide practical work for their students, in a situation where laboratory resources, and funding can be low.

Feedback from trials in schools was obtained both from teachers and students, and was positive overall, with lots of constructive criticisms. Both teachers, who returned written feedback, would intend to use or would like to use microscale techniques, finding overall the experience a positive one for both themselves and the students. According to one teacher:

> *'They liked the challenge, the responsibility, the competition and the success.'*

The students generally enjoyed the experiments, and problems encountered were often due to lack of familiarity with equipment or apparatus not working, e.g. hot-plates. In some cases, student feedback was taken on board and the experiments adapted to better suit the real school chemistry laboratory.

As mentioned earlier, the research has resulted in production of a microscale manual, which will soon be made available to chemistry teachers following some editing. Student comments from school 3 on the procedure and written instructions were taken on board when adapting the microscale manual. Future work includes investigating the use of microscale techniques to promote and enhance PBL in university and school laboratories and to further develop use of microscale techniques for Junior Certificate science investigations.

In conclusion, there is a global move toward microscale, with many schools and universities using it. The many benefits of microscale for both teachers and students have been highlighted. In an Irish context, it has been shown that the general trend in take up of chemistry at Leaving Certificate is not good. One solution to this, it is suggested, is the provision of more hands-on, practical experiences for students. Microscale provides a means for this in an environment where teachers' time is in high demand, laboratory resources are low, and school budgets are under serious constraint. The need for microscale techniques at Junior Certificate level is also emphasised and some research has already been carried out on this[29]. Finally, some students even find micrscale fun…

> *'I thought the experiment today was a lot more interesting because of the equipment.'*
> *'I enjoyed using the micro-equipment'*
> *'It was very interesting using this equipment, as it was very different to everything else we've been using this year.'*
> *'Working on my own was a bit daunting at first but once I got the swing of things it got easier. I'm looking forward to the next practical class'.*

References

[1] Department of Education & Science, *Leaving Certificate Chemistry Syllabus (Ordinary and Higher Level);* Dublin, The Stationary Office (1999)

[2] Physical Science Initiative. Information about the syllabus. [Online] 17/08/05 http://ps.slss.ie/downloads/ch_sy_rationalenewsyll.pdf

[3] Department of Education and Science. Report on the Physical Sciences. [Online] 19/08/05 http://www.education.ie/servlet/blobservlet/physical_sciences_report.pdf

[4] Finlayson, Odilla,& Killen, Lynn; *Case Studies on Schools Successful in Science* in 'Report on the Physical Sciences' (February 2002) [Online] 19/08/05 http://www.education.ie/servlet/blobservlet/physical_sciences_report.pdf

[5] Milo Connolly. Personal communication.

[6] Kelly, O. & Finlayson, O.; *Small scale chemistry in the school laboratory*. Paper presented at ChemEd Ireland, Limerick (October 2002)

[7] BASF Minilab Manual Pg 1

[8] SHAW Scientific Limited. http://www.shawscientific.com/

[9] Lennox Laboratory Supplies Limited. http://www.lennoxlabs.com/

[10] John Daly. Personal Communication.

[11] AGB Scientific Limited. http://www.agb.ie/

[12] Mullally, S.; *Chemistry Now!*, Dublin, Gill & MacMillan (2000)

[13] Kennedy, D.; *Chemistry Live!*,Dublin, Folens Publishers (2000)

[14] Kealey, D. & Haines, P.J.; *Instant Notes Analytical Chemistry*, BIOS Scientific Publishers (2002)

[15]

[16] Singh, M.M, Szafran, Z. & Pike, R.M, *Journal of Chemical Education* (1991) Vol. 68 Pg A125

[17] Singh, M.M., McGowan, C., Szafran, Z. & Pike, R.M, *Journal of Chemical Education* (2000) Vol. 77 Pg 625

[18] Mattson Creighton. Microscale Gas Chemistry: Experiments with Ethene. [Online] 19/08/05 http://mattson.creighton.edu/C2H2/index.html

[19] Joling, E., Goedhart, M.J. & Van der Berg, B.; *Journal of Chemical Education* (Sept 2002) Vol. 79 Pg 1109

[20] Singh, M.M, Pike, R.M. & Szafran, Z.; '*Microscale & Selected Macroscale Experiments for General & Advanced General Chemistry – an Innovative Approach'*; New York, John Wiley & Sons, Inc.(1995)

[21] Szafran, Z., Pike, R.M. & Foster, J.C.; *'Microscale General Chemistry Laboratory with Selected Macroscale Experiments'*, New York, John Wiley & Sons, Inc. (1993)

[22] Mattson Creighton. Microscale Gas Chemistry: Experiments with Ethyne. [Online] 19/08/05 http://mattson.creighton.edu/C2H2/

[23] Bretherick, L., *Hazards in the Chemical Laboratory*, 3rd Edition, London, Royal Society of Chemistry, (1981)

[24] Mattson Creighton. Microscale Gas Chemistry: Experiments with Oxygen. [Online] 19/08/05

http://mattson.creighton.edu/O2/index.html

[25] Ealy, J. & Pickering, M.*; Journal of Chemical Education* (1991) Vol. 68 Pg A120-122

[26] Henly, R., *Chemistry for Today*, Dublin, Folens Publishers International (1989)

[27] Amend, J.R., Tucker, K.A. & Furstenau, R.P., *Journal of Chemical Education* (1991) Vol. 68 Pg 857

[28] Jones, L. & Atkins, P.; *Chemistry – Molecules, Matter and Change*; W.H. Freeman, New York, 4th Edition (1999)

[29] Kelly, O. & Finlayson, O.; *Microscale – Promoting learning through hands-on investigative activities.* Paper presented at the Sharing Science Conference, Dundalk (2004)

OVERALL SUMMARY AND CONCLUSIONS

Students' approaches to learning where investigated using the ASSIST inventory and it has been shown that science students in DCU on entry to third level show a preference for deep and strategic approaches over surface. Similar results were also reported for science students in Australia. Furthermore, a study of 6th year students, who were nearing the end of their second level career, showed similar trends. This suggested that students are coming into third level with preferences for learning and studying which are influenced by their previous experience at school, which seems to be a positive experience. This tendency for a deep approach is surprising in the light of the strategic nature of the Leaving Certificate examinations and in spite of concerns of the negative effect of the highly pressurised final examination system which would encourage students to adopt a surface approach. Conversely, students reported a significant preference for teaching which transmits information over teaching which supports understanding at the initial intake to third level.

The change in students' approach to learning at third level over time is worrying however, with students reporting lower preferences for deep and strategic approaches over time in university and increasing preferences for a surface approach. This is coupled with an increasing preference for teaching which transmits information and a decreasing preference for teaching which supports understanding. One inference from this is that the teaching and learning environment at third level is encouraging students to adopt a surface approach to the detriment of a deep approach. Further investigation revealed interesting differences between males and females and between recent school leavers and mature students. For example, though female students reported a preference for a strategic approach over their male counterparts, they were also shown to be highly influenced by a fear of failure.

An investigation into the relationship between students’ approach to learning and their achievement in assessment revealed interesting results. There were positive correlations between a strategic approach and academic achievement and negative correlations between a surface approach and academic achievement. However, there were inconsistent correlations between a deep approach and academic achievement. This suggests that the assessment system does not encourage students to adopt a deep approach and instead rewards a strategic approach.

A PBL module was developed and implemented over three years. The PBL module aimed to encourage a deep approach to learning and enhance students' engagement with chemistry in the laboratory. Though the effect of the alternative approach on students' preference for a deep approach was not evident, it was consistently shown to discourage a surface approach. The students who followed the PBL module, despite showing similar profiles at the initial intake, scored the surface approach lower than those who followed the traditional laboratory module. Subscales such as 'Syllabus boundness' and 'Unrelated memorising' were shown to be lower for the PBL students. Furthermore, the PBL students also reported higher study skills such as 'Organised studying'.

In terms of academic achievement, the PBL students performed as well as the traditional students in their written chemistry exams. However, in a test designed to assess students understanding of chemistry, practical laboratory skills and ability to do basic calculations, based on their laboratory module, the PBL students did significantly better. Furthermore, PBL students were shown to retain the knowledge to the same extent as the traditional students a year later. This is very encouraging especially since the traditional students who completed the test were following a pure chemistry degree and therefore doing more chemistry courses and had better previous experience with chemistry. The PBL laboratory was also shown to have a positive correlation between a deep approach and academic achievement, suggesting that the assessment system in the module encourages a deep approach.

Finally, students following the PBL approach reported the beneficial effects of the various aspects of the PBL approach and 83% indicated that they would chose to follow a similar course in second year if given a choice. The pre-lab, group work and practical work was well received by the students, and they appreciated the benefit of them in terms of their learning.

The development of microscale experiments for Leaving Certificate was described and an evaluation of its effectiveness in schools showed that generally students and teachers could see the benefit of microscale. Because it allows for more hands-on investigative work, in a safe environment, there is a definite potential to combine microscale techniques with a PBL approach to further enhance the learning experience of students in the laboratory.

In conclusion, this work has shown conclusively that an alternative PBL approach to laboratory work in introductory chemistry at third level is possible. Furthermore, students engage more fully with the chemistry and rely less on surface approaches. This effect is extremely worthwhile in light of the fact that it has been shown that the general science student cohort has a tendency to adopt a surface approach as they continue their studies at third level. Furthermore, the PBL approach resulted in at least a similar understanding to the traditional approach, as measured by the formal examinations, and a greater understanding in terms of their laboratory course. Finally, this approach can cater effectively for both students with and without prior knowledge in chemistry and requires no extra resources in terms of demonstrators, chemicals or apparatus.

APPENDIX

APPENDIX CONTENTS VOLUME-PAGE

APPENDIX 1.1: PUBLISHED PAPER

Small-scale chemistry in the school laboratory

Orla Kelly and Odilla E. Finlayson
School of Chemical Sciences, Dublin City University, Glasnevin, Dublin 9

Introduction

Practical work is now a major part of the Leaving Certificate chemistry syllabus. However, it is a real challenge for teachers to find the time to do all the experiments, prepare for practical work, maintain stock levels, dispose of chemical waste, and last but certainly not least, to keep safety a priority in the laboratory. Developing ways to overcome this challenge is one of the motivations behind this research. The other is that within the School of Chemical Sciences in DCU, there has been a major push towards a reduction in chemical waste over the last few years. This has been done using small-scale laboratory techniques. This work reports on the use and benefits of small-scale laboratory techniques in a second level school laboratory.

Small-scale chemistry - what is it?

Reduction of chemical use to the minimum level at which experiments can be effectively performed is known as microscale or small-scale chemistry. It is an environmentally safe pollution prevention method of performing chemical processes using small quantities of chemicals without compromising the quality, precision or accuracy.[i] In this set of leaving certificate chemistry experiments, there is at least an 80% decrease in reagent quantities for all experiments when compared to conventional scale and a 90% decrease for most.

Our experience of microscale at undergraduate level in DCU shows that students find the smaller scale more challenging in terms of getting accurate and precise results and/or product yields but they develop better laboratory techniques. They realise that losing ¼ of a gram during the experiment will greatly affect their end result and so take much more care. Since experiment times are reduced there is more time for investigative work and development of theory. The smaller scale is also more student-friendly in terms of ease of use of apparatus. For example, how many times have you seen students kneeling on stools to fill their burettes? Countless times I'm sure. Using a micro-burette, this hazard is removed.

In terms of the academic and technical staff in DCU, they found laboratory techniques improved with the generation of accurate and precise results. There has been a phenomenal decrease in waste generated and therefore financial benefits. Since it often costs more now to dispose of a chemical then it does to purchase it in the first place, [ii] students are more careful and there is a safer laboratory environment due to less clutter on the benches. There is also an improvement in air quality and a decrease in hazards compared to conventional synthesis. By decreasing hazards, microscale opens up the possibilities of using chemicals that are too hazardous to use on a larger scale, therefore increasing students' experience of practical chemistry. Less storage space is required for both apparatus and chemicals, and there is a decrease in experiment preparation times. Finally, students have an opportunity to increase their learning due to reduced experimental times e.g. they can do several tests on a small-scale that would have taken longer on conventional scale.

Microscale experimentation has been around for a long time however specialist kits were required [ii]. These kits received some negative responses from teachers, including ' Many experiments require specialised glassware and although it might be possible for schools to purchase 1 or 2 kits, it is unlikely that they would be prepared to equip a whole class. Also breakages are costly to repair.' [ii] Therefore, as much as possible, the approach taken in this work is to use glassware on a small-scale that is available from regular laboratory suppliers and other glassware that would normally be present in the laboratory e.g. well-plates and petri dishes. Some particular items were made/developed, including the microburette, which we made ourselves.

Figure 1: Conventional and Microscale apparatus for organic synthesis

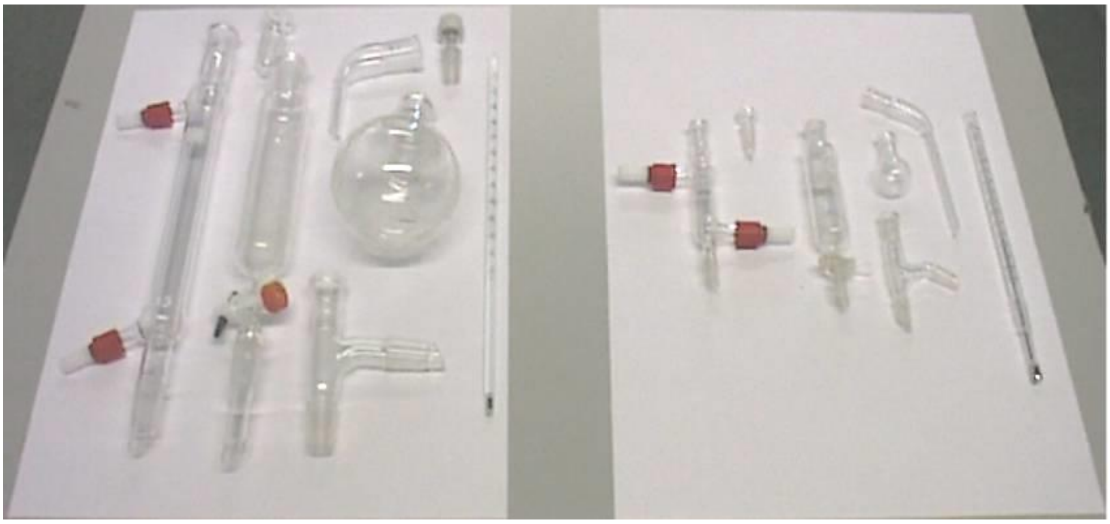


Figure 1 shows the organic synthesis apparatus for conventional and microscale. A sand bath is the preferred method for safe heating of organic reactions, made by filling a metal soup bowl with sand!

Leaving Certificate syllabus - a quick reminder
What experiments are on the syllabus?

- titrations
- rate of reaction studies
- identification tests
- gas preparations
- organic synthesis

We will now take a closer look at these on a microscale.

Titrations:
Titrations make up a large proportion of the Leaving Certificate syllabus, and a microburette is used instead of the conventional 25ml or 50ml burette. It is made using a 2ml graduated glass pipette and a 5ml plastic syringe. 25ml volumetric and conical flasks are also used. But just how accurate and precise is the microburette. Tests were carried out to compare the microburette and conventional 25ml burette. The % ethanoic acid in vinegar titration was used. In this trial, the same stock solutions were used and therefore the burettes were the only variables. To analyse precision the standard deviation was calculated for each trial. The microburette favoured comparably to the conventional burette with values from 0.00 - 0.06 compared to 0.00 - 0.13 for the

conventional one. To measure accuracy, the % acidity was measured. The results determined over several trials were 4.96 - 4.98% for the microburette compared to 4.87 - 4.91% for the conventional burette. This shows a relative accuracy between the two burettes.

Using the determination of %w/v of hypochlorite in bleach titration the effect of the reduction in reagent concentration was determined. As well as reducing the volume of solutions used in the conventional titration, the microscale titration allows a reduction in the concentration of the reagents. Table 1 summarises the results obtained for this titration using

(i) conventional scale apparatus reagent concentrations
(ii) reagent concentrations as in (i) and microscale apparatus
(iii) tenfold reduction in reagent concentrations with microscale apparatus

The standard deviation and %w/v determined for each trial is shown. It can be seen that the precision of both micro titrations favour comparably to the normal titration. The %w/v is also shown. It is important to note here the two-fold benefit of microscale i.e. there is less reagents used but also they are used at a much lower concentration.

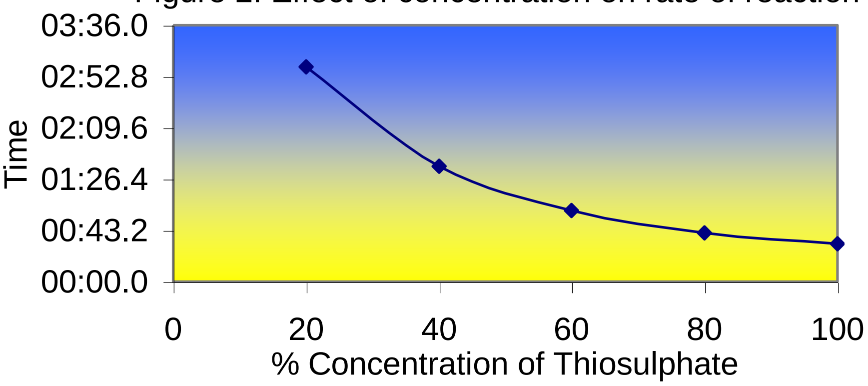
Table 1: Summary of the results obtained for the 3 different titrations

	Conventional scale	Microburette	Microburette with ten-fold decrease in concentration
Conc. $Na_2S_2O_3$	0.1M	0.1M	0.01M
Bleach sample	1/10 dilution	1/10 dilution	1/100 dilution
Volumetric volume	250cm^3	25cm^3	25cm^3
Burette volume	25cm^3	2cm^3	2cm^3
Standard deviation	0.50-2.42	0.01-0.03	0.01-0.14
%w/v	3.82-4.30	4.40-4.57	3.78-4.21

Reaction Rates:

The reaction of sodium thiosulphate with hydrochloric acid is often used for rate of reaction studies as the sulphur formed forms a dense yellow cloud in the flask and therefore the time taken for an 'X' marked under the flask to disappear can be measured as a function of reagent concentration and temperature. Normally conical flasks are used and a large amount of smelly sulphur containing acidic waste is produced. Using microscale, this reaction is done in a well-plate using no more than one ml of reagent in each well. This is very effective and very quick. The results obtained for a study on the effect of concentration of sodium thiosulphate on the rate of reaction is shown in Figure 2.

Figure 2: Effect of concentration on rate of reaction



Using 0.2M sodium thiosulphate and 2M hydrochloric acid, the experiment was carried out using the quantities of reagents shown in table 2. The time taken for disappearance of the 'X' marked under the well was noted. Total amount of waste generated in this experiment was only 5mls. Results are just as clear as on conventional scale.

Table 2: The quantities of reagents required to determine the effect of thiosulphate concentration on the rate of reaction.

Well	Drops of $Na_2S_2O_3$	Drops of H_2O	Drops of HCl
A1	20	0	2
A2	16	4	2
A3	12	8	2
A4	8	12	2
A5	4	16	2

Testing for Anions:

Well-plates can also be used for various anion identification tests. On a conventional scale, the testing of anions requires a large number of test-tubes and generally test-tubes are filled with the reagents used! However, only a well-plate and a few pasteur pipettes are required on a microscale. Table 3 below shows a procedure for the identification and confirmation of carbonates, hydrogencarbonates, chlorides, sulphates, sulphites, and phosphates.

Table 3: Identification of anions using well-plates

Well	A1	A2	A3	A4	A5	A6
Add	10* of CO_3^{2-}	10 of HCO_3^-	10 of Cl^-	10 of SO_4^{2-}	10 of SO_3^{2}	10 of PO_4^-
Add	10 of $MgSO_4$ **	10 of $MgSO_4$ **	5 of $AgNO_3$	10 of $BaCl_2$	10 of $BaCl_2$	10 of $Ba(NO_3)_2$ **
Add			15 of NH_3 sol^n **	10 of HCl **	10 of HCl **	

Well A1 to A6 denote the particular well of the well-plate
* Number of drops of solution ** Confirmatory test

Lets take a closer look at the testing of sulphates and sulphites in well A4 and A5 respectively. Initially 10 drops of sulphate solution is added to well A4 and 10 drops of sulphite solution is added to well A5. Then 10 drops of $BaCl_2$ is added to each well A4 and A5 and if a white precipitate forms, it suggests the presence of either sulphates or sulphites. To confirm this, hydrochloric acid is added (10 drops). The sulphate precipitate is insoluble, whereas the sulphite precipitate is soluble. An added advantage of well-plates is that 'unknown' salts can be easily tested alongside known anions thereby giving rapid comparison of tests.

Gas Preparations:

There are 2 gas preparations on the Leaving Certificate syllabus - the preparation of ethene and the preparation of ethyne. The normal scale synthesis of ethyne involves dropping funnels, two hole stoppered conical flasks, test-tubes and troughs of water. Using microscale, 60cm^3 plastic syringes, syringe cap fittings, and plastic pipettes are all that is required. Only 0.2g of CaC_2 is used per student. This is a huge safety benefit since CaC_2 is a pyrophoric substance and the smaller the amount used the better. The gas is produced within the syringe in a controlled sealed environment. Potassium permanganate is added to the syringe. A colour change from purple to brown is observed, showing the presence of unsaturated compounds. [iii] This procedure was taken from a Microscale Gas Chemistry website.

Organic Synthesis:

There are four organic synthesis reactions on the current Leaving Certificate syllabus

- preparation of soap
- preparation of ethanal
- preparation of ethanoic acid
- steam distillation of clove oil (so far this has proved too difficult to microscale).

The preparation of soap on a microscale involves only 0.2g of sodium hydroxide, 0.2g of lard and 1.5mls of a 50/50 ethanol/water mix, compared to 4g of sodium hydroxide, 4g of lard and 50mls of the ethanol/water mix on a conventional scale. The procedure followed is the same as that for conventional synthesis and typical yields are 0.2-0.3g of soap. Figure 3 shows a slight adaptation to the normal apparatus. Instead of a Liebig condenser, which uses cold water to condense gases being formed, this apparatus uses an air condenser. It is basically a long tube connected to the round bottom flask, which allows air to condense the gases. It proved to be as effective as the typical apparatus giving yields of between 0.20-0.35g of soap, thus giving a much greater ease in setting up the apparatus.

Figure 3: Microscale apparatus for preparation of soap using air condenser

Figure 4: Microscale apparatus for preparation of ethanal

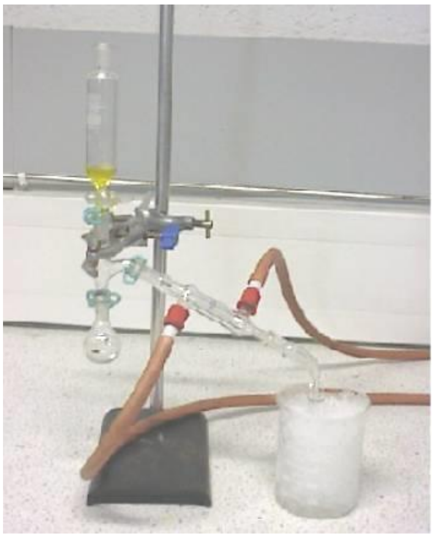


Figure 4 shows the synthesis of ethanal. The small-scale synthesis of ethanal involves 2.5g of sodium dichromate compared to 12g and 2mls of ethanol compared to 10mls. The typical yield of ethanal was between 2-3mls.

The small-scale synthesis of ethanoic acid involves only 2.4g of sodium dichromate, 1mls of ethanol and 0.4mls of concentrated sulphuric acid compared to 12g, 5ml, and 2mls respectively for the normal scale synthesis. Again the typical yield was 2-3mls. For both the ethanal and ethanoic acid, the yields obtained were enough to carry out the necessary characterisation tests on asmall-scale.

Costs and Savings:
Table 4 gives an overall estimate of the cost of running the Leaving Certificate chemistry experiments. From the table, it is clear that the purchase of equipment is similar for both small-scale and conventional scale laboratories. However, there is a huge annual saving on chemicals of about 450euro. These figures were compiled from data supplied by Lennox Lab Supplies, Dublin, (2002). The amount of waste generated for disposal is greatly reduced; the costs associated with waste disposal have not been estimated.

Table 4: Estimate of cost of running the experiments on small and conventional scale and typical waste generated

	Small-scale	Conventional scale
Apparatus	€22,811	€24,355
Chemicals	€130	€586
Organic waste	280mls	1600mls
Dichromate waste	130mls	700mls

TRANSITION YEAR MODULES:

(i) Test for primary, secondary and tertiary alcohols
(ii) Test to differentiate between methanol and ethanol
(iii) Preparation of an alcohol in a petri dish - namely 2,4,6-trichlorohydroxybenzene (commonly known as TCP)
(iv) Purity of alcohols

Transition year microscale chemistry modules are being developed at present. So far, a polymer and an alcohol module have been completed. These are meant to introduce students to leaving certificate chemistry and to act as 'fuels' for learning about topical aspects within the syllabus. Well-plates and petri dishes alone were used for the 4 experiments in the alcohol module. They are all quick, and easy.

Conclusion
What have people said about microscale?
Students said it was 'chemistry for barbies', 'more challenging but different', 'fun', and 'quick and easy'. Technicians say 'a lot safer', 'waste dramatically reduced', and 'less work for us'. The teachers and academics say 'more skill involved', 'accuracy and precision improved', 'safer lab environment' and 'manipulative skills improved'. **So all that is left to say is that it saves money, it's safer and students like it, so why not try it!**

References
[i] http://www.silvertech.com/microscale/what_is_microscale.html
[ii] Skinner, J., Microscale Chemistry – Experiments in Miniature, The Education Division, The Royal Society of Chemistry, 1997
[iii] http://mattson.creighton.edu/Microscale_Gas_Chemistry.html

APPENDIX 1.2: PUBLISHED ABSTRACTS - ORAL PRESENTATIONS

Investigation into gender differences in approach to learning of undergraduate science students

Orla Kelly, Odilla Finlayson; CASTeL, Dublin City University, Ireland
Audrey Wilson; Department of Chemistry, University of Wollongong, Australia

Introduction

Good teaching is measured by effective student learning. The way students learn is influenced by many different factors; including the immediate teaching and learning environment, students' perception of assessment and their prior experience. The way students go about studying also influences the quality of their learning, though this is not necessarily reflected in their attainment in assessments (Entwistle 2000a).

Differences in approach to learning and studying can be distinguished as deep or surface. This stemmed from one study, (Marton 1976) among others, on how students approached reading/reviewing an article. 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 (Entwistle 2000b).

The deep learner was characterised as

- 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.

The surface learner, on the other hand, had the intention to memorise. The author implied that a deep approach related to a deep level of understanding, associated with a better recall of data. Findings show that there is a clear distinction between deep and surface processes, and is firmly established as a useful way of describing approaches to learning (Entwistle 1981). Interviews on everyday studying drew attention to the influence of assessment on learning and studying. It suggested the need for an additional category – strategic approach – in which the intention is to achieve the highest possible grades by using organised study methods and good time-management (Entwistle 2000b).

Entwistle (2000a) comments 'Particularly in the first year of studying, correct information is often seen to be all that is required to reach the next stage'. This reflects a surface approach to learning, and, certainly in an Irish context (Byrne 1997), is also what some students experience at second level.

Aims

The motivation behind this research paper is to investigate

- If differences exist between males and females in their approach to learning and studying, and if so, what are the factors which influence this difference
- If there is a correlation between approach and performance in formal assessment

Methods and Sample

Entwistle's Approaches and Study Skills Inventory for Students (ASSIST) (Entwistle 1996) is a questionnaire designed to classify students' predominant approach to learning and studying. Students can be classified as deep, surface or strategic, or a combination of two using this inventory. Many studies investigating students' approaches to learning have been done using the ASSIST, from accounting (Byrne 2002), to health sciences (Kelly 2004), to psychology (Lake 2002, Larrington 2002). The inventory consists of 52 statements to which students respond on a 5-point Likert scale, indicating the strength to which they agreed (5) or disagreed (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 of 20.

A cohort of 1st year undergraduate science students from various disciplines from two universities, Dublin City University, Ireland (DCU) and the University of Wollongong, Australia (UOW) were given the opportunity to complete the ASSIST inventory. All students were taking the introductory chemistry laboratory class offered and were asked to base their answers on their experience in chemistry labs.

The inventory was validated for use with this sample of students. Cronbach's alpha, α, was used to determine the internal consistency, whereas a factor analysis confirmed the structure of the inventory. Deep, strategic and surface approaches showed α coefficients of 0.83, 0.83 and 0.72 respectively; therefore the inventory has high internal consistency for this sample. A factor analysis revealed three distinct factors, corresponding accordingly to deep, strategic, and surface. Thus confirming construct validity.

The survey was carried out at three intervals with the same cohort of students. First at the start of their university experience, then at the end of their first semester, and again with the same cohort of students at the end of semester 3 of their 2nd year. The table below gives a summary of the sample size for each university, gender and interval. The inventory was filled out voluntarily by the students, which may account for the reduction in numbers over time. Also, in 2nd year the numbers of students taking chemistry were smaller in both universities.

Table 1: Number of students per university, gender, and interval

	Start of university	End semester 1 (1st year)	End semester 3 (2nd year)
DCU Male	66	37	14
DCU Female	85	50	31
UOW Male	77	37	1
UOW Female	110	68	14
Total	*338*	*192*	*60*

Data analysis and Results / Findings

Studies within and across universities with respect to gender were carried out. Paired and independent t-tests checked if differences between mean scores were statistically significant. All statistical differences are to 99% significance, unless other wise stated.

Table 2: Mean scores for each approach at start of university

	Deep	Strategic	Surface
DCU Male	13.89	13.44	11.72
DCU Female	14.04	15.09	12.67
UOW Male	14.85	13.79	11.31
UOW Female	14.99	15.14	11.58

An in-depth analysis of all the research findings will be presented in the paper. Key initial findings include that at the beginning of 1st year, females from both DCU and UOW were significantly more inclined to adopt a strategic approach to their learning than their male counterparts. A further investigation, into what factors within the strategic approach females students scored higher, revealed that both female cohorts scored significantly higher in 'organised study', 'time management', and 'alertness to assessment'. Interestingly, within the surface approach, both female cohorts also scored 'fear of failure' significantly higher than the male cohorts. Also, at 95% significance, the DCU female cohort scored the surface approach higher than their male counterparts.

After 12 weeks of university teaching, both female cohorts reveal a significant decrease in their preference for a strategic approach, whereas the male cohorts report a preference for deep followed by strategic then surface.

By the end of semester 3 in their second year, the female cohort in DCU were significantly more inclined to adopt a surface approach to their learning than their male counterparts, showing 'lack of purpose' and 'syllabus-boundness' as the two subscales which give rise to this difference.

Throughout the study, the deep approach remains quite constant for all students. In terms of the DCU cohort, 76% of the initial cohort, 76% of the end of semester 1 1st year cohort and 79% of the end of semester 3 (2nd year) cohort score deep as either their 1st or 2nd preference.

With respect to correlations between performance and approach, initial findings show that there is a significant positive correlation between achievements, in both the written exams and the chemistry laboratory module, and a strategic approach. Further research findings into correlations between approach and achievement will also be reported.

Conclusions and Implications

It is encouraging that students, in general, report a preference for deep and strategic over surface. However, the study reveals that on average 21% of the DCU cohort, and 16% of the UOW cohort report a surface approach as their first choice of approach to learning.

In line with common perception, it is shown that the females are in fact more inclined toward a strategic/achieving approach. This is particularly of interest in an Irish context where females consistently score higher than males in the final secondary school state exam (Elwood 2002), and a high percentage of both the DCU and UOW cohorts are recent school leavers. Trends such as these are not restricted to Ireland. Girls have been shown to be outperforming boys at the end of compulsory schooling in the UK, Australia, New Zealand, USA and other European countries. (Epstein 1998)

Overall, male students show a preference for a deep approach. However, the fact that females over time are moving towards a surface approach is not favourable, and conditions, which bring about positive approaches to learning, must be encouraged. An investigation into the effect of a problem-based learning module on approaches to learning is currently being investigated.

References

Byrne, M, and Willis, P (1997) An analysis of accounting at second level. *The Irish Accounting Review*. 4 (Spring) 1-26

Byrne, M, Flood, B and Willis, P (2002) The relationship between learning approaches and learning outcomes: a study of Irish accounting students. *Accounting Education*. 11(1), 27-42

Elwood, J (2002) *Differential performance by gender and achievement in the Certificate Examination Results 2000/2001* Initial Findings from the Research Conducted on behalf of the National Council for Curriculum and Assessment (NCCA). Accessed at http://www.ncca.ie/j/study/NCCAstudy2001.htm on 26 January 2005

Entwistle, N (1981) *Styles of Learning and Teaching, An Integrated Outline of Educational Psychology for Students, Teachers and Lecturers*, Chichester, New York, Wiley

Entwistle, N.J, & Tait, H. (1996) *Approaches and Study Skills Inventory for Students (ASSIST)* Edinburgh: Centre for Research on Learning and Instruction, University of Edinburgh.

Entwistle, N (2000a) *How students learn and study* The Higher Education Academy Accessed at http://www.ltsn.ac.uk/application.asp?app=resources.asp&process=full_record&section=generic&id=490 on 21 January 2005

Entwistle, N (2000b); *Promoting deep learning through teaching and assessment: conceptual frameworks and educational contexts*. Paper presented at the TLRP Conference, Leicester, 2000.

Epstein D, Elwood J, Hey V and Maw, J (1998) (eds) *Failing Boys? Issues in Gender and Achievement*, Buckingham: Open University Press.

Kelly, M (2004) *Student learning profiles in the Faculty of Health Sciences Trinity College*. Paper presented at the AISHE Inaugural Conference 2004. Accessed at http://www.aishe.org/conf2004/abs/abs25.html on 21 January 2005

Lake, H and Stratford, R (2002) *The relationship between approaches to learning and assessment methods in the psychology degree*. Paper presented at the Psychology Learning and Teaching Conference 2002. Accessed at http://ltsnpsy.york.ac.uk/LTSNPsych/PLAT2002/Programme/Full_Programme/stratford___lake.Monday3.45.ppt on 21 January 2005

Larrington, C and Lindsay, R (2002) Equal among firsts: Reviewing quality in Psychology. *Psychology Learning and Teaching*, 2(1), 6-11

Marton, F, Saljo, R (1976); On Qualitative Differences in Learning: I – Outcome and Process. *British Journal of Educational Psychology*, 46, 4-11

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

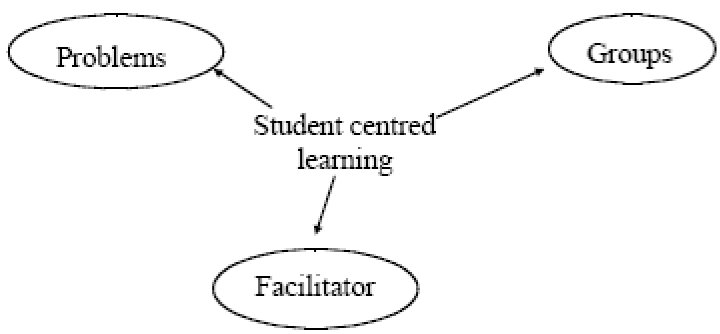
Odilla Finlayson and Orla Kelly; CASTeL, Dublin City University, Ireland

Introduction

Problem-Based Learning, PBL, involves the use of complex, "real world" problems as a stimulus and framework for learning. It is based on the premise that students will be motivated to 'want to know' and solve the problem posed because it is presented in a context that simulates real world situations'. Harper-Marinick (2001) The aim of PBL is to develop self-directed, reflective, lifelong learners who can integrate knowledge, think critically and work collaboratively with others. (MacKinnon 1999) By using unstructured real-life problems rather than the content as the focus students are given opportunities to really learn how to learn. (Tan 2004)

There are many definitions describing PBL but first and foremost, the problem is used to drive the learning. It also turns the curriculum back to front. Students move from passive to active learning and from dependence to independence. The teachers act as facilitators, letting the students do most of the talking! It offers students opportunities to engage with complexity and help them both to see ambiguity and learn to manage the ambiguities that prevail in professional life. (Savin-Baden 2000)

Figure 1: The main aspects of PBL



The 'real-world' problem engages the students in thinking about the subject matter in ways that are designed to increase their interest in it and to improve their understanding of it. The problem motivates learning and it is a means by which the students become competent in knowledge management and in covering the required curriculum. PBL is much in line with the constructivists school of thinking, that knowledge is built through active participation and interactions with the content. (Coombs 2004) The students work in small groups, which are facilitated by an instructor. The facilitator is there to keep the group focused and assist them in their research, and investigation; not to give them answers.

Aims

An introductory PBL laboratory based chemistry course was devised to cover all the experimental tasks carried out in the traditional first year chemistry laboratory in Dublin City University. The aim of this work is to monitor and evaluate the experiences and outcomes of a group of students who followed this PBL course and correlate those outcomes with the individual's approach to learning. Their experiences are compared to those of other students following the traditional laboratory course.

As with the general chemistry lab, the PBL module aims 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 and to provide, as appropriate, some support to the theoretical work. (DCU 2003) The PBL module however, also aims to develop and enhance communication, group-work, researching, problem solving and scientific reporting skills. Overall promoting a deep approach to learning, in contrast to a surface approach. Kelly 2003, and Kelly 2004 have described the development of the PBL module.

Methods and Sample

Typically, the number of first year students taking the laboratory-based chemistry module is approximately 180 students. These are made up of students from various degree courses, but the majority take a general first year course. A cohort of students was identified, which had a similar background and ability to the rest of the cohort, took similar modules and also, were a small enough cohort to be accommodated in one laboratory session.

Table 1: Details of sample

BSc Science Education	Academic year 2003-2004	Academic year 2004-2005
Males	13	10
Females	13	16
Total	26	26

The intake in 1st year consists mostly of recent school leavers, with or with out a chemistry background. Also, it is important to take into consideration their confidence with practical work, as some may have had very little previous experience with hands-on, experimental work.

During the course of the study various surveys were carried out with both the sample cohort and the other 1st year students taking the general laboratory module. These included student experience questionnaires, study skills survey, and the ASSIST inventory (Approaches and Study Skills Inventory for Students) (Entwistle 1996). Further more, the knowledge of the PBL cohort in terms of practical skills, problem solving and understanding was assessed and compared with those of the traditional students. Small group interviews were also conducted with a sample of students from both the PBL (#10) and traditional (#7) cohorts, which consisted of both a discussion on their experiences, and a PBL type problem to be solved. The students chosen, from both the PBL and traditional cohorts, were representative of the whole group since students of all abilities were chosen, based on their lab performance, and both male and female students were interviewed.

Data analysis and Results

Overall, the results were in favour of the PBL approach. At the end of each semester students from the PBL cohort were asked to pick a preference between a PBL and a traditional approach. The number increased from 66% in favour of PBL in semester 1 to 89% in semester 2 in 2003-2004. This suggests that students begin to enjoy and get more out of the PBL module, the more familiar they are with it. This was backed by comments made in the interviews. The students found that the real world problems ‘gave meaning to a lot of chemistry’ and that they were good because it was ‘more interesting’ and they knew ‘why they were doing it [the chemistry experiment]’. They seemed to struggle with the self-directed learning at the start, and are looking for the one right answer. However, with PBL, there is not necessarily one right answer and certainly not one way to do solve it.

The pre-lab assignment and discussion is an integral part of the PBL module, and in general the students found this useful. The pre-lab assignment ranged from researching background information to chemistry theory and relevant calculations. Students commented that the pre-lab stimulated interest and meant that they knew what they were doing before they came into the lab. In the written questionnaires, group work was one of the features, which was highly rated, along with hands-on experience. The pre-lab and everyday problems were other positive aspects of the PBL approach.

Oral and poster presentations are part of the module, and these got highly favourable ratings, especially in the interviews. The presentations involve groups of students arguing their results, in support of their typically conflicting solutions to the problem.
Student 1 on presentations:

> *'You didn't want to mess up because you were going to have to present it'*

Student 2 on presentations:

> *'[I was thinking] how can I use this result to make my point'*

Student 3 on presentations:

> *'Made sure results were correct because you had to defend them'*

Initial findings suggest that achievement of the PBL cohort in their assessments is negatively correlated with a surface approach to learning. There are positive correlations with both deep and strategic approaches, however these are not significant. The PBL cohort also seems to be better able to approach problems than their traditional counterparts. In the interviews conducted with both sets of students, the PBL students were able to suggest numerous solutions, from simple to complex, to the everyday problem given whereas the traditional students were very unsure of how to go about it, and suggested few solutions. A similar assessment was conducted with larger samples in the academic year 2004-2005 and similar results were found.

Conclusions and Implications:
The PBL module is an effective and enjoyable was to teach chemistry. It provides a real situation for student centred learning to take place, with everyday problems, which engage the students in learning. A 'tug-of-war' exists between the new approach being promoted, and their previous experiences. Stronger students want the 'right answer', and the weak students can struggle due to lack of chemistry background and/or confidence in self-directed learning. However, over time, they seem to appreciate the benefits. The following comments sum-up the features of a successful PBL course – activities requiring active research, real-life problems, group work and self-directed learning.

What do you feel was the most beneficial aspect of the labs?

> *'The pre labs. Gave me as a student who hasn't done chemistry before an opportunity to get to grips with what I was doing before I went in'.*
>
> *'Working in groups – helping each other'*
>
> *'The use of real problems to learn rather than following the lab manual'.*

'Having to figure a lot out by yourself'

The evidence provided shows that the PBL module was successful, to some extent, at achieving its aims and it is now ready for implementation to larger numbers of students in the first year cohort. However, there are barriers to innovation and change, which need to be addressed before full-scale implementation can occur. Concerns of faculty members include potential reduction in content coverage, adoption of inaccurate experimental techniques and reduced safety.

References

Coombs, G. & Elden, M. (2004); *Journal of Management Education*, Vol. 28, No. 5, October 2004, Pg 523-535

Dublin City University (2003). DCU Online Prospectus. Accessed at http://www.dcu.ie/prospects/modules/contents.php?function=2&subcode=CS151&print=1 on 7 August 2003

Entwistle, N.J, & Tait, H. (1996) *Approaches and Study Skills Inventory for Students (ASSIST)* Edinburgh: Centre for Research on Learning and Instruction, University of Edinburgh.

Harper-Marinick (2001) Maricopa Centre for Learning and Instruction. Engaging Students in Problem-Based Learning. Accessed at http://www.mcli.dist.maricopa.edu/forum/spr01/tl1.html on 28 September 2002

Kelly, O and Finlayson, O (2003) *Problem-Based Learning in the 1st Year Chemistry Laboratory – A Work in Progress*. Paper presented at the Variety in Chemistry Education with Irish Variety in Chemistry Teaching, Dublin 2003

Kelly, O and Finlayson, O (2004) *A non-traditional approach to 1st year general chemistry practical work*. Paper presented at the SMEC International Conference, Dublin, 2004

MacKinnon, M.M. (1999); *New Directions for Teaching and Learning*, No. 78, Summer 1999, Pg 49-58

Savin-Baden, M (2000); *Problem-Based Learning in Higher Education: Untold Stories.* Philadelphia: Society for Research into Higher Education.

Tan, O.S. (2004); *Innovations in Education and Teaching International*, Vol. 41, No 2, May 2004, Pg 169-184

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

Orla Kelly, Odilla Finlayson, CASTeL, Dublin City University, Ireland.*
Audrey Wilson, Chemistry Department, University of Wollongong, Australia.
orla.kelly2@mail.dcu.ie, odilla.finlayson@dcu.ie

Entry to third level science courses in Ireland is a competitive process with selection based on the individual students performance in a state examination at the end of their second level schooling. In the second level system, students are generally well prepared by their teachers for the state examinations. However, the transition to university education can be challenging for many students and non-progression is a problem after first year.

Within the context of a University education, the development of critical thinking skills is a key focus as well as the promotion of deep learning. The deep learner is characterised as (Marton and Saljo, 1997)

- Having the intention to understand the meaning;
- Using evidence;
- Relating to previous knowledge and experience;
- Having an interest in the subject matter.

However, an investigation into the type of teaching and learning which undergraduates experience reveals a potentially serious problem. The aim of this research is to determine what kind of learning students are involved in at university, and to determine what factors of the teaching and learning environment may contribute to this learning.

In this work, the approaches that first year undergraduate students (who were taking Chemistry in their undergraduate programmes) were determined. A subset of this group was then tracked when in second and third year. The measuring tool used to determine the study approaches was the ASSIST inventory. ASSIST (Entwistle & Tait 1996) is an inventory, which quantitatively measures the approaches and study skills of students. It allows for learners to be classed as predominantly deep or surface, with a third factor - strategic. All data was analysed and statistically verified.

This presentation reports on the results from a series of studies on 1st and 2nd year undergraduate chemistry students from two universities (Dublin City University and University of Wollongong), with approximately 450 students being examined initially. Since both cohorts of students have experienced a similar senior secondary school education and the fact that the Australian cohort has a similar experience in their first year chemistry module as their Irish counterparts, this analysis enabled for overall trends in performance and study processes to be established. The ASSIST inventory was validated for use in both university student cohorts. Key findings suggest that while students initially are tending towards a deep-strategic approach, this changes over the years spent in the University with some cohorts moving towards a more strategic and even surface-strategic approach.

The overall findings will be presented in terms of gender, age differences and the different approaches taken by students over the two universities. A similar study, within the Business School in Dublin City University, provides another platform for comparison. (Byrne *et al.* 2002) The type of teaching which students prefer will also be put into context, revealing interesting results. The study spanned three academic years, allowing two 1st year groups to be tracked into 2nd year.

References

1. Marton, F. & Saljo, R. (1997); *Approaches to Learning*. In F. Marton, D. Hounsell, N. Entwistle (Eds); The Experiences of Learning, Implications for Teaching and Studying in Higher Education, Edinburgh, Scottish Academic Press, 2nd Edition

2. Entwistle, N.J, & Tait, H. (1996) *Approaches and Study Skills Inventory for Students (ASSIST)* Edinburgh: Centre for Research on Learning and Instruction, University of Edinburgh.

3. Byrne, M; Flood, B; Willis, P (2002); *Accounting Education*, Vol 11(1), Pg 27-42

Keywords: Approaches to learning, ASSIST, critical thinking.

First Year Undergraduate Laboratories in Chemistry –
Experience of a problem-based laboratory approach

Odilla Finlayson, Orla Kelly, CASTeL, Dublin City University, Ireland.*
odilla.finlayson@dcu.ie, orla.kelly2@mail.dcu.ie

First year undergraduate chemistry students typically spend at least three hours per week in the chemistry laboratory. While in the laboratory, they carry out a series of generally predetermined tasks, designed to give predetermined outcomes in the limited time available. Students then submit results and a report on the laboratory session for marking. Introductory laboratory sessions focus on correct use of apparatus and concentrate on increasing manipulative skills. They can also be designed to complement lecture courses. Laboratory sessions are an extremely expensive component of the undergraduate programme and the questions that we asked were:

- Were the students benefiting from the experience, in the way that the lecturers on the course had envisaged?
- Was the laboratory session the most suitable place to tackle all the learning outcomes expected?
- Could an alternative approach be taken in the first year session to enhance the experience for the student and also achieve the expected learning outcomes?

After examination of the laboratory programme and discussion with students, an alternative laboratory programme was put in place. This programme involved the development of approx 16 problems that the students are then asked to solve in the laboratory. Each problem has a pre laboratory element that has to be completed before the laboratory session – this can range from writing reaction equations to deciding how to design a suitable experiment to solve the practical problem. The pre laboratory problem is then discussed on the day of the laboratory session before any laboratory activity can take place. Students then carry out the experimental task over one or two sessions (depending on the problem); generally, there are several ways of tackling the experimental task, so each student group may approach the problem in different ways. Specific examples of some of the problems will be shown and discussed.

This is a type of problem-based learning, a student-centred approach to teaching and learning which involves a shift from content coverage to problem engagement, and from students as passive recipients to active problem-solvers. (Tan, 2004) PBL promotes higher order thinking, and meta-cognition and has been shown to enhance student knowledge and motivation. (Yuzhi 2003)

The final laboratory report can take many forms depending on the nature of the task assigned. Formal reports are required after some problems; others require the students to take a particular stance in a debate based on the laboratory results obtained and arguing the outcomes of the experiment. A poster presentation is also required in another case.

This revised problem based laboratory session has now run with first year undergraduate chemistry students for two years. The outcomes have been very interesting. On comparison with the other first year chemistry students, who take the conventional introductory laboratory, the problem based approach students have fared equally in chemistry examinations and in laboratory marks. However, a remarkable feature is that students will comment that they prefer the problem based laboratories (even if they have not taken chemistry before at second level), that they will engage more during the laboratory and that they are prepared to put in more effort themselves in pre-laboratory exercises.

Several tools have been used to evaluate the effectiveness of the problem-based approach, and results from these will be presented in the presentation. One evaluation involved interviewing several student groups on their experiences. On giving each interview group a small problem to tackle (based on the laboratory exercises carried out by both groups), the groups who had followed the problem based laboratory course could make reasonable attempts to tackle the problem while the groups who followed the conventional approach were unable to progress very far.

In conclusion, there is much time and energy devoted to introductory practical work in chemistry and we should be sure that our students are appropriately challenged and engaged in the process.

References:

1. Tan, O.S. (2004); *Innovations in Education and Teaching International*, Vol. 41, No. 2, Pg 169-184
2. Yuzhi, W. (2003) Using Problem-Based Learning in Teaching Analytical Chemistry. In M. Peat (ed.) *The China Papers: Tertiary Science and Mathematics Teaching for the 21st Century*, **2**,Pg 28-33.

Keywords: Problem based learning, Introductory Chemistry Laboratory

Problem Based Learning in the 1st Year Chemistry Laboratory – A Work in Progress

Orla Kelly, and Odilla Finlayson, Dublin City University

Having looked at the contrast between the desirable outcomes of undergraduate education, and the present objectives of the 1st year chemistry laboratory module in DCU, it was decided to take a Problem Based Learning (PBL) approach to the 1st semester chemistry labs. PBL is a powerful learning tool, which uses real world problems to motivate students to identify and research the concepts and principles they need to know to work through these problems. The Science Education cohort was chosen as a sample group. It was proposed that regardless of the outcome of the trial, it would be of help to them in their teaching.

Appropriate problems were developed to suit the current curriculum, and the time and workload typical of this course. 10 experiments were carried out over a 10-week period, with one experiment a week. The students were given the problem the week before, and were expected to return the following week with a practical solution to the problem. Their solutions were discussed prior to entry to the lab and the students then carried out the experiment. Several difficulties were encountered which has led to further development and changes to the PBL approach. Some of these changes are due to students responses made in a survey carried out at the end of the semester.

Last year the focus was on the pre-lab write-up and pre-lab session, the focus this time round however, is on a PBL approach, in the purest form:

- Groups solving the problem together using a variety of resources
- The experiment not being tied to completion within one-lab session
- More flexibility within the curriculum, in terms of both theory and experimental procedures

The revised PBL approach will be run over the course of the 2 semesters in the coming academic year, covering the entire range of 1st year chemistry experiments and techniques.

APPENDIX 1.3: PUBLISHED ABSTRACTS - POSTER PRESENTATIONS

Microscale Chemistry – Evidence of its effective use in teaching practical chemistry to senior cycle second level students

Orla Kelly, Odilla Finlayson; CASTeL, Dublin City University, Ireland

Introduction

Microscale chemistry is practical chemistry carried out on a reduced scale using small quantities of chemicals and often, but not always, simple equipment. There are many advantages to microscale chemistry apart from the benefits of reduced waste and improved environmental protection. It increases safety in the laboratory, and it reduces the time to do experiments. It is easier to manage the laboratory, and it's financially beneficial, due to less chemical usage, and in many cases, simple more robust apparatus being used.(Singh 1995, Skinner 1997) Microscale chemistry provides a solution to the problem which many teachers face: lack of resources, lack of time, and issues concerning safety, therefore making practical chemistry much more accessible to teachers and students.

In a worldwide context, the uptake of the physical sciences has been a concern for many years. In an Irish setting, this is very true, with the % uptake of chemistry at senior secondary falling from 18.2% in 1988 to 12.3% in 2004 (DES 2002, Childs 2004). Studies of Irish schools with high take-up of physical sciences suggest a number of strategies for increasing take-up, including an emphasis on practical work, with a student survey confirming the positive impact of practical work (DES 2002). These schools also had a higher level of laboratory resources than the schools with low uptake of the physical sciences. According to a case study on schools successful in science, the teachers stated they spent approximately half of their time doing practical work (Finlayson 2002). This shows that practical work is an important aspect for the student, and is one of the main factors determining uptake of the physical sciences subjects by students.

The final school exam taken by students at second level in Ireland is the Leaving Certificate, taken by student's aged 17-18. Students take a minimum of six subjects, which they study over the course of two years, typically assessed by a final written exam and in some cases, with elements of continuous assessment. The Leaving Certificate Chemistry syllabus was revised four years ago. The syllabus now has 28 mandatory experiments, which all students are required to carry out, and answer questions on in their final exam.

Aims

The aim of this work was to determine if chemistry teachers and students could effectively carry out the mandatory Leaving Certificate experiments at microscale. The ultimate aim is to detail the experiences in the classroom so that other teachers may be encouraged to adopt this approach and hence, carry out more experimentation in schools. Reports on microscaling the Leaving Certificate chemistry experiments were presented in 2003 and 2004. (Kelly 2003, Kelly 2004). This paper reports on a series of trials of these microscale chemistry experiments with a number of Leaving Certificate chemistry classes.

Methods and Sample

Four second level schools were selected for study - one 'all boys'A, two 'all girls'B & C, and one 'mixed' school D. The schools selected were representative of the Irish School system with 1 Community School and 3 Secondary Schools. The fifth year chemistry class was selected in each school where the students were approximately 16yrs of age and in their first year of studying Chemistry. Over 40 students were involved in total. These schools and classes were chosen as they all did experimental work regularly, and so the students were used to doing practical work.

In this study, it is important to point out that the teacher was still involved in conducting the experimental class. The teacher was supplied with the procedures, and apparatus, as well as training in the use of new equipment before the class. One of the authors (OK) was present during the class to observe. Eighteen different classes were observed which covered 12 of the 28 mandatory experiments on the syllabus. Table below summarises the classes and the experiments observed.

Table: Experiments / classes observed

Mandatory Experiment	**No***	**School A**	**School B**	**School C**	**School D**
Titrimetric analyses	10	2	1	1	2
Organic Preparations	6	1	0	0	4
Rates of Reaction	2	2	2	0	0
Colourimetric determination of Chlorine	1	0	0	0	1
Le Chatelier's principle	1	1	0	0	0
Tests for anions and cations	1	0	0	0	0
Determination of heat of reaction	1	0	0	0	0
Other simple experiments	6	0	0	0	0

* number of mandatory experiments that relate to this section of the syllabus

It is clear that titrations and volumetric analysis make up a large portion of the syllabus, therefore it was very important that the microscale titration techniques were well-assessed. Each school did at least one titration.

Students doing the microscale experiments were recorded on video, and afterwards the students and teachers were invited to write comments on their experience of microscale chemistry. Actual results from the students' experiments were also recorded to allow for analysis of accuracy and precision.

Data analysis and Results

Titrations

In general a favourable response was received from both students and teachers. Significantly, students noted that they felt more confident and comfortable using the microburette over the normal scale burette, stating that it was "easier to use", "easier to control", "easier to fill". One student commented that s/he could actually "reach everything". The smaller quantities of chemicals used was also an attractive feature for the students.

The teachers involved noted the accuracy of results obtained, being similar to their experience with macrotitrations. The male students did have some difficulties initially with handling the microburette, however, this improved with practice.

Organic preparations

Class groups were involved in preparation of soap, ethyne and ethanal at microscale level during the course of the trials, with teachers really noticing the safer laboratory environment and the students commenting on the ease of use, even when working on their own! Students' comments on these experiments are particularly interesting:

Student 3 on preparation of soap:

> *'It was easy to assemble it* [the apparatus] *to boil under reflux but got a bit awkward when I had to change to distillation…this experiment was easy to complete by myself.'*

Student 4 on ethyne preparation:

> *'This experiment took a very short amount of time to do. Everything was easy to use because the instructions were so clear. I think it would be a better idea to do this experiment separately because there is not much work involved to share between two people'*

Teacher particularly liked the ethyne preparation stating *'This worked and its biggest attraction was that it is a safer method.'* One teacher summed up the experience of microscale in her classroom as follows:

> *'At no point did I feel that anything was unsafe. I was very happy about using smaller amount of chemicals. They* [the students] *felt they learnt more as they were in charge of each step of the experiment themselves.'*

Conclusions and Implications

Overall, the pilot study was very effective. It clearly showed that there are both positive and negative features to microscale at second level. However, the negative features were specifically related to ease of handling of the equipment e.g. where they had already gained familiarity with macroburettes, then the change to microburettes was more challenging. Also, the boys from the all-boys school seemed to struggle with the small equipment at times, in contrast to the mixed-school boys, where there was no significant negative feedback on ease of use of equipment.

However, the positive feedback was very encouraging from both students and teachers. In this pilot, the use of microscale has appeared to give the students more confidence in their ability to do practical work, as they are able to complete the experiments by themselves. Also, they appear to have engaged more with the chemistry involved in the experiment. The teachers felt that overall it was beneficial to the students as it gave the students the opportunity to engage more with the experiment, often allowing them to work on their own. Also, the issues of safety, and cost were important.

The investigation has allowed for real testing of the robustness of the techniques for general use in school laboratories. Student and teacher reactions have indicated the beneficial effects of this methodology on interest and engagement with the practical work. These results will be used to encourage a greater uptake of microscale at second level. A Leaving

Certificate Microscale Chemistry manual has now been developed and is ready for distribution to all relevant teachers (funding required).

References

Childs, P.E. (2004) 2004 LC Results and CAO Offers in Science. *Chemistry in Action*, 74, Autumn 2004

DES (2002) Department of Education and Science. Task Force on the Physical Sciences Report and Recommendations. Accessed at http://www.education.ie/servlet/blobservlet/physical_sciences_report.pdf March 05

Finlayson, O.E., and Killen, L. (2002); *Case Studies of Schools Successful in Science* in Task Force on the Physical Sciences Report and Recommendations. Pg 175-197 Accessed at http://www.education.ie/servlet/blobservlet/physical_sciences_report.pdf on March 05

Kelly, O. and Finlayson, O.E. (2003) Small-scale chemistry in the school laboratory. *Chemistry in Action*, 69, Spring 2003

Kelly, O. and Finlayson, O.E. (2004) *Microscale Chemistry for Leaving Certificate - a safe and effective practical experience for teachers and students.* Paper presented at the ISTA/ASE Northern Ireland AGM and Conference, Dundalk 2004

Skinner, J. (1997) *Microscale Chemistry Experiments in Miniature*. London, Education Division, Royal Society of Chemistry.

Singh, M.M., Pike, R.M. and Szafran, Z. (1995) *Microscale & Selected Macroscale Experiments for General & Advanced General Chemistry – An Innovative Approach.* New York, John Wiley & Sons, Inc.

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

Orla Kelly, and Odilla Finlayson, Dublin City University, Dublin 9

Microscale is reduced scale experimentation; using small quantities of chemicals and reduced scale apparatus. It has many benefits to teachers and students; making life easier for teachers in the practical laboratory, and allowing hands-on experience for students. Previous papers have shown its use for Leaving Certificate Chemistry, Junior Certificate Investigative Science and Transition Year Science. This research presents evidence of it effective use for Leaving Certificate Chemistry in three schools; one all-boys, one all-girls, and one mixed.

Titrations, making up a large proportion of the mandatory practical syllabus, were tried out by all schools, rates of reaction experiments, including effect of temperature, concentration and catalyst on reaction rate, were also tried out, and finally some organic preparations were carried out in one of the schools. The use of dataloggers go hand-in-hand with microscale techniques, as often only small amounts of chemicals are needed, as with the case of the colorimetric determination of chlorine, tried out by one of the schools.

Student comments from individual experiments, as well as sample results will be shown. Finally, the overall teachers' opinions, and comments on the use of microscale for Leaving Certificate chemistry will be highlighted.

A non-traditional approach to 1st year general chemistry practical work

Orla Kelly, and Dr. Odilla Finlayson, Dublin City University, Dublin 9
orla.kelly2@mail.dcu.ie

The structure of traditional chemistry courses erects numerous road-blocks to students becoming actively involved in their own learning. They follow a procedure, get a result and write up a report; engaging only the very interested and enthusiastic students. Problem-based learning (PBL) courses on the other hand start with problems, motivating students toward the acquisition of knowledge and skills through a problem presented in a 'real-world' context, together with associated learning materials and support from a facilitator. PBL stems from social constructivist theory, with group work an integral part of the overall process.

A cohort of 26 1st year science students, out of a total of around 200, took part in a year-long PBL chemistry course at DCU, covering analytical, physical and organic chemistry. Appropriate problems were developed to suit the current curriculum, and the time and workload typical of this course. In the 1st semester, a series of 8 problems were tackled over a 10 week period and in the 2nd semester a series of 6 problems were tackled over an 8 week period. A selection of these problems will be discussed and evaluated.

Finally, there was an attempt at an overall evaluation of the PBL course, entailing various surveys. These included

- Detailed profile of the PBL cohort
- Assessment of the whole 1st year cohorts approach to study, and study skills
- Brief questionnaire on student perception of the PBL module
- Interviews with a sample of students from both the PBL cohort and the traditional students

The results of these surveys will be shown and discussed.

Microscale Modules for use as an Introduction to Chemistry

Orla Kelly, and Odilla Finlayson, Dublin City University

Dublin City University, like many other 3rd level institutions, is involved with bridging the gap between school and college education through school liaison activities. The School of Chemistry has a big role to play in this. By the encouragement and promotion of chemistry, it is seen as an enjoyable and wise subject choice both for life itself, and further advancement in the world of science. In this research, a series of microscale modules are promoted as effective and fun experiments to carry out as school liaison activities in any chemistry department.

Microscale chemistry is chemistry carried out on a reduced scale using small quantities of chemicals and often, but not always, simple equipment. It has many advantages for students, educators and, most importantly, for the environment. It is a global phenomenon with many institutions now using microscale at undergraduate level. When developing modules, the main aim was to keep it relevant and interesting for the students. Social and applied topics were at the forefront. These modules are useful as starting off points for many areas of chemistry: organic chemistry, metals, chemical analysis, redox reactions, pollution control, chromatography etc.

A tried and tested microscale module is an alcohol one, which has been used at both student and teacher courses held in DCU. However, the recently developed modules are in more topical areas such as analytical chemistry and its relevance in industry, and materials, including polymers and plastics. Other modules include colour chemistry, working with fabrics and dyes and chemistry in the kitchen, testing food and drink products commonly found in the kitchen. These are, in general, modules that can be covered in a 1-hour session. Each module contains 3-4 experiments; with each experiment relatively quick, and simple.

Microscale Chemistry in the School Laboratory

Orla Kelly & Odilla Finlayson, School of Chemical Sciences, Dublin City University

Reduction of chemical use to the minimum level at which experiments can be effectively performed is known as Microscale Chemistry. Microscale chemistry is an environmentally safe pollution prevention method of performing chemical processes using small quantities of chemicals with out compromising the quality and standard of chemical applications in education and industry. The objective of the current research is to microscale the Leaving Certificate mandatory experiments. Titrations make up a large proportion of experiments and these have been microscaled successfully. A microburette, 2ml capacity, is used instead of the 25, or 50ml burette and it was found to be as accurate as the traditional burette. The organic reflux/distillation experiments have been carried out using small-scale quickfit apparatus. Some of the experiments have been carried out in cheap, easily available apparatus such as well plates, and plastic syringes. Hazardous waste was greatly reduced overall and a time reduction was observed for most of the experiments. There are also many benefits for students. For example, it encourages excellent lab skills, improves students' accuracy and precision and allows for more investigation.

[i] http://www.silvertech.com/microscale/what_is_microscale.html
[ii] Skinner, J., Microscale Chemistry – Experiments in Miniature, The Education Division, The Royal Society of Chemistry, 1997
[iii] http://mattson.creighton.edu/Microscale_Gas_Chemistry.html

APPENDIX 2.1: RAW DATA FOR VALIDATION OF ASSIST

Factor analysis – First year 01-02

KMO and Bartlett's Test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.743
Bartlett's Test of Sphericity	Approx. Chi-Square	452.546
	df	105
	Sig.	.000

Rotated Factor Matrix

Subscales	1	2	3	4
Seeking meaning	0.301	0.765	-0.090	0.097
Relating ideas	0.278	0.752	-0.003	-0.225
Use of evidence	0.059	0.806	0.214	-0.142
Interest in ideas	0.168	0.686	-0.040	-0.182
Organised studying	0.776	0.166	-0.103	-0.019
Time management	0.804	0.081	-0.026	-0.170
Alertness to assessment demands	0.626	0.242	0.244	-0.003
Achieving	0.787	0.235	-0.139	0.019
Monitoring effectiveness	0.512	0.449	0.033	0.251
Lack of purpose	-0.063	-0.013	0.589	-0.086
Unrelated memorising	0.031	-0.007	0.801	0.278
Syllabus-boundness	-0.147	-0.177	0.373	0.542
Fear of failure	0.042	0.163	0.534	0.351
Supporting understanding	0.287	0.357	-0.023	-0.563
Transmitting information	0.119	-0.047	0.075	0.644

Extraction Method: Principal Axis Factoring.
Rotation Method: Varimax with Kaiser Normalization.
a Rotation converged in 5 iterations.

Factor Analysis with eigenvalues below 0.3 discarded

Subscales	1	2	3	4
Seeking meaning	0.301	0.765		
Relating ideas		0.752		
Use of evidence		0.806		
Interest in ideas		0.686		
Organised studying	0.776			
Time management	0.804			
Alertness to assessment demands	0.626			
Achieving	0.787			
Monitoring effectiveness	0.512	0.449		
Lack of purpose			0.589	
Unrelated memorising			0.801	
Syllabus-boundness			0.373	0.542
Fear of failure			0.534	0.351
Supporting understanding		0.357		-0.563
Transmitting information				0.644

Factor analysis – First year 02-03

KMO and Bartlett's Test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.774
Bartlett's Test of Sphericity	Approx. Chi-Square	587.469
	df	105
	Sig.	.000

Rotated Factor Matrix

Subscales	1	2	3
Seeking meaning	0.312	0.596	0.025
Relating ideas	0.102	0.784	0.011
Use of evidence	0.238	0.651	-0.101
Interest in ideas	0.255	0.697	-0.189
Organised studying	0.699	0.266	0.066
Time management	0.821	0.159	-0.009
Alertness to assessment demands	0.243	0.246	0.315
Achieving	0.822	0.176	0.004
Monitoring effectiveness	0.719	0.287	0.085
Lack of purpose	-0.425	-0.003	0.408
Unrelated memorising	-0.065	-0.074	0.795
Syllabus-boundness	-0.129	-0.206	0.710
Fear of failure	0.079	-0.007	0.692
Supporting understanding	0.064	0.716	-0.291
Transmitting information	0.174	-0.235	0.571

Extraction Method: Principal Axis Factoring.
Rotation Method: Varimax with Kaiser Normalization.
a Rotation converged in 5 iterations.

Factor Analysis with eigenvalues below 0.3 discarded

Subscales	1	2	3
Seeking meaning	0.312	0.596	
Relating ideas		0.784	
Use of evidence		0.651	
Interest in ideas		0.697	
Organised studying	0.699		
Time management	0.821		
Alertness to assessment demands			0.315
Achieving	0.822		
Monitoring effectiveness	0.719		
Lack of purpose	-0.425		0.408
Unrelated memorising			0.795
Syllabus-boundness			0.710
Fear of failure			0.692
Supporting understanding		0.716	
Transmitting information			0.571

Factor analysis – First year 03-04

KMO and Bartlett's Test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.866
Bartlett's Test of Sphericity	Approx. Chi-Square	1863.554
	df	105
	Sig.	.000

Rotated Factor Matrix

Subscales	1	2	3
Seeking meaning	0.324	0.671	-0.065
Relating ideas	0.071	0.763	-0.178
Use of evidence	0.243	0.740	-0.097
Interest in ideas	0.270	0.633	-0.165
Organised studying	0.798	0.217	-0.003
Time management	0.848	0.125	-0.143
Alertness to assessment demands	0.385	0.221	0.228
Achieving	0.732	0.205	-0.167
Monitoring effectiveness	0.606	0.423	-0.010
Lack of purpose	-0.217	-0.207	0.516
Unrelated memorising	0.050	-0.071	0.673
Syllabus-boundness	-0.286	-0.201	0.648
Fear of failure	0.149	0.021	0.717
Supporting understanding	0.177	0.546	-0.349
Transmitting information	-0.022	-0.171	0.463

Extraction Method: Principal Axis Factoring.
Rotation Method: Varimax with Kaiser Normalization.
a Rotation converged in 5 iterations.

Factor Analysis with eigenvalues below 0.3 discarded

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

Factor analysis – First year 04-05

KMO and Bartlett's Test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.775
Bartlett's Test of Sphericity	Approx. Chi-Square	505.108
	df	105
	Sig.	.000

Rotated Factor Matrix

Subscales	1	2	3	4
Seeking meaning	0.244	0.790	-0.170	0.047
Relating ideas	0.226	0.690	0.042	-0.171
Use of evidence	0.158	0.802	-0.261	0.093
Interest in ideas	0.265	0.541	-0.162	-0.441
Organised studying	0.737	0.202	-0.065	-0.167
Time management	0.803	0.103	-0.072	-0.127
Alertness to assessment demands	0.591	0.128	-0.152	0.108
Achieving	0.850	0.267	-0.032	-0.213
Monitoring effectiveness	0.610	0.441	-0.086	0.122
Lack of purpose	-0.300	-0.198	0.484	0.265
Unrelated memorising	-0.100	-0.191	0.931	0.084
Syllabus-boundness	-0.078	-0.080	0.394	0.630
Fear of failure	-0.030	-0.044	0.557	0.262
Supporting understanding	0.215	0.121	-0.113	-0.651
Transmitting information	0.100	0.107	0.103	0.620

Extraction Method: Principal Axis Factoring.
Rotation Method: Varimax with Kaiser Normalization.
a Rotation converged in 5 iterations.

Factor Analysis with eigenvalues below 0.3 discarded

Subscales	1	2	3	4
Seeking meaning		0.790		
Relating ideas		0.690		
Use of evidence		0.802		
Interest in ideas		0.541		
Organised studying	0.737			
Time management	0.803			
Alertness to assessment demands	0.591			
Achieving	0.851			
Monitoring effectiveness	0.610	0.441		
Lack of purpose			0.484	
Unrelated memorising			0.931	
Syllabus-boundness			0.394	0.630
Fear of failure			0.557	
Supporting understanding				-0.651
Transmitting information				0.620

Factor analysis – Leaving Certificate 2005

KMO and Bartlett's Test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.775
Bartlett's Test of Sphericity	Approx. Chi-Square	810.195
	df	78
	Sig.	.000

Rotated Factor Matrix

Subscales	1	2	3
Seeking meaning	0.244	0.790	-0.170
Relating ideas	0.226	0.690	0.042
Use of evidence	0.158	0.802	-0.261
Interest in ideas	0.265	0.541	-0.162
Organised studying	0.737	0.202	-0.065
Time management	0.803	0.103	-0.072
Alertness to assessment demands	0.591	0.128	-0.152
Achieving	0.850	0.267	-0.032
Monitoring effectiveness	0.610	0.441	-0.086
Lack of purpose	-0.300	-0.198	0.484
Unrelated memorising	-0.100	-0.191	0.931
Syllabus-boundness	-0.078	-0.080	0.394
Fear of failure	-0.030	-0.044	0.557
Supporting understanding	0.215	0.121	-0.113
Transmitting information	0.100	0.107	0.103

Extraction Method: Principal Axis Factoring.
Rotation Method: Varimax with Kaiser Normalization.
a Rotation converged in 5 iterations.

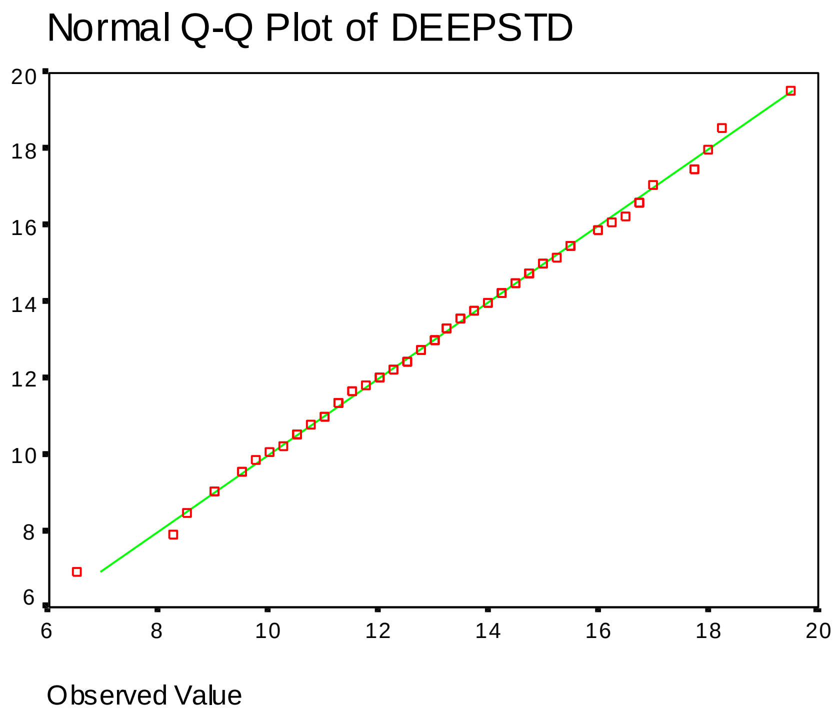
Factor Analysis with eigenvalues below 0.3 discarded

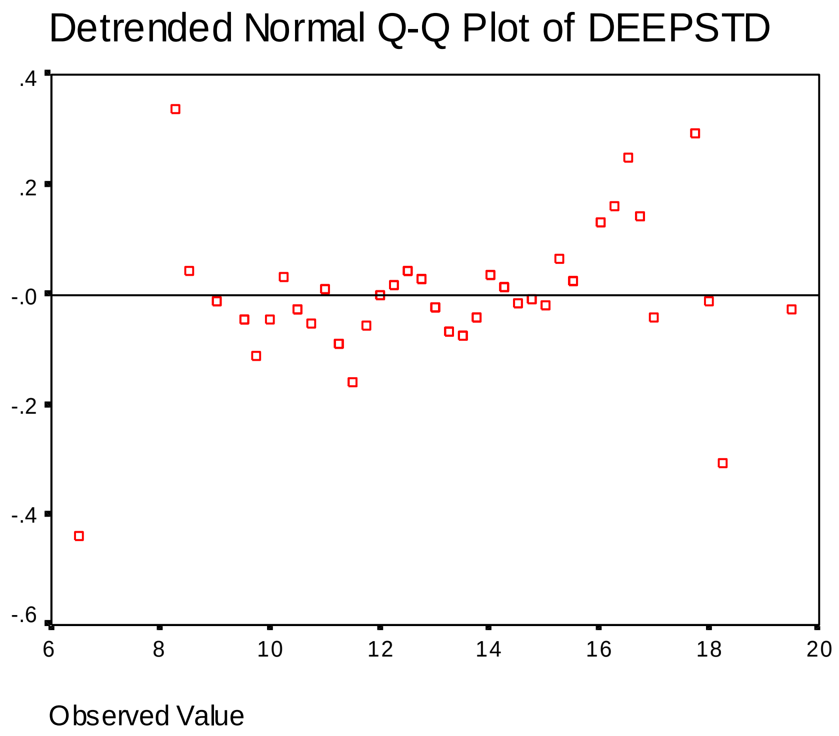
Subscales	1	2	3
Seeking meaning			0.686
Relating ideas			0.686
Use of evidence			0.733
Interest in ideas	0.316		0.357
Organised studying	0.785		
Time management	0.834		
Alertness to assessment demands	0.419		
Achieving	0.755		
Monitoring effectiveness	0.468		0.402
Lack of purpose		0.765	
Unrelated memorising		0.769	
Syllabus-boundness		0.630	
Fear of failure		0.414	
Supporting understanding			0.686
Transmitting information			0.686

APPENDIX 2.2: Q-Q PLOTS DEMONSTRATING NORMAL DISTRIBUTION OF THE THREE FIRST YEAR COHORTS

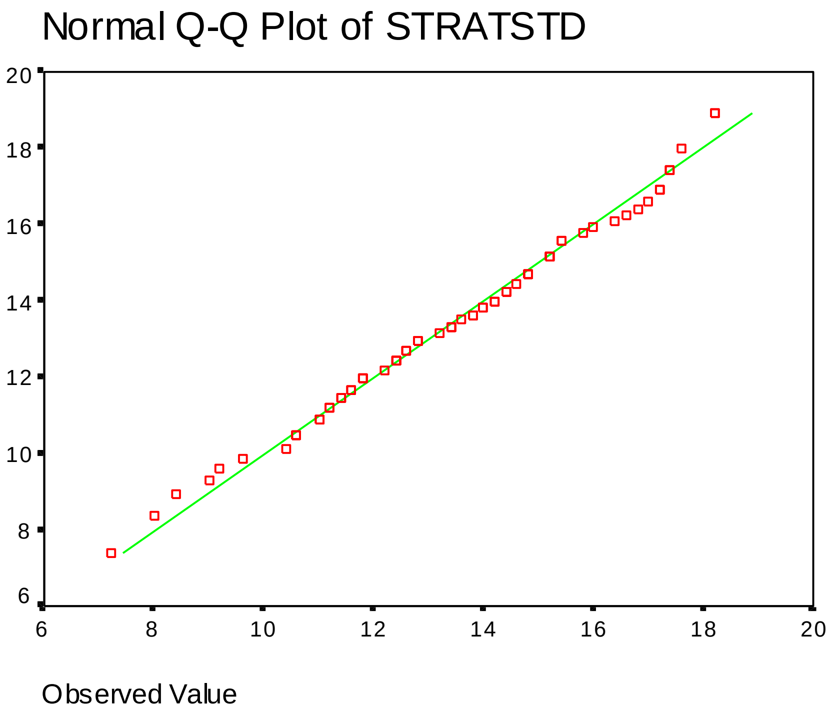
If the sample is from a normal distribution the cases fall more or less in a straight line in the Normal Probability Plot, and the second graph demonstrates a normal distribution since there is no pattern to the clustering of the points.

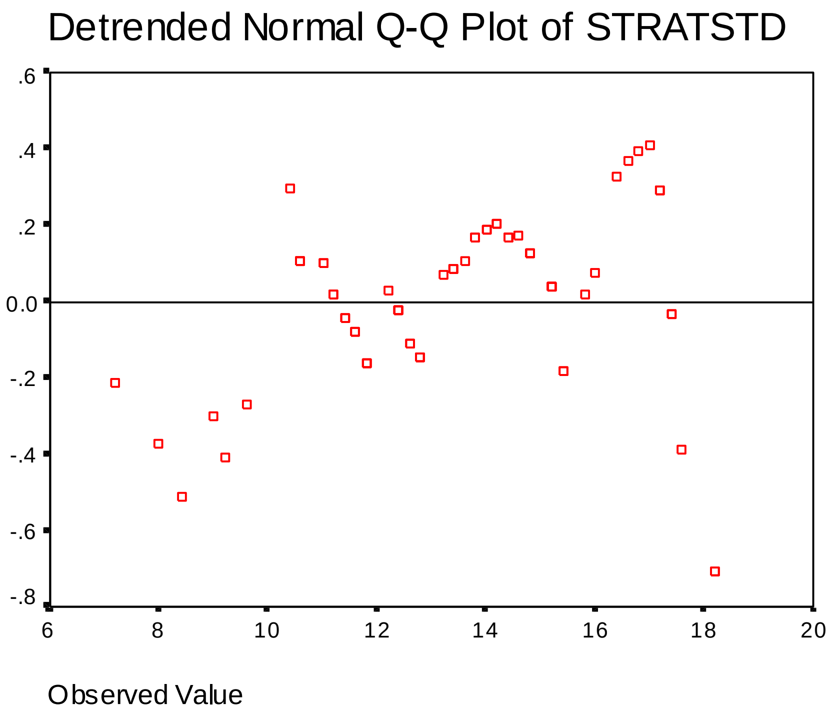
First year 01-02 - Deep Standard



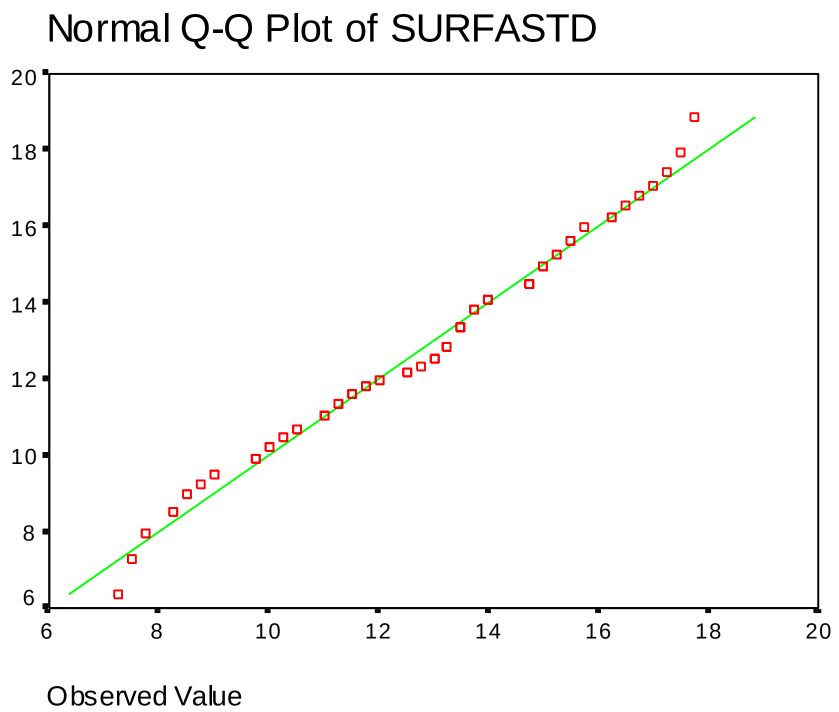


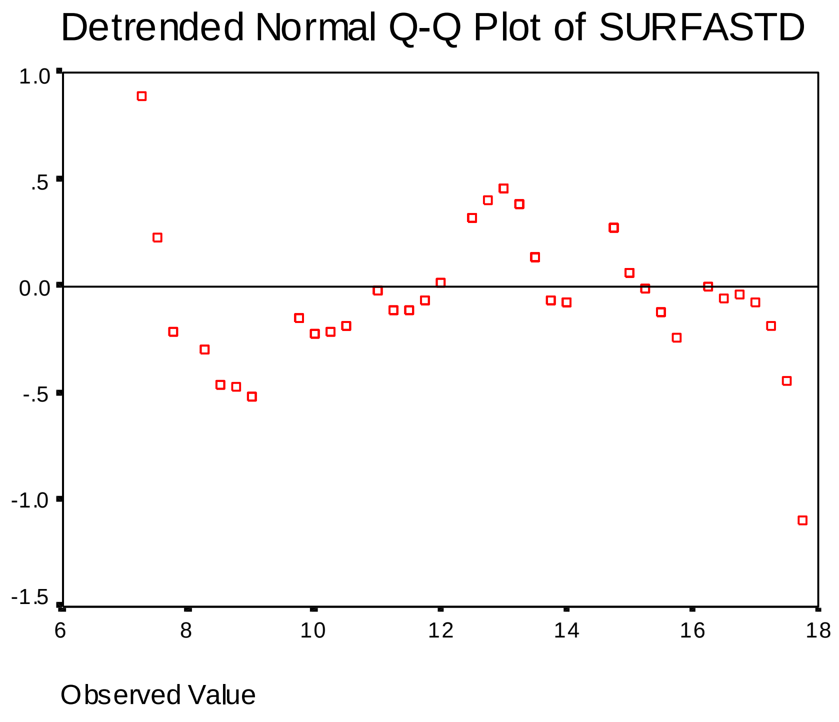
<u>First year 01-02 – Strategic standard</u>



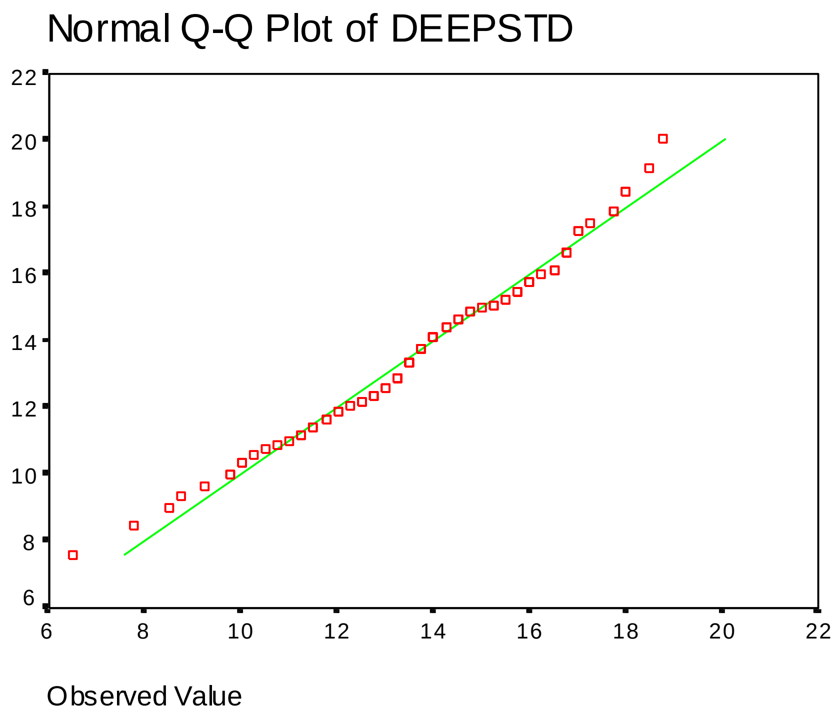


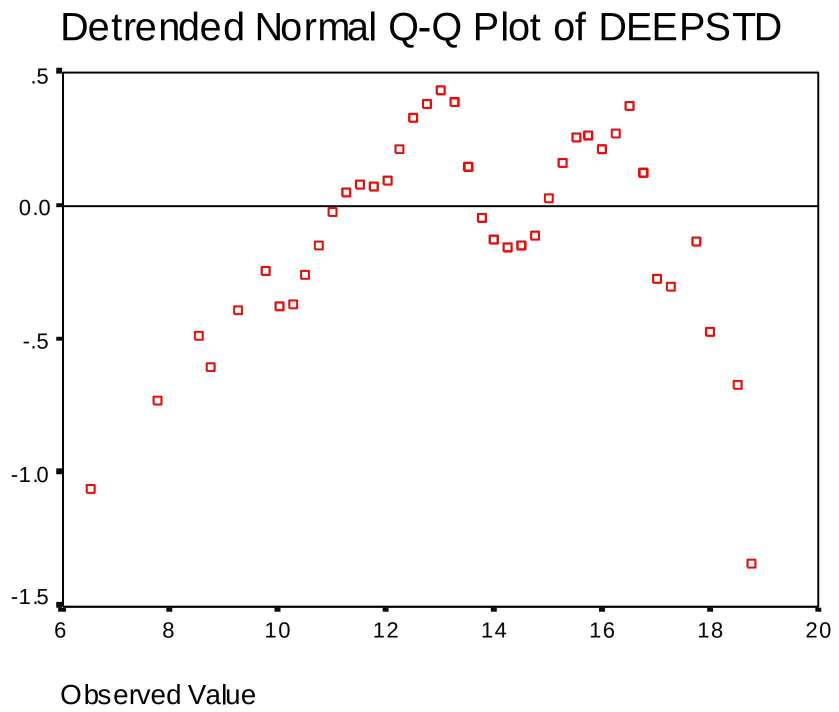
First year 01-02 - Surface Standard



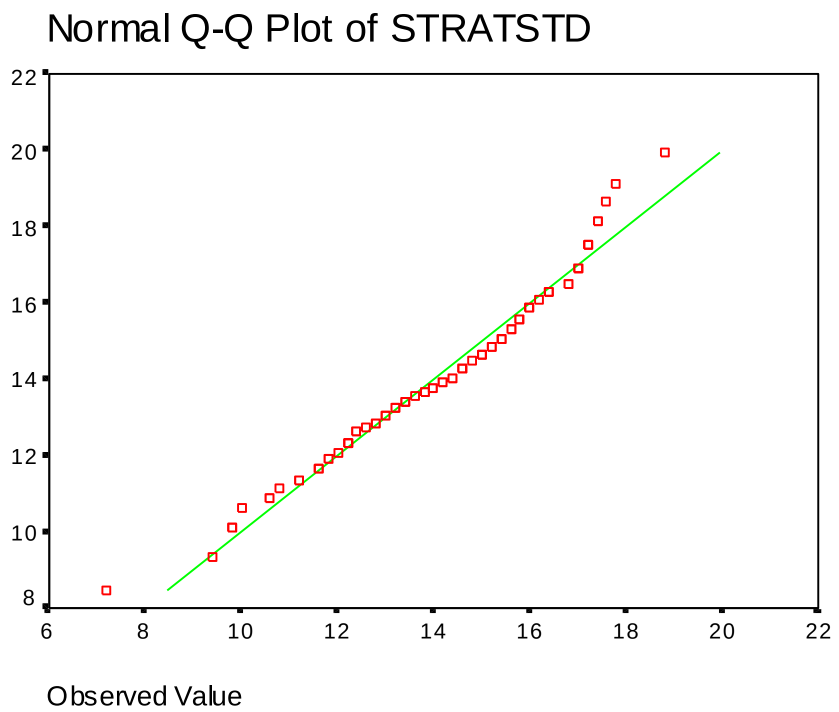


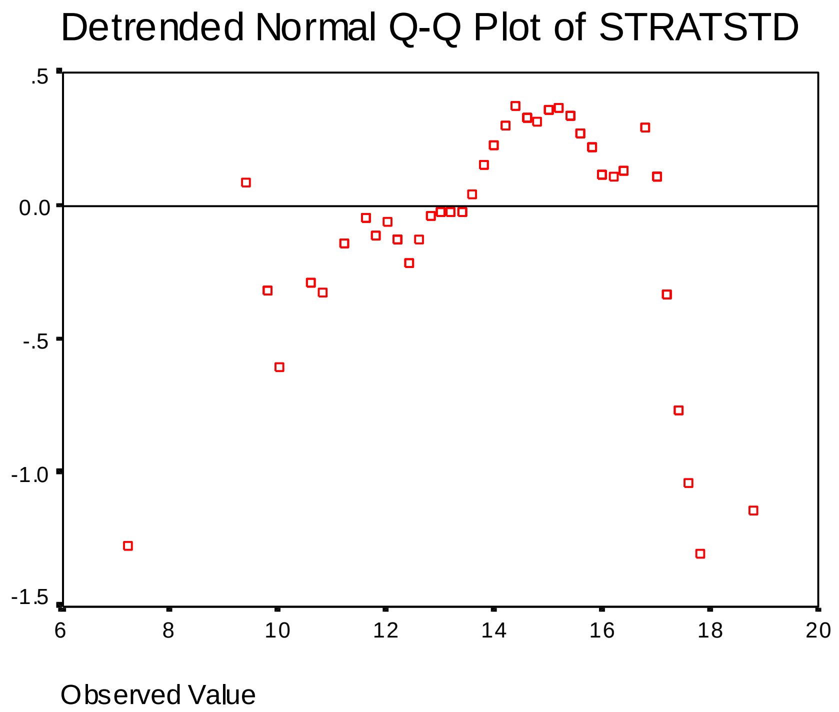
First year 02-03 - Deep Standard



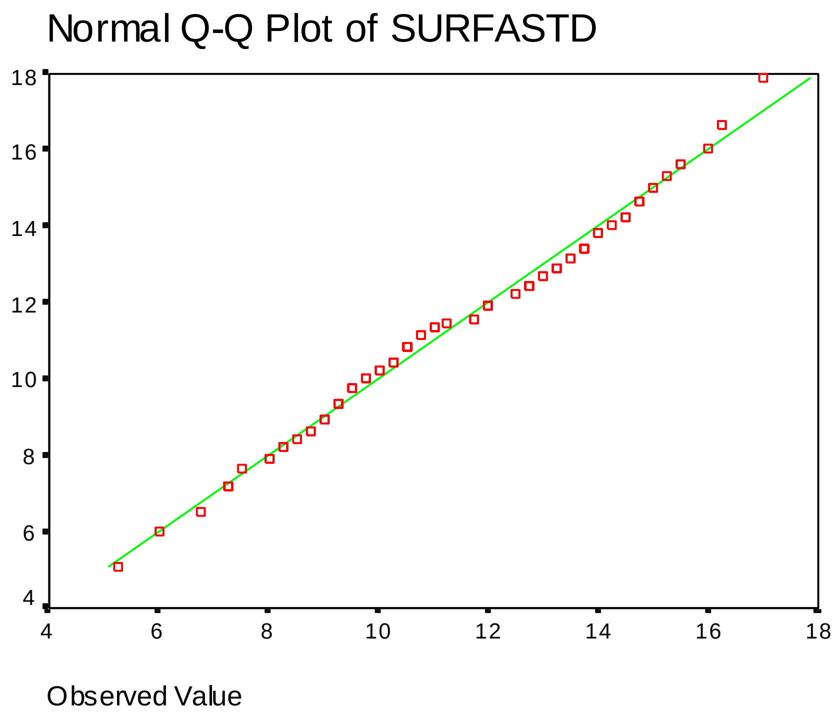


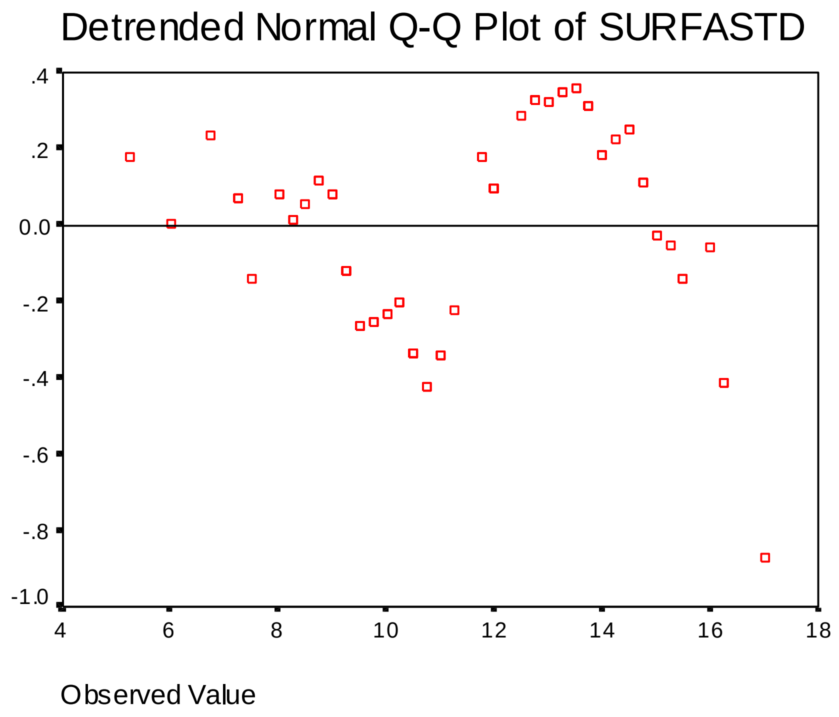
First year 02-03 - Strategic Standard



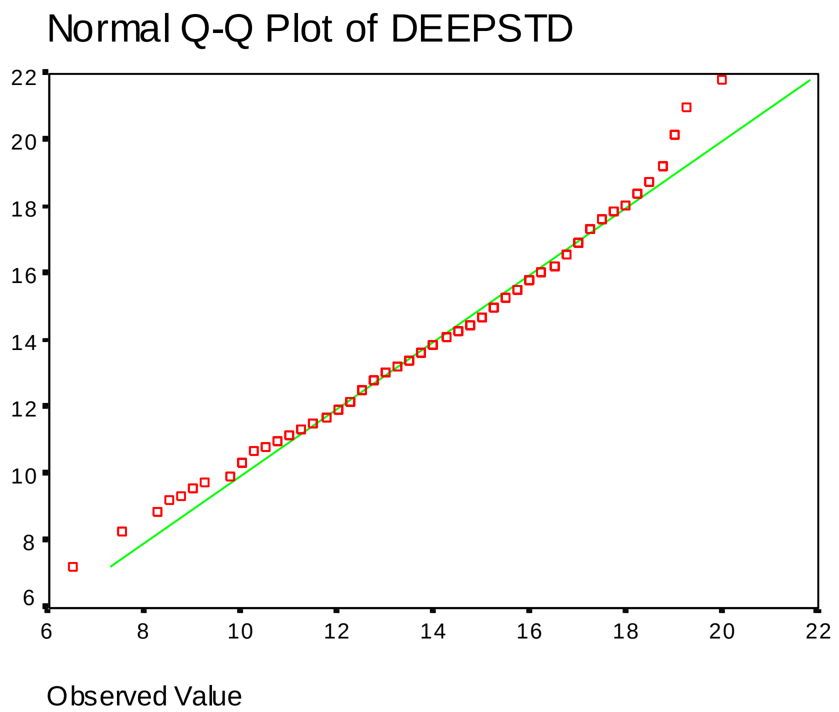


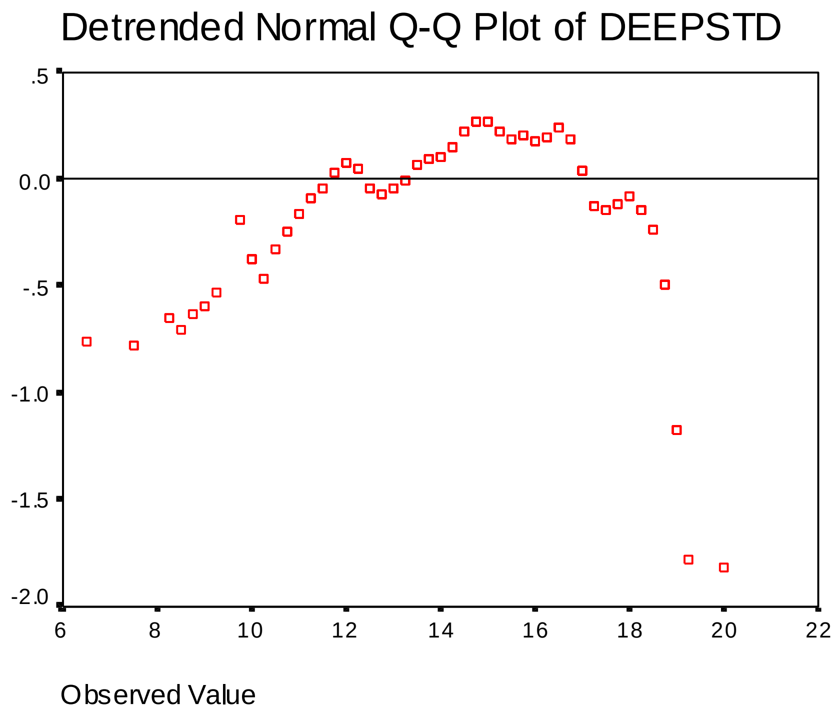
First year 02-03 - Surface Standard



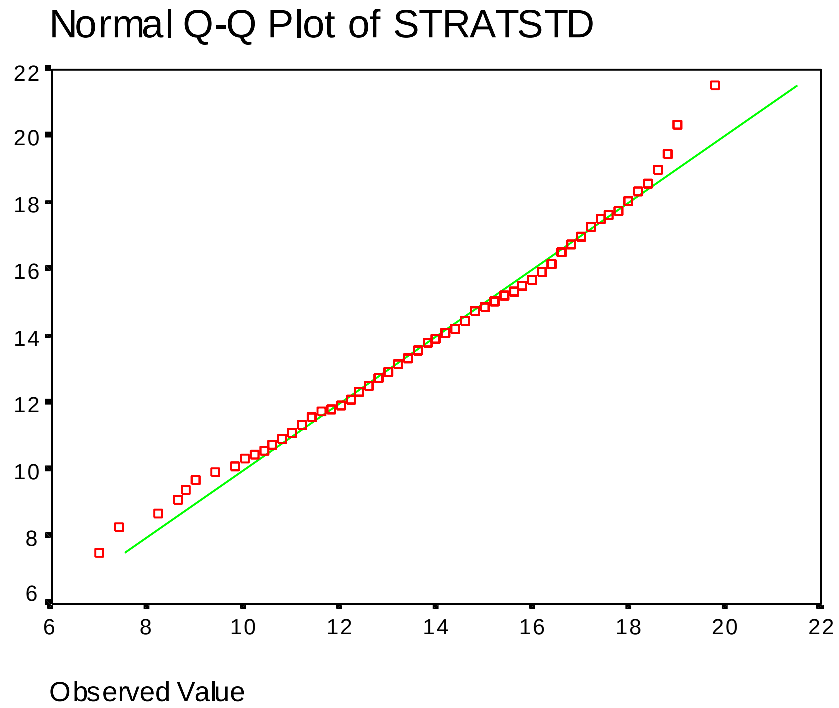


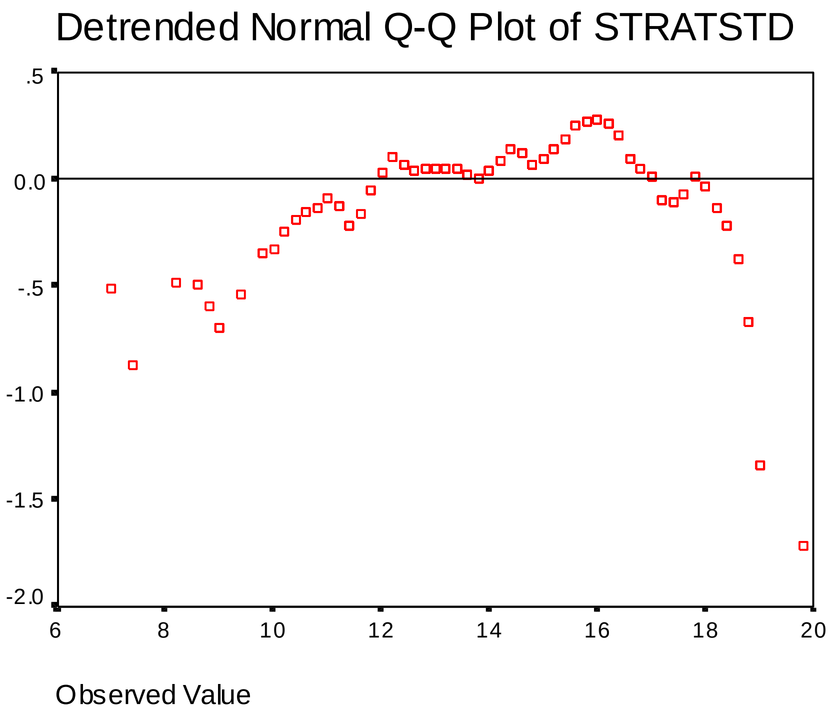
First year 03-04 - Deep Standard



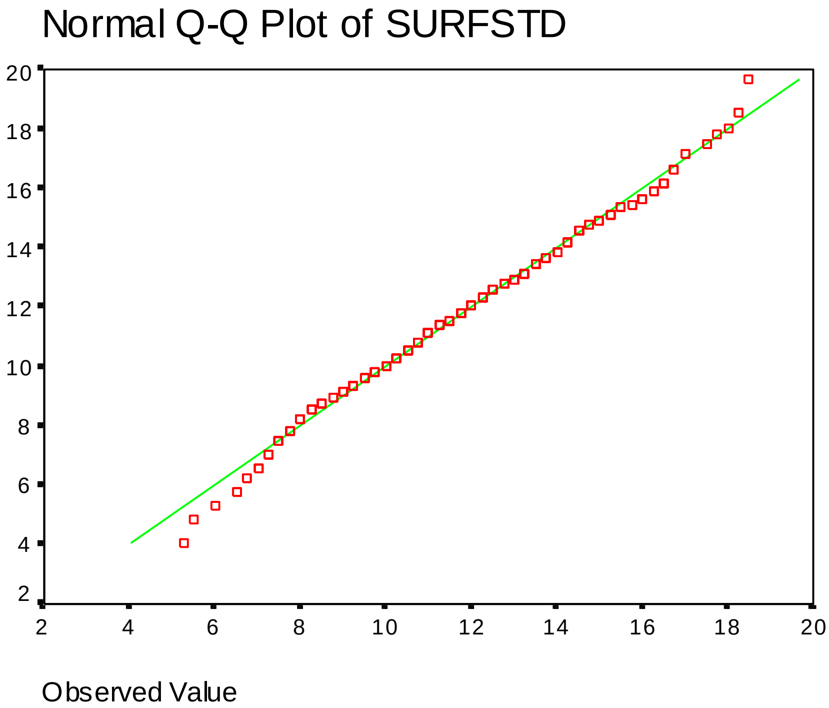


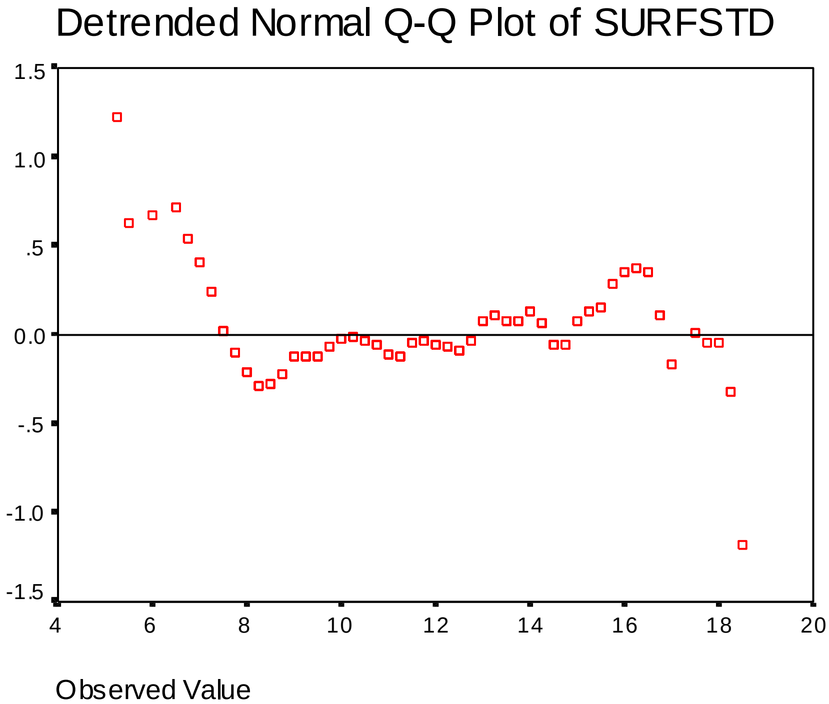
First year 03-04 - Strategic Standard



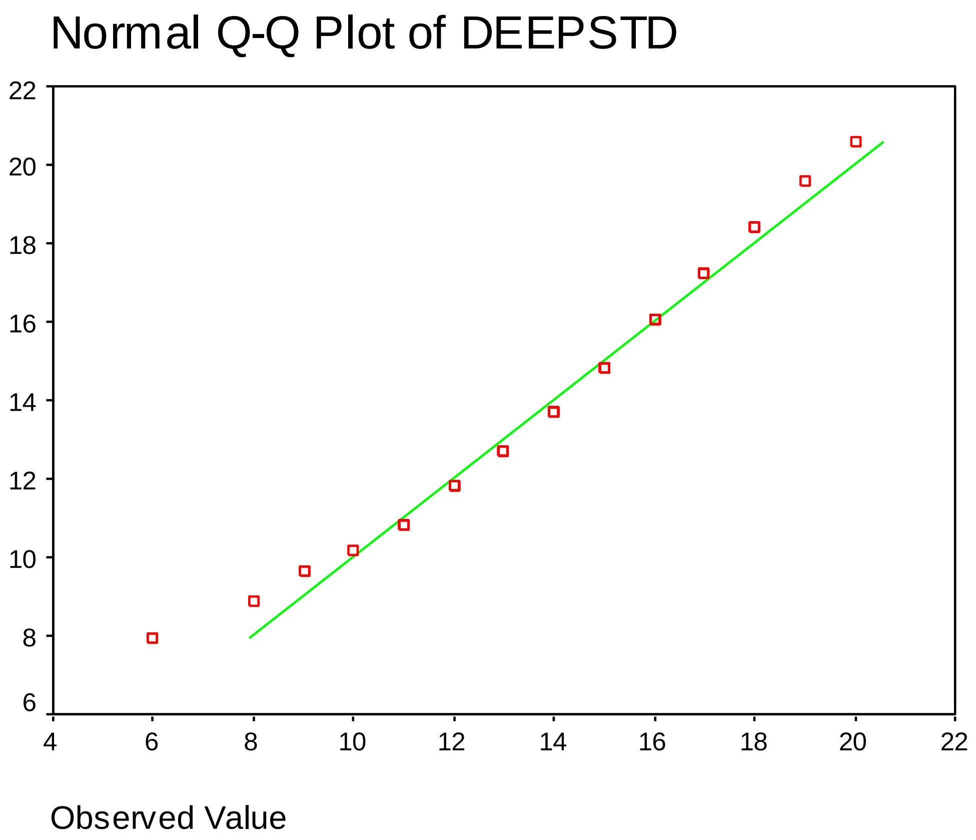


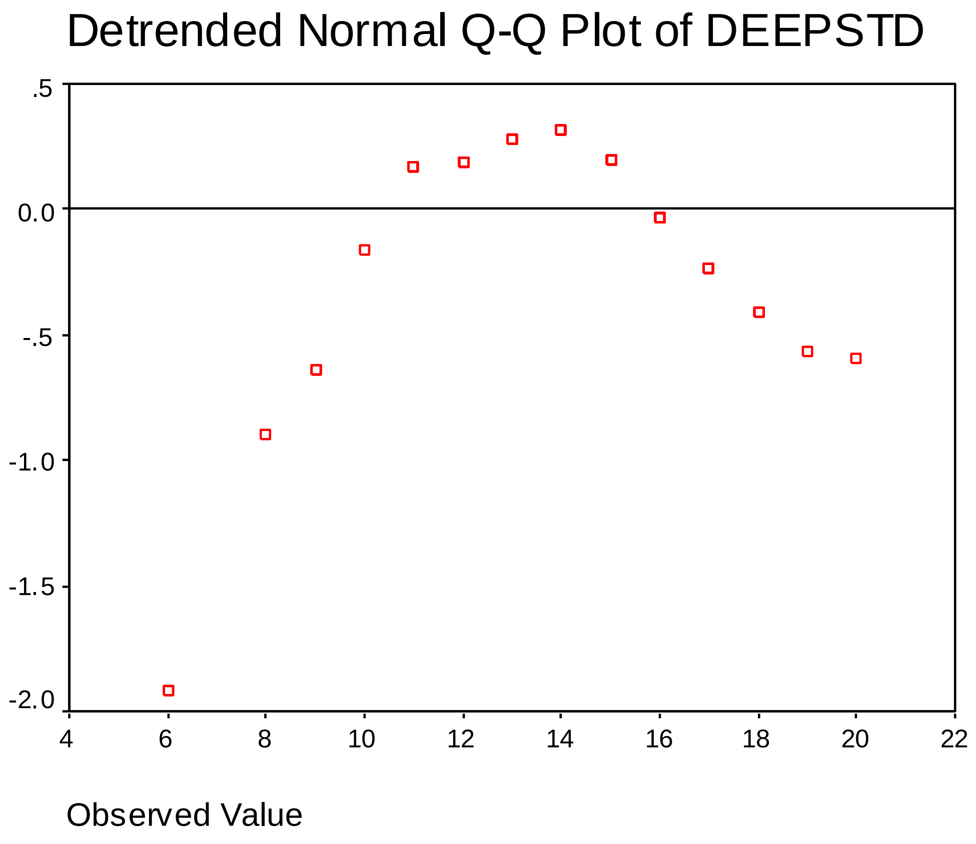
First year 03-04 - Surface Standard





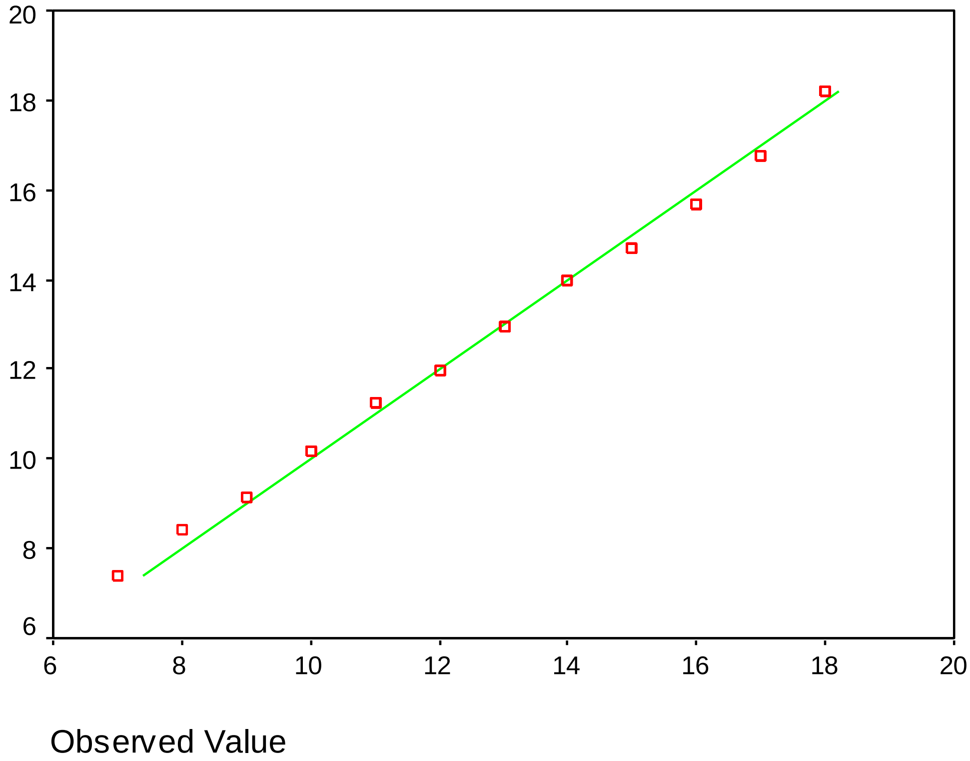
First year 04-05 – Deep standard



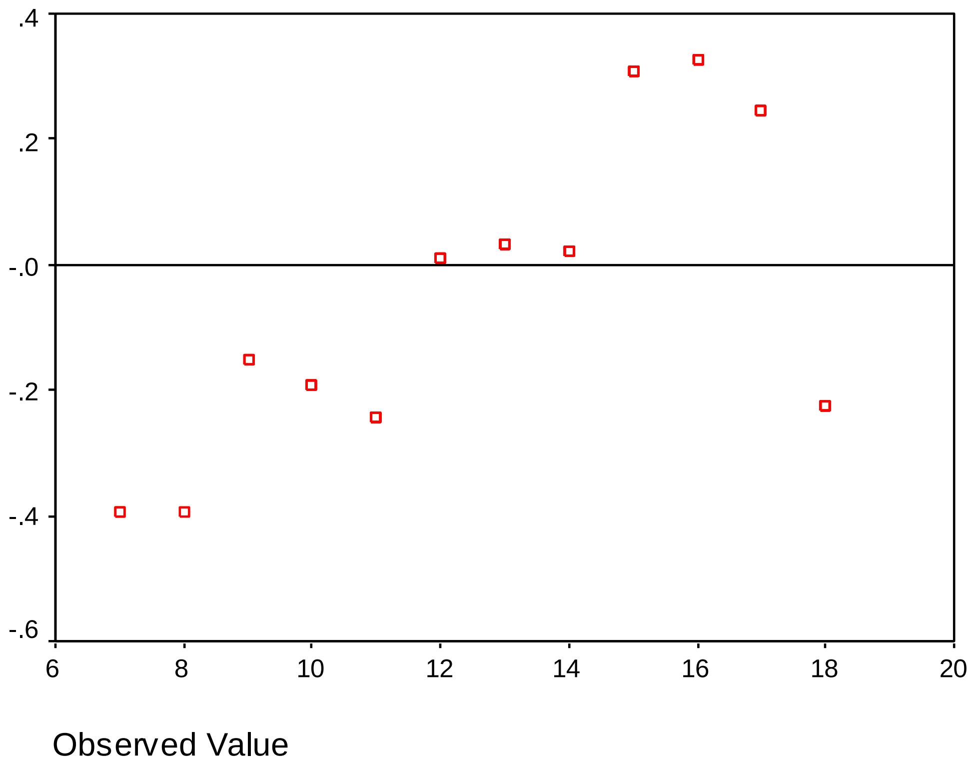


<u>First year 04-05 – Strategic Standard</u>

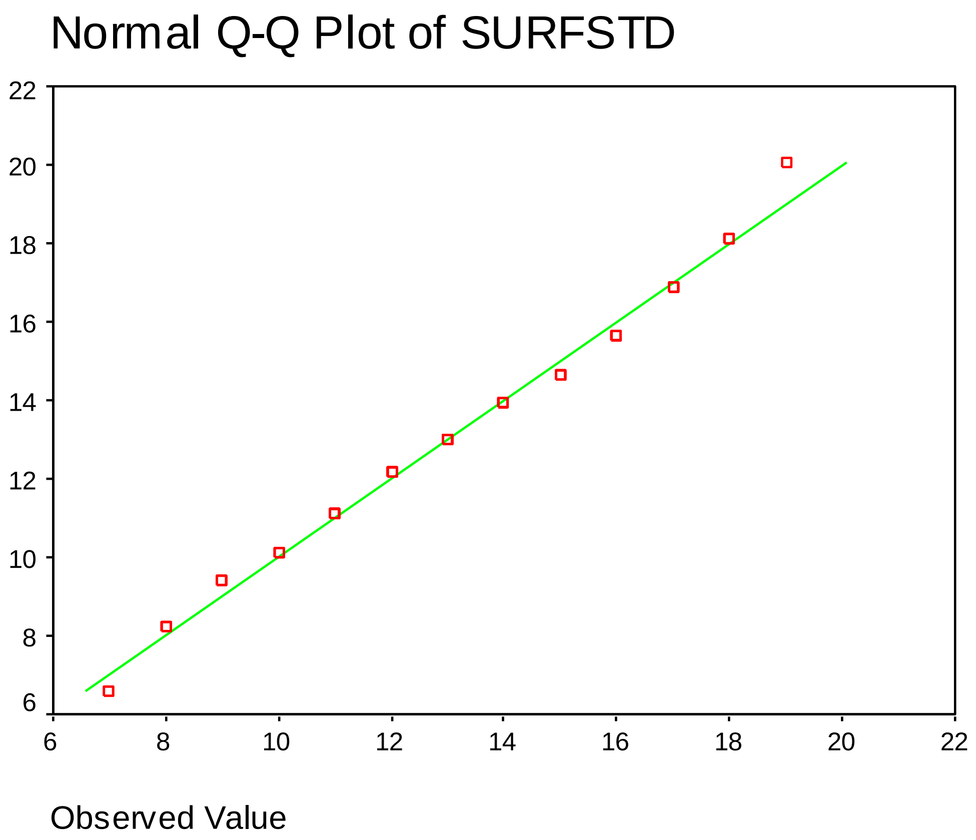
Normal Q-Q Plot of STRATSTD

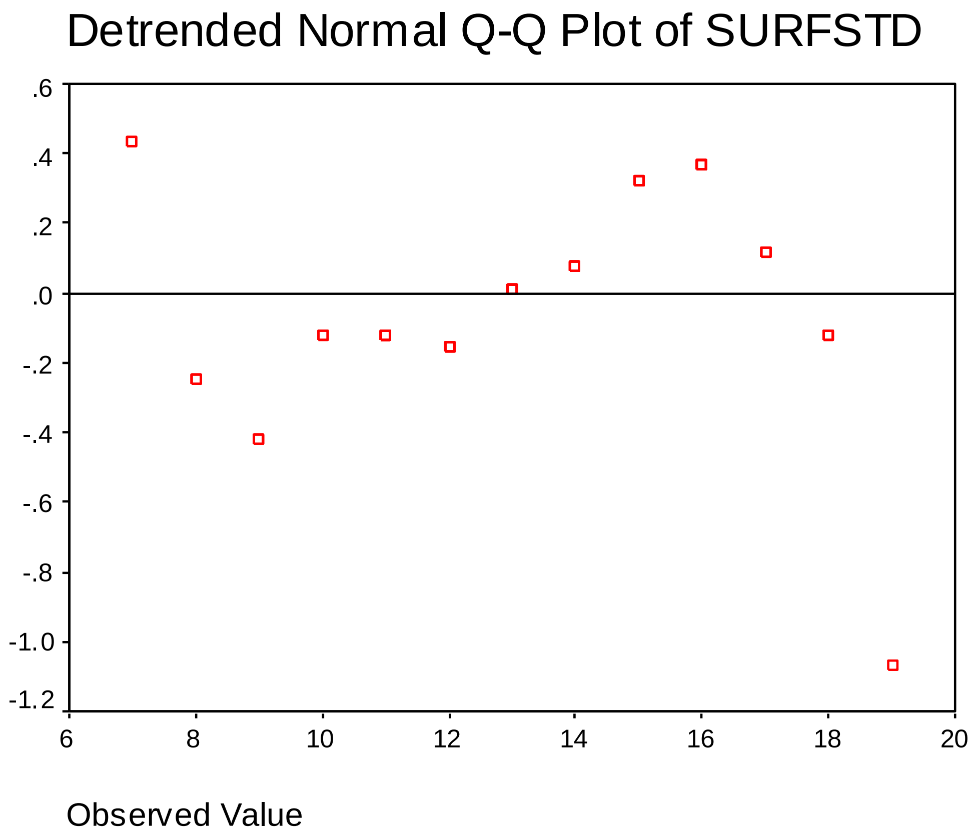


Detrended Normal Q-Q Plot of STRATSTD

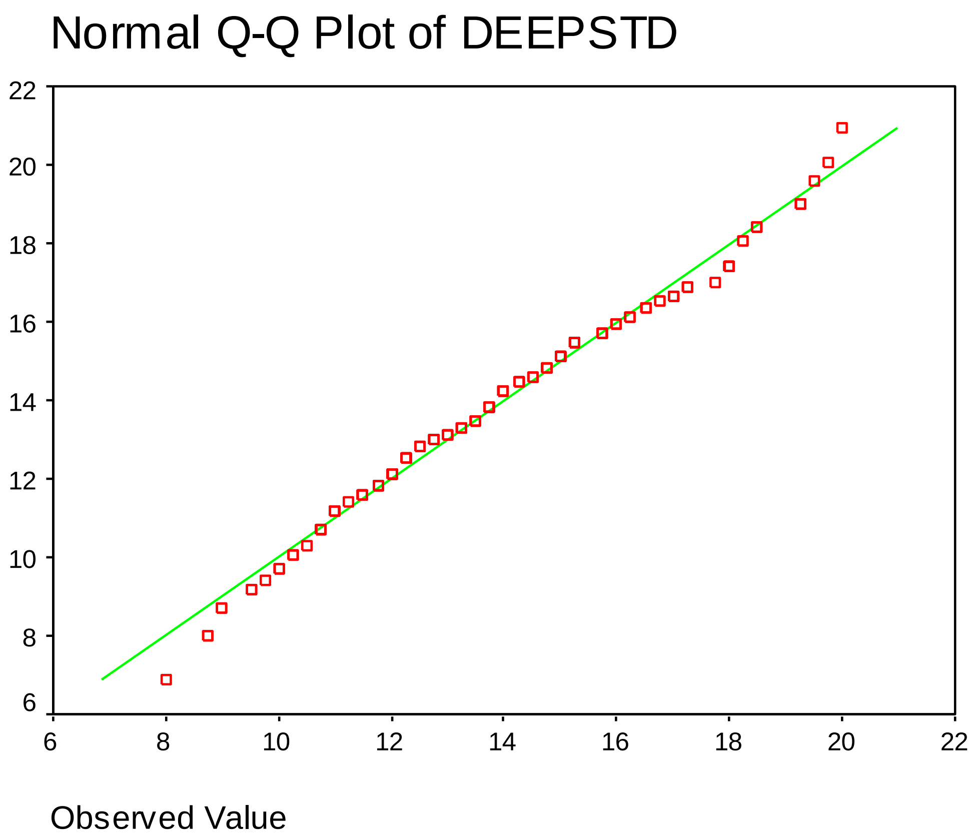


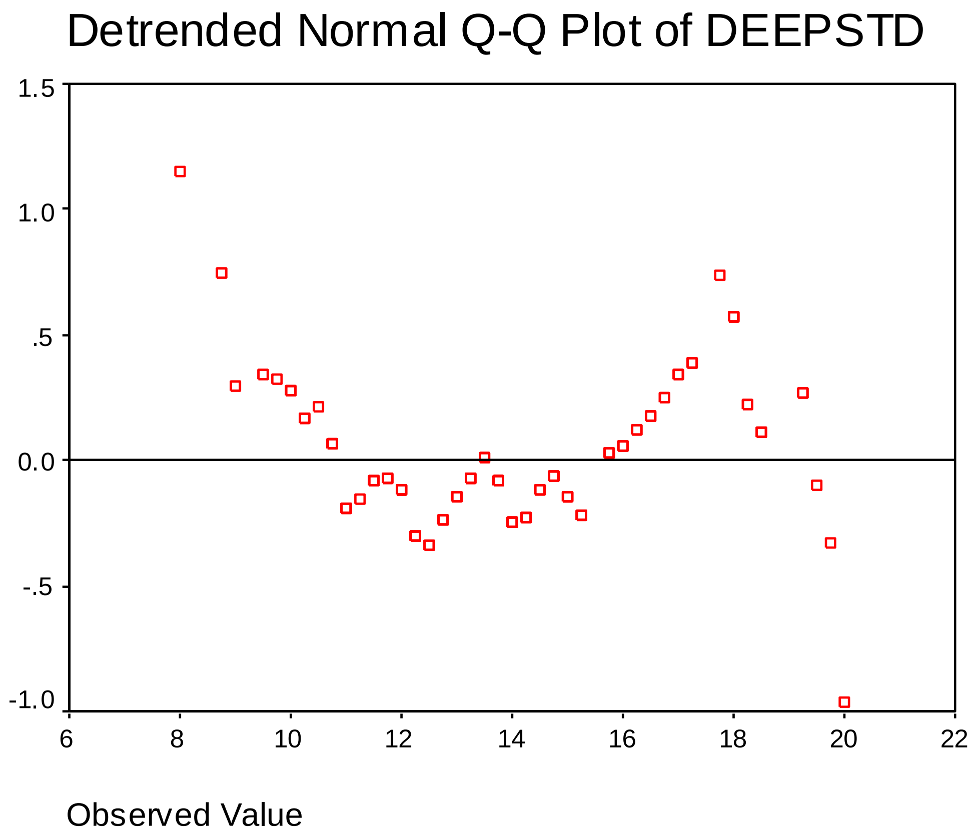
First year 04-05 – Surface Standard



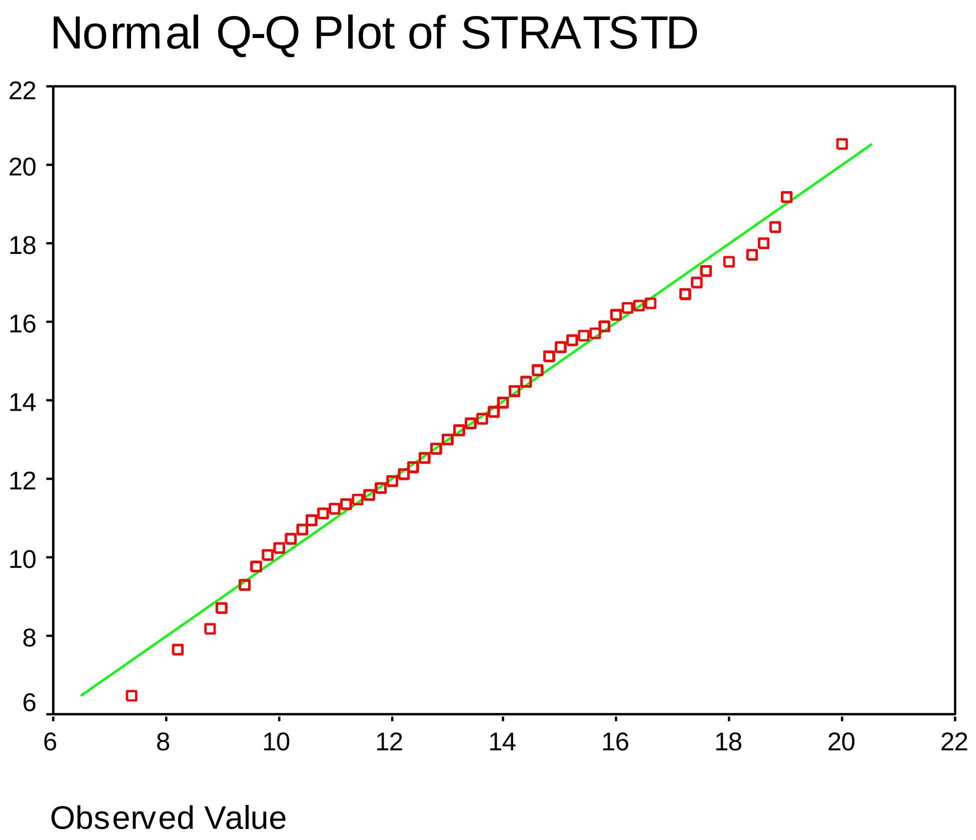


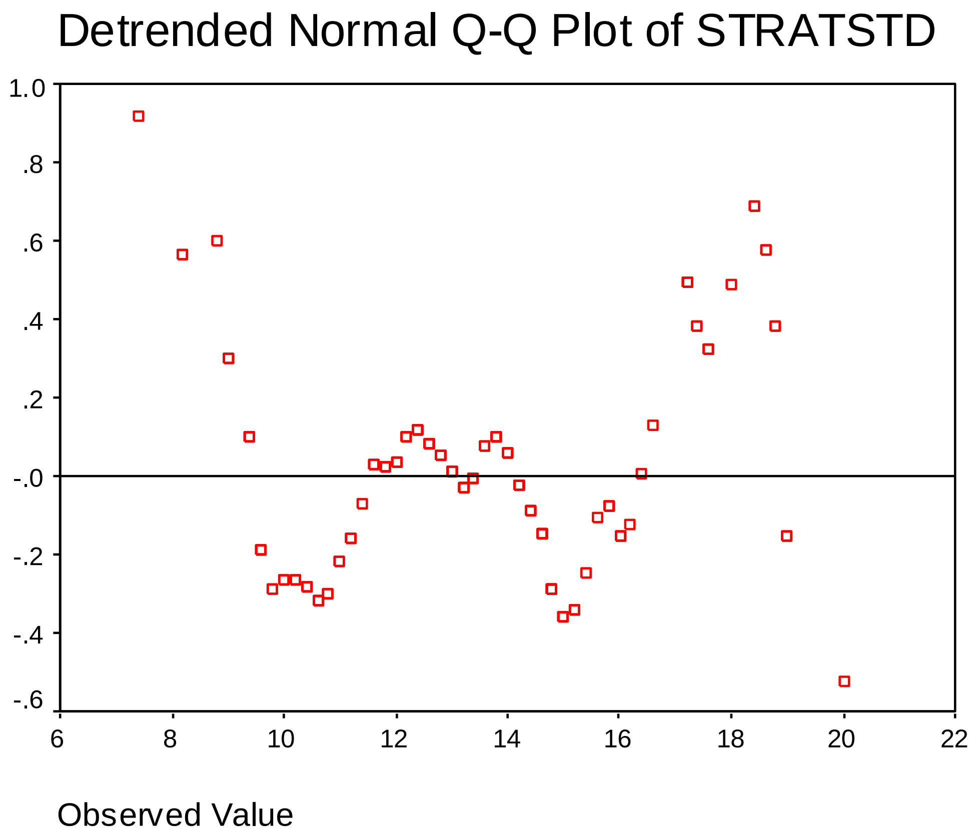
Leaving Certificate 2005 – Deep standard



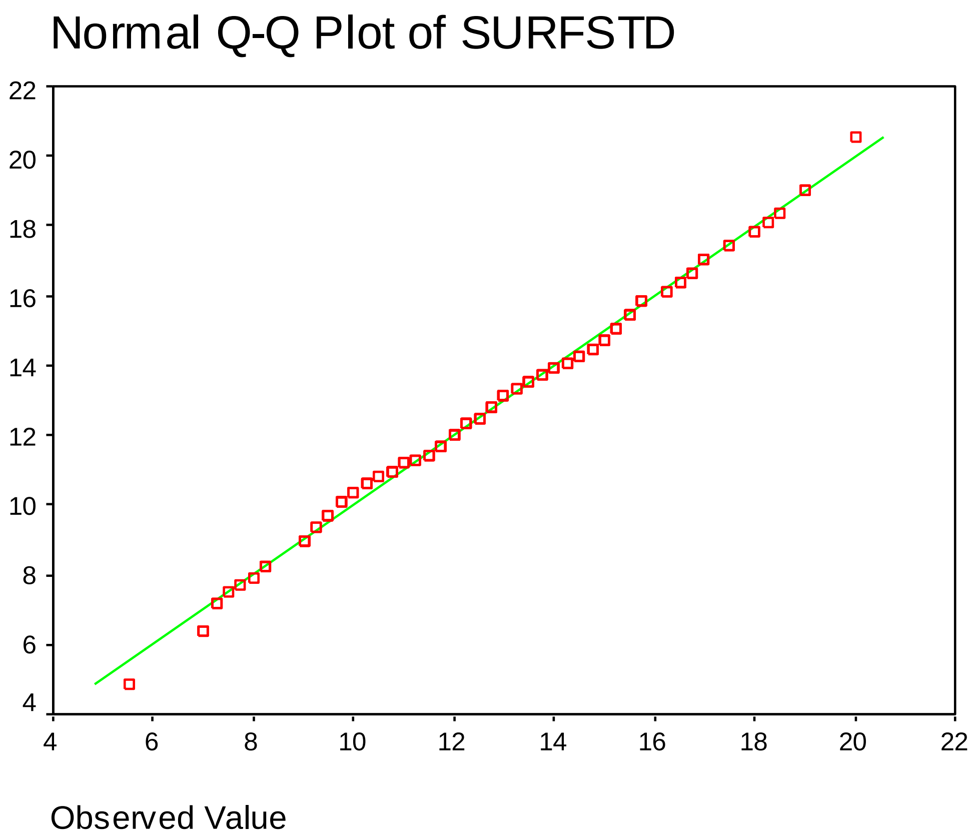


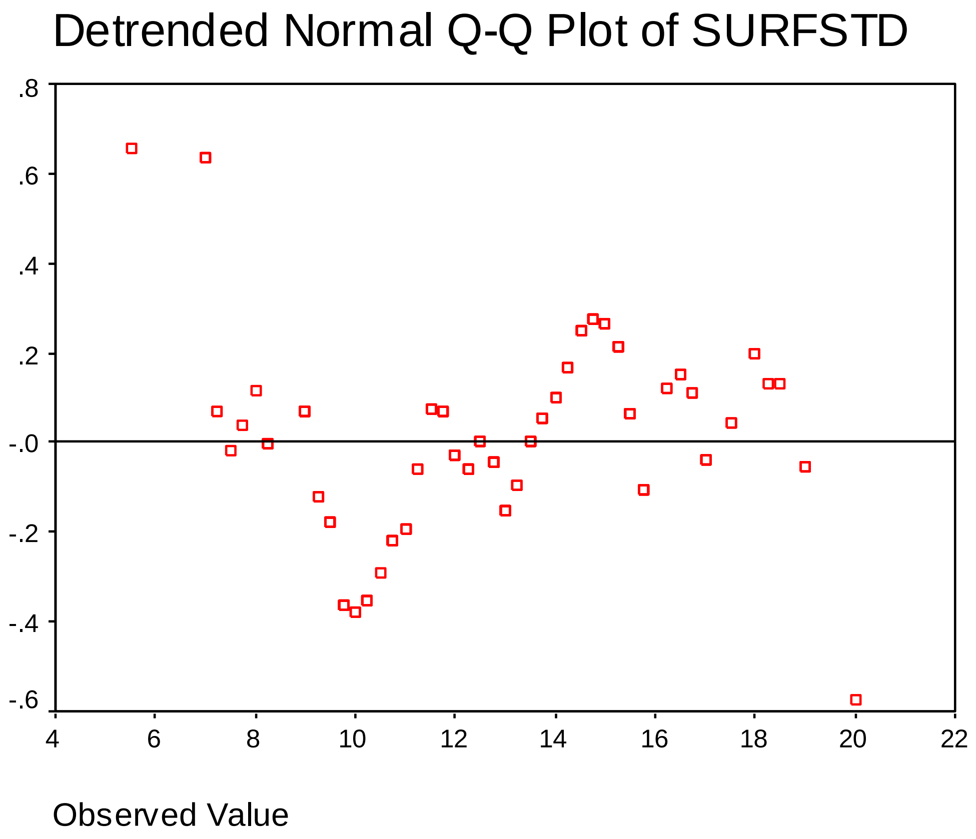
Leaving Certificate 2005 – Strategic standard





Leaving Certificate 2005 – Surface standard





APPENDIX 2.3: STATISTICAL TABLES

Distribution of t (two-tailed)

ν\2P	0.5	0.2	0.1	**0.05**	0.02	**0.01**	0.001
ν\%	50	80	90	**95**	98	**99**	99.9
1	1.000	3.078	6.314	**12.706**	31.821	**63.657**	636.619
2	0.816	1.886	2.920	**4.303**	6.965	**9.925**	31.599
3	0.765	1.638	2.353	**3.182**	4.541	**5.841**	12.924
4	0.741	1.533	2.132	**2.776**	3.747	**4.604**	8.610
5	0.727	1.476	2.015	**2.571**	3.365	**4.032**	6.869
6	0.718	1.440	1.943	**2.447**	3.143	**3.707**	5.959
7	0.711	1.415	1.895	**2.365**	2.998	**3.499**	5.408
8	0.706	1.397	1.860	**2.306**	2.896	**3.355**	5.041
9	0.703	1.383	1.833	**2.262**	2.821	**3.250**	4.781
10	0.700	1.372	1.812	**2.228**	2.764	**3.169**	4.587
11	0.697	1.363	1.796	**2.201**	2.718	**3.106**	4.437
12	0.695	1.356	1.782	**2.179**	2.681	**3.055**	4.318
13	0.694	1.350	1.771	**2.160**	2.650	**3.012**	4.221
14	0.692	1.345	1.761	**2.145**	2.624	**2.977**	4.141
15	0.691	1.341	1.753	**2.131**	2.602	**2.947**	4.073
16	0.690	1.337	1.746	**2.120**	2.583	**2.921**	4.015
17	0.689	1.333	1.740	**2.110**	2.567	**2.898**	3.965
18	0.688	1.330	1.734	**2.101**	2.552	**2.878**	3.922
19	0.688	1.328	1.729	**2.093**	2.539	**2.861**	3.883
20	0.687	1.325	1.725	**2.086**	2.528	**2.845**	3.850
21	0.686	1.323	1.721	**2.080**	2.518	**2.831**	3.819
22	0.686	1.321	1.717	**2.074**	2.508	**2.819**	3.792
23	0.685	1.319	1.714	**2.069**	2.500	**2.807**	3.768
24	0.685	1.318	1.711	**2.064**	2.492	**2.797**	3.745
25	0.684	1.316	1.708	**2.060**	2.485	**2.787**	3.725
26	0.684	1.315	1.706	**2.056**	2.479	**2.779**	3.707
27	0.684	1.314	1.703	**2.052**	2.473	**2.771**	3.690
28	0.683	1.313	1.701	**2.048**	2.467	**2.763**	3.674
29	0.683	1.311	1.699	**2.045**	2.462	**2.756**	3.659
30	0.683	1.310	1.697	**2.042**	2.457	**2.750**	3.646
40		1.300	1.684	**2.021**	2.420	**2.704**	3.551
60		1.300	1.671	**2.000**	2.390	**2.660**	3.460
120		1.290	1.658	**1.980**	2.360	**2.617**	3.373
∞	0.674	1.282	1.645	**1.960**	2.326	**2.576**	3.291

Pearson's correlation coefficient (r)

ν\2P	0.05	0.01
1	0.997	1.00
2	0.950	0.990
3	0.878	0.959
4	0.811	0.917
5	0.754	0.875
6	0.707	0.834
7	0.666	0.798
8	0.632	0.765
9	0.602	0.735
10	0.576	0.708
11	0.553	0.684
12	0.532	0.661
13	0.514	0.641
14	0.497	0.623
15	0.482	0.606
16	0.468	0.590
17	0.456	0.575
18	0.444	0.561
19	0.433	0.549
20	0.423	0.537
25	0.381	0.487
30	0.349	0.449
35	0.325	0.418
40	0.304	0.393
45	0.288	0.372
50	0.273	0.354
60	0.250	0.325
70	0.232	0.302
80	0.217	0.283
90	0.205	0.367
100	0.195	0.254

APPENDIX 2.4: APPROACHES AND STUDY SKILLS INVENTORY FOR STUDENTS (ORIGINIAL VERSION)

A S S I S T

Approaches and Study Skills Inventory for Students

(Short version)

This questionnaire has been designed to allow you to describe, in a systematic way, how you go about learning and studying. The technique involves asking you a substantial number of questions which overlap to some extent to provide good overall coverage of different ways of studying. Most of the items are based on comments made by other students. Please respond truthfully, so that your answers will **accurately** describe your **actual** ways of studying, and work your way through the questionnaire quite **quickly.**

Background information

Name or Identifier .... **Age** .... **years** **Sex** M / F

University or College .... **Faculty or School** ....

Course .... **Year of study** ....

A. What is learning?

When you think about the term 'LEARNING ', what does it mean to you?

*Consider each of these statements carefully, and rate them in terms of how close they are to **your own** way of thinking about it.*

		Very close	*Quite close*	*Not so close*	*Rather different*	*Very different*
a.	Making sure you remember things well.	5	4	3	2	1
b.	Developing as a person.	5	4	3	2	1
c.	Building up knowledge by acquiring facts and information.	5	4	3	2	1
d	Being able to use the information you've acquired.	5	4	3	2	1
e.	Understanding new material for yourself.	5	4	3	2	1
f.	Seeing things in a different and more meaningful way.	5	4	3	2	1

© 1997a Centre for Research on Learning and Instruction, University of Edinburgh

Please turn over

B. Approaches to studying

The next part of this questionnaire asks you to indicate your relative agreement or disagreement with comments about studying again made by other students. Please work through the comments, giving your **immediate** response. In deciding your answers, think in terms of **this particular lecture course.** It is also very important that you answer **all** the questions: check you have.

5 means agree (√) 4 = agree somewhat (√?) 2 = disagree somewhat (x?) 1 = disagree (x).

Try not to use 3 = unsure (??), unless you really have to, or if it cannot apply to you or your course.

	√	√?	??	x?	x
1. I manage to find conditions for studying which allow me to get on with my work easily.	5	4	3	2	1
2. When working on an assignment, I'm keeping in mind how best to impress the marker.	5	4	3	2	1
3. Often I find myself wondering whether the work I am doing here is really worthwhile.	5	4	3	2	1
4. I usually set out to understand for myself the meaning of what we have to learn.	5	4	3	2	1
5. I organise my study time carefully to make the best use of it.	5	4	3	2	1
6. I find I have to concentrate on just memorising a good deal of what I have to learn.	5	4	3	2	1
7. I go over the work I've done carefully to check the reasoning and that it makes sense.	5	4	3	2	1
8. Often I feel I'm drowning in the sheer amount of material we're having to cope with.	5	4	3	2	1
9. I look at the evidence carefully and try to reach my own conclusion about what I'm studying.	5	4	3	2	1
10. It's important for me to feel that I'm doing as well as I really can on the courses here.	5	4	3	2	1
11. I try to relate ideas I come across to those in other topics or other courses whenever possible.	5	4	3	2	1
12. I tend to read very little beyond what is actually required to pass.	5	4	3	2	1
13. Regularly I find myself thinking about ideas from lectures when I'm doing other things.	5	4	3	2	1
14. I think I'm quite systematic and organised when it comes to revising for exams.	5	4	3	2	1
15. I look carefully at tutors' comments on course work to see how to get higher marks next time.	5	4	3	2	1
16. There's not much of the work here that I find interesting or relevant.	5	4	3	2	1
17. When I read an article or book, I try to find out for myself exactly what the author means.	5	4	3	2	1
18. I'm pretty good at getting down to work whenever I need to.	5	4	3	2	1
19. Much of what I'm studying makes little sense: it's like unrelated bits and pieces.	5	4	3	2	1
20. I think about what I want to get out of this course to keep my studying well focused.	5	4	3	2	1
21. When I'm working on a new topic, I try to see in my own mind how all the ideas fit together.	5	4	3	2	1
22 I often worry about whether I'll ever be able to cope with the work properly.	5	4	3	2	1
23. Often I find myself questioning things I hear in lectures or read in books.	5	4	3	2	1
24. I feel that I'm getting on well, and this helps me put more effort into the work.	5	4	3	2	1
25. I concentrate on learning just those bits of information I have to know to pass.	5	4	3	2	1
26. I find that studying academic topics can be quite exciting at times.	5	4	3	2	1
27. I'm good at following up some of the reading suggested by lecturers or tutors.	5	4	3	2	1
28. I keep in mind who is going to mark an assignment and what they're likely to be looking for.	5	4	3	2	1
29. When I look back, I sometimes wonder why I ever decided to come here.	5	4	3	2	1
30. When I am reading, I stop from time to time to reflect on what I am trying to learn from it.	5	4	3	2	1

		√	√?	??	x?	x
31.	I work steadily through the term or semester, rather than leave it all until the last minute.	5	4	3	2	1
32.	I'm not really sure what's important in lectures so I try to get down all I can.	5	4	3	2	1
33.	Ideas in course books or articles often set me off on long chains of thought of my own.	5	4	3	2	1
34.	Before starting work on an assignment or exam question, I think first how best to tackle it.	5	4	3	2	1
35.	I often seem to panic if I get behind with my work.	5	4	3	2	1
36.	When I read, I examine the details carefully to see how they fit in with what's being said.	5	4	3	2	1
37.	I put a lot of effort into studying because I'm determined to do well.	5	4	3	2	1
38.	I gear my studying closely to just what seems to be required for assignments and exams.	5	4	3	2	1
39.	Some of the ideas I come across on the course I find really gripping.	5	4	3	2	1
40.	I usually plan out my week's work in advance, either on paper or in my head.	5	4	3	2	1
41.	I keep an eye open for what lecturers seem to think is important and concentrate on that.	5	4	3	2	1
42.	I'm not really interested in this course, but I have to take it for other reasons.	5	4	3	2	1
43.	Before tackling a problem or assignment, I first try to work out what lies behind it.	5	4	3	2	1
44.	I generally make good use of my time during the day.	5	4	3	2	1
45.	I often have trouble in making sense of the things I have to remember.	5	4	3	2	1
46.	I like to play around with ideas of my own even if they don't get me very far.	5	4	3	2	1
47.	When I finish a piece of work, I check it through to see if it really meets the requirements.	5	4	3	2	1
48	Often I lie awake worrying about work I think I won't be able to do.	5	4	3	2	1
49	It's important for me to be able to follow the argument, or to see the reason behind things.	5	4	3	2	1
50.	I don't find it at all difficult to motivate myself.	5	4	3	2	1
51.	I like to be told precisely what to do in essays or other assignments.	5	4	3	2	1
52.	I sometimes get 'hooked' on academic topics and feel I would like to keep on studying them.	5	4	3	2	1

C. Preferences for different types of course and teaching

5 means definitely like (√)   4 = like to some extent (√?)   2 = dislike to some extent (x?)   1 = definitely dislike (x).
Try not to use 3 = unsure (??), unless you really have to, or if it cannot apply to you or your course.

		√	√?	??	x?	x
a.	lecturers who tell us exactly what to put down in our notes.	5	4	3	2	1
b.	lecturers who encourage us to think for ourselves and show us how they themselves think	5	4	3	2	1
c.	exams which allow me to show that I've thought about the course material for myself.	5	4	3	2	1
d.	exams or tests which need only the material provided in our lecture notes.	5	4	3	2	1
e.	courses in which it's made very clear just which books we have to read.	5	4	3	2	1
f.	courses where we're encouraged to read around the subject a lot for ourselves.	5	4	3	2	1
g.	books which challenge you and provide explanations which go beyond the lectures.	5	4	3	2	1
h.	books which give you definite facts and information which can easily be learned.	5	4	3	2	1

Finally, how well do you think you have been doing in your assessed work overall, so far?

*Please rate yourself **objectively**, based on the grades you have been obtaining*

Very well		*Quite Well*		*About average*		*Not so well*		*Rather badly*
9	8	7	6	5	4	3	2	1

Thank you very much for spending time completing this questionnaire: it is much appreciated.

APPENDIX 2.5: APPROACHES AND STUDY SKILLS INVENTORY FOR STUDENTS (ADAPTED FOR LEAVING CERTIFICATE STUDENTS)

ASSIST

Approaches and Study Skills Inventory for Students

This questionnaire has been designed to allow you to describe, in a systematic way, how you go about learning and studying **Chemistry**. The technique involves asking you a substantial number of questions which overlap to some extent to provide good overall coverage of different ways of studying. Most of the items are based on comments made by other students. Please respond truthfully, so that your answers will **accurately** describe your **actual** ways of studying, and work your way through the questionnaire quite **quickly.**

Background information

Age _____   Sex M/F

School ____________________

Year of study _______

Other science subjects you are taking for Leaving Certificate:

Biology: ___________ Physics: ___________ Phys/Chem: ____________ Other: ____________

A. What is learning?

When you think about the term 'LEARNING " what does it mean to you?

Consider each of these statements carefully; and rate them in terms of how close they are to ***your own*** *way of thinking about it.*

	Very close	*Quite close*	*Not so close*	*Rather different*	*Very different*
a. Making sure you remember things well.	5	4	3	2	1
b. Developing as a person.	5	4	3	2	1
c. Building up knowledge by acquiring facts and information.	5	4	3	2	1
d. Being able to use the information you've acquired.	5	4	3	2	1
e. Understanding new material for yourself.	5	4	3	2	1
f. Seeing things in a different and more meaningful way.	5	4	3	2	1

B. Approaches to studying

The next part of this questionnaire asks you to indicate your relative agreement or disagreement with comments about studying again made by other students. Please work through the comments, giving your **immediate** response. In deciding your answers, think in terms of **the Leaving Certificate Chemistry course.** It is also very important that you answer **all** the questions: check you have.

5 *means agree* (√) 4 = *agree somewhat* (√?) 2 = *disagree somewhat* (*x?*) 1 = *disagree*(*x*).
Try <u>*not*</u> *to use* 3 = *unsure* (??), *unless you really have to, or if it cannot apply to you or your course.*

	√	√?	??	x?	x
1. I manage to find conditions for studying which allow me to get on with my own work easily.	5	4	3	2	1
2. When working on an assignment, I'm keeping in mind how best to impress the marker.	5	4	3	2	1
3. Often I find myself wondering whether the work I am doing here is really worthwhile.	5	4	3	2	1
4. I usually set out to understand for myself the meaning of what we have to learn.	5	4	3	2	1
5. I organise my study time carefully to make the best use of it.	5	4	3	2	1
6. I find I have to concentrate on just memorising a good deal of what I have to learn.	5	4	3	2	1
7. I go over the work I've done carefully to check the reasoning and that it makes sense.	5	4	3	2	1
8. Often I feel I'm drowning in the sheer amount of material we're having to cope with.	5	4	3	2	1
9. I look at the evidence carefully and try to reach my own conclusion about what I'm studying.	5	4	3	2	1
10. It's important for me to feel that I'm doing as well as I really can on my chosen subjects.	5	4	3	2	1
11. I try to relate ideas to those in other topics or other courses whenever possible.	5	4	3	2	1
12. I tend to read very little beyond what is actually required to pass.	5	4	3	2	1
13. Regularly I find myself thinking about ideas from Chemistry classes when I'm doing other things.	5	4	3	2	1
14. I think I'm quite systematic and organised when it comes to revising for exams.	5	4	3	2	1
15. I look carefully at teachers ' comments on course work to see how to get higher marks next time.	5	4	3	2	1
16. There's not much of the Chemistry course that I find interesting or relevant.	5	4	3	2	1
17. When I read an article or book, I try to find out for myself exactly what the author means.	5	4	3	2	1
18. I'm pretty good at getting down to work whenever I need to.	5	4	3	2	1
19. Much of what I'm studying makes little sense: it's like unrelated bits and pieces.	5	4	3	2	1
20. I think about what I want to get out of this course to keep my studying well focused.	5	4	3	2	1
21. When I'm working on a new topic, I try to see in my own mind how all the ideas fit together.	5	4	3	2	1
22 I often worry about whether I'll ever be able to cope with the work properly.	5	4	3	2	1
23. Often I find myself questioning things I hear in class or read in books.	5	4	3	2	1
24. I feel that I'm getting on well, and this helps me put more effort into the work.	5	4	3	2	1
25. I concentrate on learning just those bits of information I have to know to pass.	5	4	3	2	1
26. I find that studying Chemistry theory can be quite exciting at times.	5	4	3	2	1
27. I'm good at following up some of the extra reading suggested by teachers.	5	4	3	2	1
28. I keep in mind who is going to mark an assignment and what they're likely to be looking for.	5	4	3	2	1
29. When I look back, I sometimes wonder why I ever decided to choose this subject.	5	4	3	2	1
30. When I am reading, I stop from time to time to reflect on what I am trying to learn from it.	5	4	3	2	1
31. I work steadily through the term, rather than leave it all until the last minute.	5	4	3	2	1
32. I'm not really sure what's important in the Chemistry course so I make lengthy notes.	5	4	3	2	1

	√	√?	??	x?	x
33. Ideas in course books or articles often set me off on long chains of thought of my own.	5	4	3	2	1
34. Before starting work on an assignment or exam question, I think first how best to tackle it.	5	4	3	2	1
35. I often seem to panic if I get behind with my work.	5	4	3	2	1
36. When I read, I examine the details carefully to see how they fit in with what's being said.	5	4	3	2	1
37. I put a lot of effort into studying because I'm determined to do well.	5	4	3	2	1
38. I gear my studying closely to just what seems to be required for assignments and exams.	5	4	3	2	1
39. Some of the ideas I come across on the course I find really gripping.	5	4	3	2	1
40. I usually plan out my week's work in advance, either on paper or in my head.	5	4	3	2	1
41. I keep an eye open for what teachers seem to think is important and concentrate on that.	5	4	3	2	1
42. I'm not really interested in this course, but I have to take it for other reasons.	5	4	3	2	1
43. Before tackling a problem or assignment, I first try to work out what lies behind it.	5	4	3	2	1
44. I generally make good use of my time during the day.	5	4	3	2	1
45. I often have trouble in making sense of the things I have to remember.	5	4	3	2	1
46. I like to play around with ideas of my own even if they don't get me very far.	5	4	3	2	1
47. When I finish an assignment, I check it through to see if it really answers the question.	5	4	3	2	1
48. Often I lie awake worrying about work I think I won't be able to do.	5	4	3	2	1
49. It's important for me to be able to follow the argument, or to see the reason behind things.	5	4	3	2	1
50. I don't find it at all difficult to motivate myself.	5	4	3	2	1
51. I like to be told precisely what to do in essays or other assignments.	5	4	3	2	1
52. I sometimes get 'hooked' on academic topics and feel I would like to keep on studying them.	5	4	3	2	1

C. Preferences for different types of course and teaching

5 *means definitely like* (√) 4 = *like to some extent* (√?) 2 = *dislike to some extent* (*x?*) 1 = *definitely dislike* (*x*).

Try _not_ *to use* 3 = *unsure* (??), *unless you really have to, or if it cannot apply to you or your course.*

	√	√?	??	x?	x
a. Teachers who tell us exactly what to put down in our notes.	5	4	3	2	1
b. Teachers who encourage us to think for ourselves and show us how they themselves think	5	4	3	2	1
c. Exams which allow me to show that I've thought about the course material for myself.	5	4	3	2	1
d. Exams or tests which need only the material provided in our class notes.	5	4	3	2	1

Finally, what grade do you think you will achieve in Leaving Certificate Chemistry:

Honours: __________________ Ordinary: ____________________

Thank you very much for spending time completing this questionnaire: it is much appreciated.

APPENDIX 3.1: STUDY SKILLS SURVEY AND FREQUENCY OF LABORATORY WORK

Student Number:

In this survey, we are attempting to form the baseline for your studies at the University. Please complete the questions below, by circling the appropriate response of A – E for each question. In each question, you should rate your level of confidence in each skill as follows:

Ability Ratings
A: I can use this skill very well
B: I can use this skill well but some improvements could be made
C: I need to improve this skill
D: I need to put in considerable work to develop this skill
E: I have not had the opportunity to develop this skill

<u>QUESTION 1</u> **General Skills:**

My ability to…….

plan ahead and demonstrate good time management	A B C D E
plan for practical work and project work	A B C D E
make, organise, and store notes effectively	A B C D E
make the most of group work, and tutorials to support my understanding	A B C D E
make the most of practical work to support my understanding	A B C D E
analyse and evaluate experimental data	A B C D E
interpret laboratory measurements and observations	A B C D E
interpret chemical information (i.e. chemical formulas, equations etc.)	A B C D E
maintain good laboratory notes	A B C D E
provide written reports on time	A B C D E
plan and present an oral presentation	A B C D E
work in groups (i.e. contributing in labs)	A B C D E
assume a range of roles within a group	A B C D E
interact with people to obtain necessary information and assistance	A B C D E

QUESTION 2 **Scientific/Practical Skills:**

My ability to……..

maintain awareness of the specific hazards relating to chemicals	A B C D E
understand the principles behind experiments	A B C D E
understand the processes involved in experiments	A B C D E
measure and observe chemical events and changes	A B C D E
record experimental data coherently	A B C D E
understand errors	A B C D E
select appropriate techniques and procedures for experimental work	A B C D E

QUESTION 3 **Improving Learning:**

My ability to……..

use feedback to improve on future work	A B C D E
maintain an interest in general science issues	A B C D E
use the internet and other resources to gain information	A B C D E
use computers to prepare reports/presentations	A B C D E
apply acquired knowledge to the solution of chemistry problems	A B C D E

QUESTION 4 **Practical work:**

How often did you do lab work in school?
Chemistry labs

Once a week ☐ Once every two weeks ☐ Once a month ☐ Less often ☐

Physics labs

Once a week ☐ Once every two weeks ☐ Once a month ☐ Less often ☐

Biology labs

Once a week ☐ Once every two weeks ☐ Once a month ☐ Less often ☐

APPENDIX 3.2: SAMPLE LABORATORY PROCEDURE – MODULE CS151

Determination of the Sodium Hypochlorite Concentration in Household Bleach

Sodium thiosulphate reacts with a solution of iodine to yield iodide ions:

$$I_2 + 2Na_2S_2O_3 \longrightarrow 2NaI + Na_2S_4O_6$$

The half reactions are:

$$I_2 + 2e^- \longrightarrow 2I^- \quad \text{reduction}$$

$$2S_2O_3^{2-} \longrightarrow S_4O_6^{2-} + 2e^- \quad \text{oxidation}$$

Many oxidising agents e.g. cupric and ferric ions, can liberate iodine quantitatively from potassium iodide and so sodium thiosulphate can be used indirectly in many such estimations by titrating the iodine liberated.

Sodium thiosulphate is generally used in the form of its hydrate $Na_2S_2O_3.5H_2O$. All subsequent calculations are based on the hydrated salt.

Part 1: *Standardisation of sodium thiosulphate with potassium iodate.*

Standard potassium iodate (KIO_3) reacts with excess potassium iodide (KI) in acidified solution to liberate iodine (I_2) which is then titrated with sodium thiosulphate.

$$IO_3^- + 5I^- + 6H^+ \longrightarrow 3H_2O + 3I_2$$

$$3I_2 + 6S_2O_3^- \longrightarrow 6I^- + 3S_4O_6^-$$

From these equations it can be seen that one mole of potassium iodate reacts quantitatively with six moles of hydrated sodium thiosulphate.

$$KIO_3 = 3I_2 = 6Na_2S_2O_3.5H_2O$$

Procedure:

1. Pipette $10cm^3$ of the 0.005M potassium iodate solution into a conical flask and add about 0.1g of potassium iodate. Acidify the solution with about $3cm^3$ of dilute sulphuric acid.
2. Titrate the liberated iodine with sodium thiosulphate until you get a straw yellow colour.
3. Add 3-4 drops of starch solution and titrate further until the blue colour disappears.
4. Calculate the molarity of the sodium thiosulphate.

Part 2: *Analysis of Household Bleach.*

The active reagent in bleach is sodium hypochlorite, NaOCl. It is a good oxidising agent and a weak base. Thus, two methods may be used to determine NaOCl concentration – pH titration and redox titration.

The method you will employ is the redox (oxidation-reduction) method. Here the oxidising agent, sodium hypochlorite is reacted with known amounts of the reducing agent, iodide, I^-On reaction of sodium hypochlorite with potassium iodide in an acidified environment the iodide ion is oxidised to iodine I_2.

$$OCl^- + 2I^- + 2H^+ \longrightarrow I_2 + Cl^- + H_2O$$

The iodine produced in this reaction can be quantitatively determined by reacting it with a standard reducing agent like sodium thiosulphate pentahydrate $Na_2S_2O_3.5H_2O$.

$$I_2 + 2S_2O_3^- \longrightarrow 2I^- + S_4O_6^{2-}$$

Procedure:

1. Pipette $5cm^3$ of household bleach into a $100cm^3$ volumetric flask and make up to the mark with distilled water. Mix this solution **very well** by inversion.
2. Pipette $10cm^3$ of the diluted bleach sample into a $100cm^3$ conical flask. Add approximately 0.25g of potassium iodide, $3cm^3$ bench (1M) sulphuric acid and $5cm^3$ distilled water - a graduated cylinder will suffice for these volumes. Your reaction solution should be dark brown and cloudy.
3. Titrate this solution with the standardised thiosulphate solution from Part 1, until the solution turns pale brown in colour. Add 6-7 drops of starch solution and titrate dropwise until the colour changes from blue/black to white.

Calculations:

Calculate the molarity of hypochlorite present and from this calculate the %w/v (grams/$100cm^3$) NaOCl in the bleach brand. Note that for this part of the experiment the stoichiometric ratio is:

$$1\ OCl^- : 2\ S_2O_3$$

Compare your result with the true value from the container.

From the class results determine which bleach brand is the most effective on the basis of it's hypochlorite concentration.

APPENDIX 3.3: END OF SEMESTER 1 SURVEY FOR SE1 CLASS 2002-2003

End of Semester 1 survey for SE1 class

Please complete this survey regarding the Problem Based Learning chemistry labs, thanks.

What do you feel was the most beneficial aspect of the labs?

____

What do you think was the least beneficial aspect of the labs?

____

Describe 3 things you liked about the labs?

1. ______________________________________
2. ______________________________________
3. ______________________________________

Describe 3 things you disliked about the labs?

1. ______________________________________
2. ______________________________________
3. ______________________________________

Rate your experience of 1st year Chemistry labs in relation to each of the following:

Fun	1 - Unenjoyable	2	3	4	5 – Very enjoyable
Learning experience	1 – Learned nothing	2	3	4	5- Learned everything
Understanding	1 – Understood nothing	2	3	4	5 – Understood everything
Competency in techniques	1 - Incompetent	2	3	4	5 – Extremely competent
Calculations	1 – Haven't a clue	2	3	4	5 – Can do and get right
Tackling problems	1 – Haven't a clue	2	3	4	5 – Sensible, researched, approach

Please tick box for preference for - traditional approach ☐

- problem based approach ☐

What changes could be made regarding how they are administered?

____

____

____

Any other suggestions/comments:

____

____

____

APPENDIX 3.4: AN EXAMPLE OF A 'PROBLEM ANALYSIS'

Problem Analysis: Week 3- Apples and Oranges

Rate, on the scale of 1 to 5, the following statements

(1- disagree, 2 – disagree somewhat, 3 – unsure, 4 - agree somewhat, and 5 – agree)

1.	The overall problem solving experience was enjoyable	1 2 3 4 5
2.	The tasks as laid out were clear	1 2 3 4 5
3.	It was difficult to devise a strategy/plan an approach	1 2 3 4 5
4.	The experimental/practical aspects of the task were easy	1 2 3 4 5
5.	The problem was sufficiently challenging	1 2 3 4 5

Have you studied chemistry before? ☐ Yes ☐ No

Could this problem be improved? Any suggestions:

____

____

____

APPENDIX 3.5: PROBLEM-BASED LEARNING MODULE – COURSE MANUAL

Science Education Year 1

PBL Lab Manual

Science Education Chemistry Laboratory Year 1
Week 2: Introduction to Problem Solving and Moles, Molarity and Molecules

You have three tasks to complete, task 1 and 2 will be completed during the lab session.

Task 1: Problem solving – Straws and Marbles

Every group has 6 straws, 0.5m of sellotape, and a marble

The challenge: 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.

Can only use equipment provided (a scissors is also available)

Cannot use sticky tape to hold the straws to the table or the marble to the straws!!

Task 2: Moles, Molarity and Molecules

How big is a Mole?

M&M'S – MOLES AND MOLECULES

Salty solutions

Task 3: Calculations (to be completed before next lab)

Calculate the number of moles in:

5.57g of KBr

100g of $KClO_4$

Calculate the grams present in:

10.20 moles of H_2S

0.100 moles of KI

Consider the molecule $CuNH_4Cl_3$ as you answer the next set of questions

Name the elements present

What is the molar mass of this molecule?

What is the mass in grams of one molecule?

How many moles would be in 6.84g of this substance?

Part 2 : Moles, Molarity and Molecules

1. How Big Is a Mole ?

Objective: To measure and observe 1 mole of each of several substances

Concepts: Mole, Avagadro's number, molar mass

Introduction: The SI unit for the amount of something is mole, abbreviated mol.
A mole is defined as *the amount of substance that contains as many entities (atoms, molecules, or other particles) as there are atoms in 12 grams of pure carbon-12 atoms.* Therefore 1 mole = 6.02×10^{23} particles. The number 6.02×10^{23} is called Avagadro's number. Thus, a mole of apples is 6.02×10^{23} apples just as a dozen apples is 12 apples. A mole of cherries would also contain 6.02×10^{23} cherries, but would weigh much less and occupy much less volume than a mole of apples. In the same way, a mole of sulfer and a mole of carbon each contain 6.02×10^{23} atoms, but they have different masses and different volumes. The molar mass of an element (atomic weight) is equal to the number of grams of the element containing 6.02×10^{23} atoms. Thus one mole of sulfer has a mass of 32.066grams and one mole of carbon 12.011 grams. The molar mass of a molecular compound (molecular weight) is equal to the number of grams of the compound containing 6.02×10^{23} molecules.

In this experiment, you will weigh out a mole of several different substances and observe the differences in mass and volume.

Procedure :

- Use periodic table to determine the molar mass of each substance provided
- Weigh out a mole of each of the four substances provided; copper sulfate, sodium chloride, water, and iron, and estimate the volume of each.
- Fill in the details in the box below.
- Return all substances to their containers,a nd clean up any spills.

SUBSTANCE	Molar Mass (g/mol)	Mass of sample (grams)	Approx. Volume of sample (cm^3)
Copper sulfate penta-hydrate ($CuSO_4.5H_2O$)			
Sodium chloride (NaCl)			
Water (H_2O)			
Iron (Fe)			

Questions :

1. What is a mole

2. Order the molar masses of the substances from the lowest to the highest. Do the molar volumes volumes follow the same order? Why or why not?

3. Why is the mole useful in chemistry ?

4. Would it be practical to sell eggs by the mole? Explain

5. Why does a mole of water weigh less than a mole of copper sulfate ?

2. M&Ms – Moles and Molecules

Objective: To demonstrate the concept of ‘counting by weighing’ and relating it to the concept of a mole

Concepts: Counting by weighing, mole, experimental errors

Introduction: This experiment illustrates the concept of counting by weighing, using small candy that comes in a pack, such as M&Ms. The number of pieces of candy is determined by weighing all of the pieces together and then weighing one piece. Atoms and molecules are counted the same way. The weight of one atom is the atomic weight in atomic mass units (amu). If the atomic weight is in grams, then the atomic weight gives the mass of Avogadros number (or one mole) of atoms. Because of these relationships, by definition there are 6.02×10^{23} amu per gram.

Procedure:

- Weigh the unopened package and record the mass (A)
- Open the package and empty the candy into a cup.
- Weigh the empty package and record the mass (B)
- Calculate the net weight of the M&Ms (A-B = C)
- Weigh and record the mass of just one M&M (D)
- Calcuate the total number of M&Ms (C/D = E)
- Count the actual number of M&Ms (F)

Data: A. ___________g

B. ___________g

C. ___________g

D. ___________g D_2. ___________g

E. ___________ E_2 ___________

F. ___________

Questions :

1. Was there an error in your calculated count (E)? If your mass measurement of a single M&M was higher or lower by 0.02g, what difference in calculated count would result ?

2. Determine the average mass of one M&M from the mass of five or ten M&Ms (D_2). Recalculate E (E_2). Do you come closer? Why?

3. Give some reasons as to why the original calculated count (E) could have been in error.

4. What does a mole of M&Ms weigh?

5. What does a mole of Al weigh? (Given 1 Al atom weighs 26.98amu and 1amu = $1.66x10^{-24}$g)

6. What does a mole of H_2O weigh? (Given 1 H_2O molecule weighs 18.015 amu)

3. Salty Solutions

Objective: To demonstrate the concept of 'molar solutions', and to prepare solutions of several different molarities

Concepts: Mole, molar solutions, concentration (mol/L), volumetric flasks

Introduction: A molar solution is made when a certain number of moles of a substance is dissolved in a certain volume of water. Therefore by dissolving 1 mole of NaCl (sodium chloride) in 1L of water, you have made a 1molar (1 mol/L) solution. The units of molarity are then mol/L. However, what if you need less than 1 litre, perhaps half a litre is enough?
Using the formula below it is possible to determine the number of moles that is needed.
Molarity = mols/vol (L).
Molarity = 1M, vol = 0.5L; the only unknown is the number of moles required. Rearranging the equation above gives **moles = molarity x vol**, therefore the number of moles required is 0.5mol. Using the equation below it is then possible to work out the weight to dissolve in the half litre of water: **moles = mass/molar mass**

Molar solutions are made up accurately using volumetric flasks, which come in a range of volumes – 1L, 0.5L, 250cm^3, 100cm^3, 50cm^3, 10cm^3.
Procedure :
To make up a 1M solution in 1L volumetric flask

- Weigh out one mole of sodium chloride or sodium chloride
- Dissolve in a large beaker (250cm^3) of water
- When disolved, add to 1L volumetric flask
- Make up to the mark with water

To make up a 1M solution in a 0.5L volumetric flask

- Weigh out 0.5mol of sodium chloride or sodium chloride
- Dissolve in a large beaker (250cm^3) of water
- When disolved, add to 0.5 volumetric flask
- Make up to the mark with water

To make up a 2M solution in a 0.25L volumetric flask

- Weigh out 0.5mol of sodium chloride or sodium chloride
- Dissolve in a large beaker (100cm^3) of water
- When disolved, add to 0.25L volumetric flask
- Make up to the mark with water

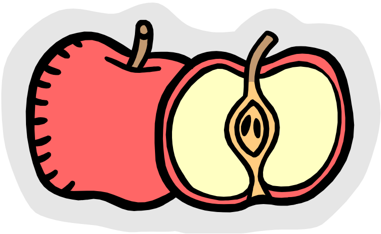
Questions:

1. Calculate the molarity of the following solutions:
   0.4g of NaOH in 100mls of water
   0.15g of NaCl in 250mls of water

2. How would you prepare the following:
   100mls of a 0.1M Na_2CO_3
   50mls of a 0.5M $CuSO_4$

Science Education Chemistry Laboratory Year 1

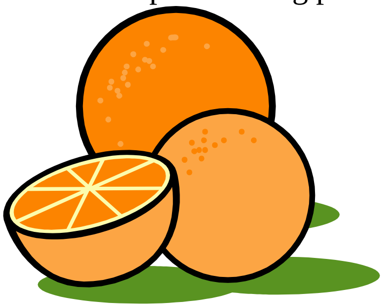
Week 3: Apples and Oranges



Everyone knows that orange juice is acidic as it contains citric acid. However, have you ever thought about apple juice?

Your task is to:

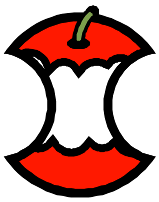
- Carry out a quick experiment to determine if the juice from oranges and apples is acidic or basic and to compare the results.
- Experimentally to determine the concentration of the acid in each case. (Remember that concentration is expressed as moles per litre or g per litre).



Notes on the lab:

- You will be working in groups of 3. Each group should meet to discuss the problem prior to the laboratory session and have a plan of the approach you are going to follow. Remember there are several ways of approaching a problem (remember the straws and marbles!).
- You will be given only 1 apple and 1 orange per group to do this problem so you must plan the whole exercise first.
- Various apparatus and equipment will be provided in the laboratory.

N.B.: Do not eat or drink in the laboratory!!



Science Education Chemistry Laboratory Year 1

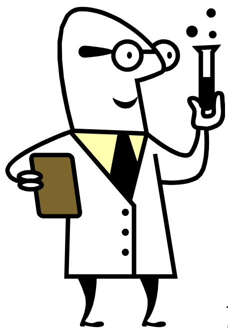
Week 4: Case of the Unlabeled Bottles

Introduction:

Professor Muddlebrain absentmindedly left some unlabeled bottles around. He knows what he put in them but can't remember what went in which bottle. Muddlebrain is now somewhere in the tropics gathering information on the local oranges, but before he left he asked you to solve the mystery of the unlabeled bottles. Below is a list of what the 5 bottles contain, and their approximate concentrations:

Acetic Acid	0.05M
Hydrochloric Acid	0.05M
Hydrochloric Acid	0.075M
Sodium Carbonate	0.01M
Sodium Hydroxide	0.025M

Muddlebrain asked you to do one other favour, that is to standardise the 0.05M acetic acid solution as he did not have time to do this prior to his departure.



Your task for is to:

- Identify the solution in each bottle using as little of each solution as possible
- Standardise the 0.05M acetic acid solution to accurately determine the molarity to 4 decimal places. (NaOH previously standardised).
- Justify experimentally your choice of indicator for the standardisation (hint: use 2 different indicators and a pH probe)

Notes on the lab:

- You will be working in pairs. Each pair should meet to discuss the problem prior to the laboratory session and have a plan of the approach you are going to follow. Remember there are several ways of approaching a problem (remember the straws and marbles!).
- You will be given only **20mls** of each solution to do this problem so you must plan the whole exercise first.
- Various apparatus and equipment will be provided in the laboratory including **well plates, pH probes and dataloggers, and various indicators**.

Week 5&6: State Laboratory vs. LabAnalysis

Supershopper, a large supermarket chain, is noted for its excellent home brand products and even better value. Recently the strength of the home brand vinegar has been questioned and the State Laboratory has been called in to further investigate by the Office of the Director of Consumer Affairs. However, *Supershopper* have also hired a private analytical chemistry company, LabAnalysis, to carry out an analysis on their behalf. The strength of vinegar is determined by its % ethanoic acid content. Several samples will be supplied for analysis.

Your task over the next two weeks is to:

- Carry out the analysis on behalf of either of the 2 parties:

  LabAnalysis or

  The State Laboratory
- Decide how best to do the analysis, then carry out the experiments, and lastly, report your findings both written and orally
- Be prepared to argue accuracy and precision of your techniques and results

Notes on the lab:

- ➢ You will be working in groups of 4, and the groups are assigned on the next page. Each group should meet to discuss the problem prior to the laboratory session and have a written plan of the approach you are going to follow.
- ➢ Various apparatus and equipment will be provided in the laboratory, including the normal scale titration apparatus, microscale titration apparatus, well-plates and pH probes and dataloggers.

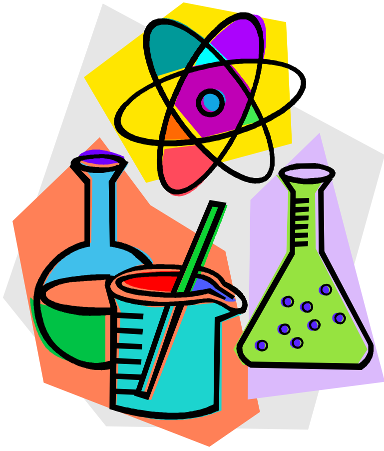
Science Education Chemistry Laboratory Year 1

Week 7: Assessment

Introduction:

This week involves a series of practical tasks, stations 1-12, and calcuations based on all aspects of chemistry you have met over the past 5 weeks in labs. The practical tasks will be done first, on a individual basis, and then the calculations will be done, also individually. The total time allowed for the task will be 2 hours. The assessment task will then be reviewed to allow for people to see if, and where they went wrong.

Your task is to:



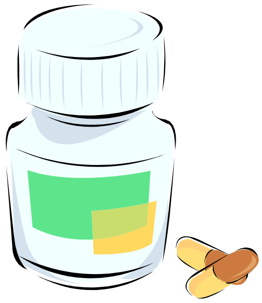
- Complete the practical tasks within 1 ¼ hours
- Complete the calculation tasks withiun ¾ hour

Notes on the lab:

- You will be working individually for both parts of the assessment.
- Each student will be assigned a station to start with, i,.e, station 3, and the student will then follow through each station in numerical order, 4, then 5 etc.
- This lab assessment will be equally weighted as per the rest of the labs.

Science Education Chemistry Laboratory Year 1

Week 8: Iron tablets and Anaemia



A 20-year old woman has been diagnosed with anaemia caused by iron deficiency. You have been asked you to carry out an analysis of a new brand of iron tablet, to determine the mg of iron in the iron tablet. Then to recommend the dosage required per day to maintain her iron at the recommended level.

As part of your pre-lab exercise, you must give some background information including:

- How much iron should people be getting?
- Why do we need iron?
- Which foods are good natural sources of iron?

The overall reaction in this experiment is a redox reaction i.e. a reduction-oxidation reaction in which one substance is oxidised and the other reduced. Up till now, we have only come across acid-base reactions. In your pre-lab, also discuss what oxidation and reduction are, and what are oxidising and reducing agents. Answer the following questions as well:

- What are the reaction equations for the two titrations in this experiment?
- Identify which substances are oxidised and which are reduced
- Which substances act as oxidising agents, and which act as reducing agents?
- What are the indicators in both titrations and the expected colour change?

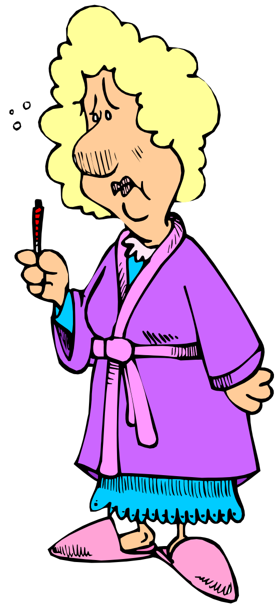
Finally, an attempt at the calculation of %w/w of iron in the tablet must be made in the pre-lab. The actual procedure is given for this experiment (see chemistry lab manual Pg 38-39)

Your task for is to:

- Carry out an analysis on an iron tablet, and determine the mg of iron in 1 iron tablet
- Calculate the % w/w of iron in 1 tablet
- Decide on the dosage of iron tablets required per day to maintain her iron at the recommended level

Science Education Chemistry Laboratory Year 1

Week 9: Old Wives Tale



Your grandmother has been suffering with indigestion and heartburn for the last few weeks. She's been taking baking soda to relieve the pain. However you are concerned that this is just an Old Wives Tale and the baking soda really has no relieving effect. Your job is to determine if baking soda is as effective as commercially available antacid tablets, e.g. Bisodol, as an antacid supplement.

In your **pre-lab write-up**, discuss/answer the following:

- What's the active ingredient in commercially available antacid supplements e.g. Rennie?
- What's the main ingredient in baking soda?
- What's the molecular weight of this ingredient?
- A typical reaction between an antacid (sodium hydrogen carbonate) and gastric juice (hydrochloric acid) yields carbon dioxide as one of the products.
    - Write the balanced equation for the overall reaction. What type of reaction is it?
    - Calculate the mass in grams of the carbon dioxide generated from 0.350g of sodium hydrogen carbonate and excess stomach acid.
- Finally, describe a procedure for this experiment in your pre-lab write–up and make an attempt at the calculations.

Hint: Start with the same weight of baking soda and antacid tablet

Your task is to:

- Carry out an experiment to accurately determine if baking soda is as effective as a commercially availably antacid tablet at relieving indigestion and heartburn.
- Calculate how much (grams) baking soda is required to neutralise the same amount of stomach acid as 1 antacid tablet.

Notes on the lab:

- You can work on the pre-lab in pairs, however, the experimental work, the write-up and calculations will be done individually, without assistance from others. In the lab, 1 person will carry out the analysis on the antacid tablet, and the other person will do the baking soda. Results will be exchanged at the end of the experimental work, and then individually, the write-up and calculations will be done.
- Time should allow you to get the write-up done during the class time, so come well prepared.

Science Education Chemistry Laboratory Year 1
Week 10: Paws Pet Food

As an analytical chemist you have been asked to do some work for Paws Pet Food. They need you to carry out analysis of their finished product. You have been specifically asked to look into their cat food, which contains sodium chloride and potassium chloride salts. You have to develop a method, which will allow for the analysis of these and determine the proportion of the two salts. A sample of the overall ingredients is shown below:

Lamb & Turkey - Gluten Free - 7.5 kilo
Ingredients:

Lamb 35%, Rice 25%, Turkey 13%, Lamb Fat 13%, Maize Protein Concentrate, Game, Fish, Heart, Beet Pulp, Calcium Carbonate, Sodium and Potassium Chlorides and Yucca Extract.

In your pre-lab write-up discuss the chemistry of your chosen method, **in your own words**. You must also give a brief outline of the procedure, and describe **in detail, and in your own words,** how you will carry out the calculations. Discuss what disposal considerations there might be and why.

Your task is to:

- Determine the weight of each salt, NaCl and KCl, in the sample.
- Calculate the % of each salt in the sample.

Note: You do not need to describe extraction of the potassium or sodium salts from the food!

Notes on the lab:

- You may find pages 44 and 45 of your lab manual useful.
- Time should allow you to get the write-up done during the class time, so once again come prepared!

Science Education Chemistry Laboratory Year 1
Week 11 & 12: Fish Kills at Fisher's Point

In Ireland the number of fish kills has been dropping since its peak in 1987. In part this may be due to increased awareness of the risks and penalties that result and there has also been an increased emphasis on safe storage of farmyard and industrial wastes. Proper treatment of sewage is also receiving greater emphasis. However although serious pollution incidents and the amount of severely polluted water has dropped the amount of moderately or slightly polluted river has increased. Pollution occurs when large quantities of compounds reach a watercourse from sources such as sewage, agricultural sources such as silage effluent or slurry, urban run-off and industrial effluents such as waste from food processing.

In this instance, the DCU Angling Association has noticed a dramatic decrease in fish catch. Also, they have noted that over the last 5 years the type of fish being caught has changed. Typically game fish, salmon and trout, was the dominant variety, however, coarse fish, perch, bream and carp, had become more abundant. However, even these are now low in number too. The table below shows the number of trout caught at an annual fishing competition at Fisher's Point, (over a period of 8 hours). Mr. Murphy, President of DCU Angling Association, provided this information.

	1/7/01	1/7/02	1/7/03	1/7/04
Trout	15	14	2	0

Mr Murphy has also suggested that the reason for the decrease in fish number is increased pollution, due to the industries or the farm upstream of Fisher's Point. The new housing development 'River View' and 'SuperShopper', a large supermarket, is also a concern, since it is bringing with it increased fishing permit costs, and a reduction in access to the river. They wrote to DCU River Authority, who promptly replied.

See the attached two letters, one from Mr Murphy and one from DCU River Authority.

Your task for the first week is to:

- Carry out a set of quick experiments to qualitatively determine possible pollutants in the water samples.
- Determine dissolved oxygen, hardness and acidity of the water samples.

Your task for the second week is to:

- Carry out any further tests required on your sample.
- From the point of view of either side make a written and oral recommendation about your findings, also discuss further analysis options and any suggestions to improve the overall situation

DCU ANGLING ASSOCIATION VS. DCU RIVER AUTHORITY

Notes on the lab:

- You will be working in groups of ¾. Each group should meet to discuss the problem prior to the laboratory session and have a plan of the approach you are going to follow.
- You will be provided with the experimental procedures, but will have to work out the calculations yourselves. Also, you will be provided with the maximum levels for various ions in river water.
- Each group will be given at least 1 water sample, which may have been filtered to get rid of any suspended solids.
- Hand-outs will be provided. Each member of the group should research a particular topic/possible pollutant, and have the resource summarised, with relevant points noted.

DCU ANGLING ASSOCIATION

DCU Angling Association
12, The Sea View,
Redbrick
Dublin

DCU River Authority
1-2 The Rise
Redbrick
Dublin

12/7/04

Dear Sir/Madam,
I wish to bring to your attention that over the last few years there has been a reduction in the number of fish, particularly trout, caught in the competition that is held at Fisher's Point on the 1st of July every year. Please find the attached note with the number of trout caught during the last 4 competitions. This has caused a great deal of concern among the members of DCU Angling Association. I hope you will remedy this as soon as possible.

The increased industrialisation and urbanisation around the river is also a major concern as it is doubling the cost of fishing permits and the reduction of access.

Yours faithfully,

Joseph Murphy
Joseph Murphy
President of DCU Angling Association

DCU River Authority

DCU River Authority
1-2 The Rise
Redbrick
Dublin

DCU Angling Authority
12, The Sea View
Redbrick
Dublin

Re: Falling Fish Number

15/7/04

Dear Mr. Murphy,
We are currently looking into your complaint. Investigators shall be sent to take samples and look into the possible cause in the perceived drop in fish numbers. From this information, we will determine whether there is a real problem, and if further investigation is required.

As for the second part of your letter, you need to bring this up with the local council and the landowners. If you have any further questions do not hesitate to contact me.

Yours sincerely,

<u>Michael Evian</u>
Michael Evian, PhD
Chief Chemist

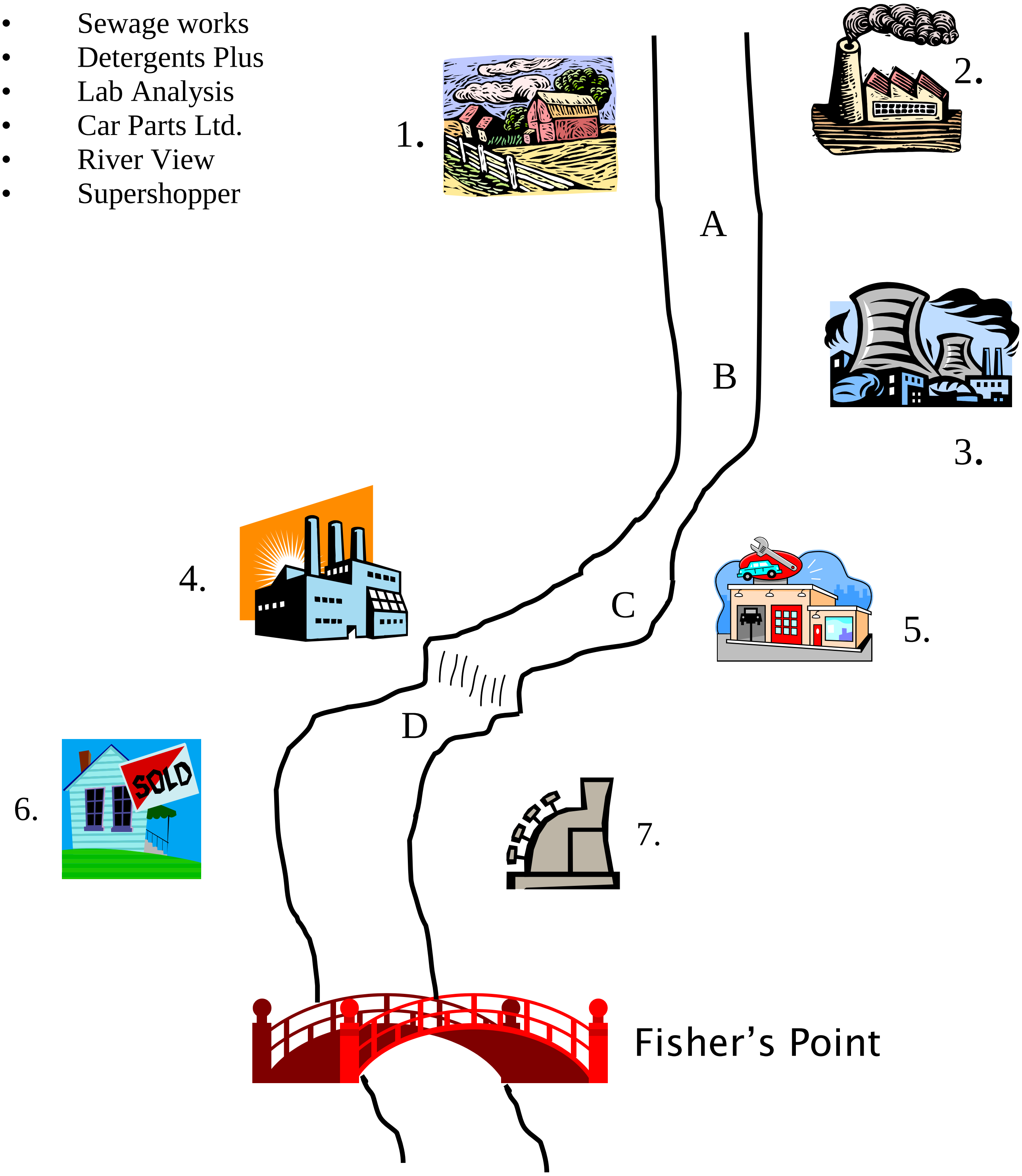
Places on the Map:

1. McDonalds is a family run arable farm, growing many different crops. They also have a large number of livestock. They directly supply many of the local shops and restaurants.
2. The small sewage works is in high demand and often exceeds consents to discharge.
3. ‘Detergents Plus’ is a manufacturer of detergents, it specialises in industrial strength cleaning products.
4. ‘LabAnalysis’ is an analytical lab, specialising in the analysis of pharmaceutical products such as iron tablets, as well as product testing for the local shops and supermarkets.
5. ‘Car Parts Ltd.’ is a manufacturing plant, which has been in the location for 10 years. Included in their product range are alloys, batteries, and spark plugs. They have recently scaled up production due both to increased demand, and a promotion, which they are running as part of their 10^{th} anniversary celebrations.
6. ‘River View’ is a new housing development, which has helped to regenerate the town. However, with this advantage, traffic is a now a major issue, with congestion on a lot of the roads at peak times.
7. ‘Supershopper’ is a low price/high quality supermarket chain, which has recently opened a store in Redbrick

Sample points: A, B, C and D

Map of Redbrick
(Not to Scale)

- McDonald’s Farm
- Sewage works
- Detergents Plus
- Lab Analysis
- Car Parts Ltd.
- River View
- Supershopper



USEFUL REFERENCES SEMESTER 1

Week 3: Apples and Oranges
Queen's University, Canada, Science Education Resource Page, Chemistry, Solutions and Solubility, Concept development, Acids and Bases
http://educ.queensu.ca/~science/main/concept/chem/c10/c10cdmo3.htm
Shodor Education Foundation Inc., UNC-Chapel Hill Chemistry Fundamentals Program, Department of Chemistry (NB : pH and Acid-Base titrations)
http://www.shodor.org/unchem/basic/ab/

Week 4: Case of the Unlabeled Bottles
Queen's University, Canada, Science Education Resource Page, Chemistry, Solutions and Solubility, Lab/Activities, Standardization of a Sodium Hydroxide Solution by Titration
http://educ.queensu.ca/~science/main/concept/chem/c10/c10lamo5.htm
Queen's University, Canada, Science Education Resource Page, Chemistry, Solutions and Solubility, Concept development, Titrations
http://educ.queensu.ca/~science/main/concept/chem/c10/c10cdmo4.htm
Yue-Ling Wang's Titration Simulator (First activity)
http://www.wfu.edu/%7Eylwong/chem/titrationsimulator/index.html

Week 5 & 6 : StateLab vs LabAnalysis
Polk Community College, Chemistry, Chem 1045, General Chemistry 1, Percent Acetic Acid in Vinegar
http://www.polk.edu/INSTRUCT/Mash/robert/CHEMISTRY/CHM1045/NONCOMPUTERLABS/12-VINEGAR.pdf
Louisiana Tech University, Chemistry, Chem122, Acid-Base Titration Techniques, Vinegar Analysis
http://www.chem.latech.edu/~deddy/chem122m/L04U00Vinegar122.htm
D. W. Brooks Site, Microscale, Titration of Vinegar
http://dwb.unl.edu/Chemistry/MicroScale/MScale19.html

Week 8 : Iron tablets and Anaemia
Vhi Health e, Irish Health Focus, Iron deficiency anaemia
http://www.vhihealthe.com/hfiles/hf-135.html
Food Safety Authority of Ireland, Chapter 3
http://193.120.54.7/publications/reports/recommended_dietary_allowances_ireland_1999.pdf
World Health Organisation, Micronutrient deficiencies
http://www.who.int/nut/ida.htm
Chemistry, *The Molecular Nature of Matter and Change, Silberberg, M.S.*

Chapter 4, The Major Classes of Chemical Reactions, Pg 148 – 156
General Chemistry, Ebbing, D.D.

Week 9 : Old Wives Tale
The Delaware Science Van Project, Science Education in Motion
http://www.k12.de.us/science/scivan/ANTACID.doc

College of Science and Technology, Texas A&M University, General Chemistry II, Titration of Antacids
http://www.sci.tamucc.edu/pals/morvant/genchem2/antacid.html
Southeast Missouri State University, CH271 Quantitative Analysis, Lab Experiments, Titration of Antacids (Last updated Summer 2002, P.W. Crawford))
http://cstl-cst.semo.edu/crawford/ch271-01/Labs/antacid%20titration.DOC
Louisiana Tech University, Chemistry, Danny Eddy, General Chemistry Laboratory 104, Chemistry 104: Analysis of Commercial Antacid Tablets
http://www.chem.latech.edu/~deddy/chem104/104Antacid.htm

Week 10 : Paws Pet Food
Re:act Nuffield Advanced Chemistry, Inorganic reactions
http://www.chemistry-react.org/go/default/Faq/Faq_11541.html
Marist College, Academics, Titration of Chloride (Mohr Method)
http://www.academic.marist.edu/~jfjp/chem351E3.htm
Ricca Chemical Company, Potassium Chromate
http://www.riccachemical.com/getTechTip.aspx?id=21

Week 11 & 12 : Fish Kills at Fishers Point
Qualitative Analysis
Introducation to Qualitative Analysis
http://chemistry.about.com/library/weekly/aa091001a.htm
ChemLab – Chemistry 3/5 Analysis of cations
http://www.dartmouth.edu/~chemlab/chem3-5/qual_cat/full_text/chemistry.html
ChemLab – Chemistry 3/5 Analysis of Anions
http://www.dartmouth.edu/~chemlab/chem3-5/qual_an/overview/procedure.html

Hardness
BASI: General information on Hardness
http://bcn.boulder.co.us/basin/data/NUTRIENTS/info/Hard.html
Determination of Water Hardnes ny Complexometric Titration Class Notes
http://homepages.ius.edu/DSPURLOC/c121/week13.htm

Dissolved Oxygen
Annis Water Resources Institute, Dissolved Oxygen
http://www.gvsu.edu/wri/education/manual/oxygen.htm
Florida International University, Dissolved Oxygen
http://www.fiu.edu/~jceli001/Dissolved%20Oxygen%20Titration%20Methods.pdf

General Environmental Information

www.enfo.ie
www.epa.ie
http://star.eea.eu.int/default.asp

Science Education Chemistry Laboratory Year 1

Semester2: Investigation of gas behavior

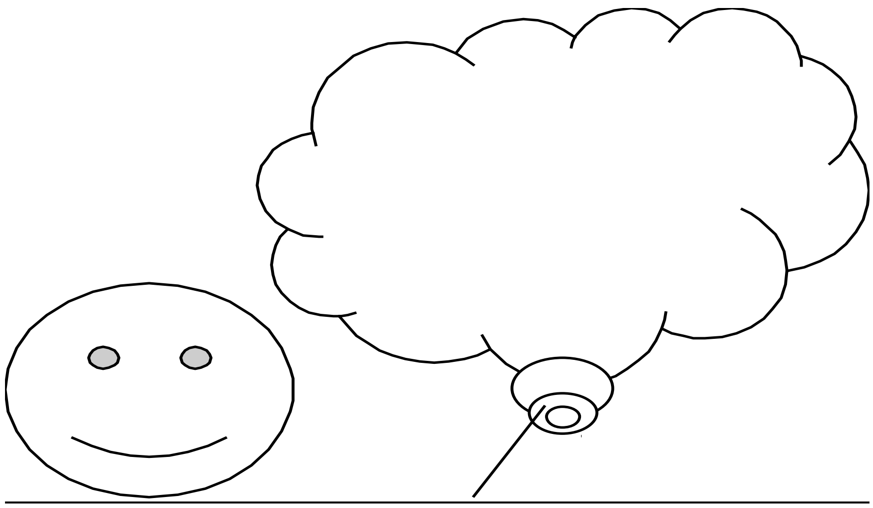
Your lab-task is to:

- Investigate the relationships between pressure, temperature and volume of a gas.

Using air as the gas, and assuming that it behaves as an ideal gas, generate a set of experimental data to show the required relationships. If time allows, devise an experiment to determine the value for R (universal gas constant).

Your write-up should include:

Aim
Diagram of apparatus used (may have three figs)
Brief procedure(s)
Tables of results (three sets)
Graphs showing relationships
Discussion of results – does your data support the gas laws



Science Education Chemistry Laboratory Year 1

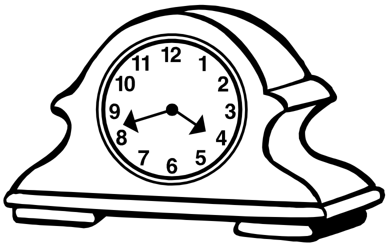
Semester2: Clock reactions

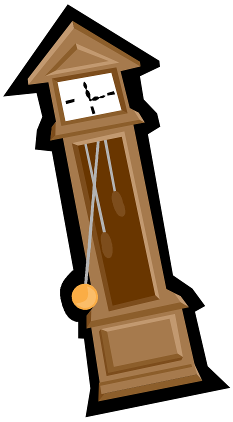
Your lab-task is to:

- Make a solution change colour after a specific time!

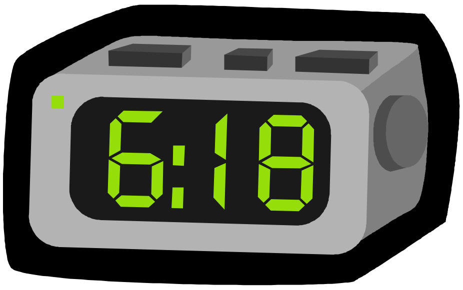
Each pair will have 2 times as listed below:

After 'x' seconds		**Pair**
Add after 7secs	Add after 7 secs	
7	82	1
21	80	2
23	80	3
25	75	4
27	68	5
29	64	6





The colour changes will be in tune with the song - 'Hate to say I told you so'.



How does it work?

Varying concentrations of sodium thiosulfate are reacted with potassium iodide, starch and a hydrogen peroxide/sulphuric acid mix. Depending on the concentration of thiosulfate, it will take a certain amount of time for the blue starch colour to appear.

What about the chemistry?

This is what I want you to tell me in your write-up, but here is a clue -

'One of the solutions is an oxidising agent, and the other is a reducing agent'.

Try the following as guidelines:

Beaker	**$Na_2S_2O_3$ Sol^n A (cm^3)**	**KI Sol^n B (cm^3)**	**Starch Sol^n C(cm^3)**	**Distilled water (cm^3)**	**H_2O_2/H_2SO_4 Sol^n D (cm^3)**
1	**1**	**2**	**1**	**16**	**20**
2	**2**	**2**	**1**	**15**	**20**
3	**3**	**2**	**1**	**14**	**20**
4	**4**	**2**	**1**	**13**	**20**
5	**5**	**2**	**1**	**12**	**20**

Add each solution in the sequence as in the table above, and when you have added in the water give the solution a stir. Then add the H_2O_2/H_2SO_4 mix and start the clock….see how long it takes for the colour to change.

Well-plates, beakers and stop-clocks are available.

Your write-up should include:

Aim
Brief procedure
Tables of results (with appropriate graph(s))
Discussion of results - how you got the desired time
- the chemistry of the reaction
Errors
Conclusion…did you get your timing spot on???

Good luck and have fun!!!

Science Education Chemistry Laboratory Year 1

Semester2: Combating Fish Disease

Mr T Sharkey is an avid fish collector and has a sizeable aquarium, where he has many different fish species. Recently, it was noted that some of the koi fish were not eating and were generally lethargic. On closer examination of one fish, Ular, there was a mass of *Saprolegnia* fungus on one side, a small area of fungus surrounded by inflammation on the other side and the tail fin was eroded. A skin scrape showed a higher than normal number of skin flukes *(Gyrodactylus).* Mr Sharkey decided to begin a treatment plan of *Malachite green* and that there was no need for any anti-bacterial treatment. The koi fish were then isolated in a separate treatment tank.

Malachite green is one of the main cornerstones of fish disease treatments having been used for many years against a range of parasites. It can be used as anti-parasite treatment against *Gyrodactylus* (skin flukes), *Dactylogyrus* (gill flukes), *Ichthyobodo (Costia), Trichodina , Chilodonella* and *Ichthyophthirius* (white spot). Malachite green also has powerful anti-fungal properties and is used against *Saprolegnia* (fungus) either when present on fish or to as a prophylactic treatment to protect fish-eggs from infection.

However, Mr Sharkey grew concerned when the fish seemed to be making no progress towards recovery. He noticed that the malachite green solution in the treatment tank had now become colourless, and he feared that the malachite green was no longer effective.

He has now called a local chemical company (SE.co) to examine why the colour has gone from the water in the tank and the effect that this has on fish recovery. Dr Clever (the MD of the company) asked what the tank had been used for before the fish were put into it. Mr Sharkey remembered that he had recently used the tank for storage of alkaline materials. He also noted that the tank had been sitting in the sunlight, and the water temperature had peaked at 30°C one day.

Can you help before Mr Sharkey calls the ‘Fish Helpline’ 1800 GO FISH, to gain more information on the treatment of fish diseases.

Your pre-lab task is to:

- Investigate the use of Malachite green in the treatment of fish diseases[1].
- Decide and show your plan of approach to tackle the problem.
- Use the books and website referenced below [2,3,4] to resource information on rates of reactions, order of chemical reactions, and integrated rate equations.

Your-lab-task is to:

- Experimentally determine the rate of reaction of malachite green with alkalie (procedure will be provided).
- To complete the equation to describe the rate of the reaction, you will have to determine the overall order of reaction, and the rate constant.

Your write-up should include:

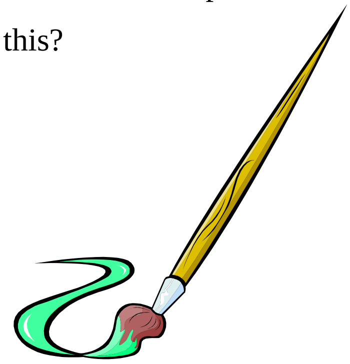
Aim (including problem summary)
Brief experimental procedure
Results with tabulated data
Graphs of the first order and second order plot
Experiment conclusion – Order of reaction
Rate constant
Problem conclusion – Why were the fish not recovering???

Science Education Chemistry Laboratory Year 1

Semester2: 'Like dissolves like'

Have you ever used white spirits to remove paint from brushes? Or maybe you've used soapy water to get rid of paint from brushes. Why is it that in some cases white spirits is used and in others water?

Well, paints fall into 2 general categories – water based and oil based. Water based paint will require only a soapy water solution to remove it; whereas oil based paint will require a solvent, such as methylated spirits. Can you explain this?



Let's look at other examples:

Alcohol is miscible with water, but oil is not.

Nail polish is removed by acetone but not with water

Your pre-lab task is to:

- Discuss the above situations, and suggest an explanation.
- Do you think it is possible that some materials could be soluble to different degrees in both aqueous and organic solvents? Suggest an experiment to test if HCl is even partially soluble in acetone as well as water. Remember, you are looking for even partial solubility.

Your lab-task is to:

- **Experimentally** determine the solubility of succinic acid in water and diethyl ether (procedure will be provided).
- From your results to determine the value of the distribution ratio, K_D of succinic acid between water and diethyl ether.
- Note: K_D = [succinic acid]$_{org}$/[succinic acid]$_{aq}$
- **Experimentally** investigate if the quantity of succinic acid used affects the value of K_D.

Your write-up should include:

Aim
Brief experimental procedure
Results with tabulated data
Calculation of K_D (x2)
Experiment **conclusions**
Calculation (from page 2)

Calculation:

$10cm^3$ of an aqueous solution contains 10g of an organic nitrophenol.

Calculate the weight of nitrophenol extracted by $100cm^3$ of diethyl ether used:

a. in one single extraction

b. in four separate extractions using $25cm^3$ of diethyl ether for each extraction.

The partition coefficient of the nitrophenol between ether and water is 3:1 at room temperature.
Comment on the relative efficiencies of extraction by routes a and b.

Science Education Chemistry Laboratory Year 1

Semester2: Purification and purity determination

Dr. Grey, an elderly doctor living in a remote town, has found a substantial amount of acetanilide in his drugs store and is intending on administering it to patients who are suffering from everyday pain and discomfort. Acetanilide has analgesic and fever-reducing properties; it is in the same class of drugs as acetaminophen (commonly known as paracetamol). However, he seems to remember there was some trouble in the past with using this drug…

He calls the local pharmaceutical company to consult on this matter. They agree to test the acetanilide for purity and to research the history of the drug, with the aim of approving or rejecting it for use as a painkiller.

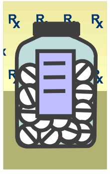
Your pre-lab task is to:

- Discuss the use of acetanilide as a painkiller and it's appropriateness for use today for medicinal purposes.
- Determine the chemical formula and structure of acetanilide, and p-dibromobenzene.

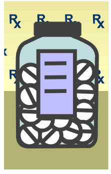
Your lab task is the:

- Recrystallisation of acetanilide from a single solvent
- Recrystallisation of p-dibromobenzene from mixed solvent

Note: You will be doing this lab on your own, so come prepared!



Science Education Chemistry Laboratory Year 1
Semester 2: ASPIRIN (Runs over 3 weeks)



LAB-EXPRESS is a new pharmaceutical company in Dublin. Their first product to be manufactured is Aspirin. However, the product has yet to go through the intensive quality control (QC) procedures. Their first consideration is whether or not their preparation procedure is good enough. Secondly, since it is of critical importance to know the exact content of the active component in the drug, to determine which of two qualitative methods is best.

Your job, as part of the QC team, is to determine if (a) the preparation procedure is effective and efficient, and (b) which of the two analysis methods, back titration and UV analysis, is more suitable.

Your pre-lab task for week 1 is to:

- Discuss, in your own-words, the history of aspirin (acetylsalicylic acid)
- Describe, in your own-words, Thin-Layer-Chromatography and how it can used to determine the purity of an aspirin sample

Your lab-task for week 1 is to:

- Experimentally prepare aspirin on a microscale
- Analyse your prepared aspirin and a commercially available aspirin tablet by TLC, and compare results
- Use the melting point to determine purity of both prepared and commercial samples

Your pre-lab task for week 2/3 is to:

- Summarise and explain the Beer-Lambert law
- Describe what UV detection is and how it can used to determine the quantity of aspirin in a sample

Your lab-task for week 2/3 is to:

- Prepare an appropriate calibration curve by making a series of standards
- Analyse your previously prepared aspirin and a commercially available aspirin tablet by UV, and compare results

Your pre-lab task for week 2/3 is to:

- Discuss the hydrolysis of aspirin
- Describe what methods might be used to determine the purity of a substance, and a technique used to improve its purity

Your-lab-task for week 2/3 is to:

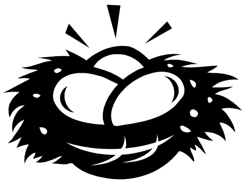
- Experimentally determine the amount of aspirin in your prepared sample and in a commercially available aspirin tablet by back titration and compare results

Science Education Chemistry Laboratory Year 1

Semester 2: 'Hard boiled or scrambled ?'

It is some time in the 21st century, fossil fuels have all but run out and all forms of heating are unimaginably expensive.

Some Science Education students lost on a Department of Education and Science expedition find an old waterproofed kiln with calcium oxide intact. Conscious that salmonella poisoning is still very much a possibility they are anxious to cook some eggs they have found…

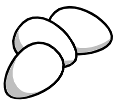


Your lab task is to:

- To cook an egg using the heat generated from the following chemical reaction

$$CaO + H_2O \rightarrow Ca(OH)_2 \qquad -\Delta H°_{hyd}$$

- Use some of the everyday materials supplied to insulate the reaction.

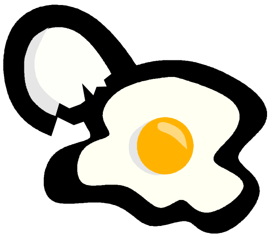


$Ca + ½ O_2 \rightarrow CaO$	$\Delta H°_{for}$ = -635.09kJ/mol
$Ca + O_2 + H_2 \rightarrow Ca(OH)_2(s)$	$\Delta H°_{for}$ = -986.09kJ/mol
$Ca + O_2 + H_2 \rightarrow Ca(OH)_2(aq)$	$\Delta H°_{for}$ = -1002.82kJ/mol
$H_2 + ½ O_2 \rightarrow H_2O$	$\Delta H°_{for}$ = -285.84kJ/mol

Warning : Calcium oxide is corrosive, which means it can cause burns.
Be extra careful !

Beware ! The energy generated by the addition of even small amounts of water to CaO may melt plastic containers.

At 3.30pm, there will be a ‘cracking open’ session to identify the winning egg.



It will be judged using the following quidelines :

1. If there are a number of cooked eggs, then the design of the apparatus and/or the amount of chemical oxide used will be taken into account.
2. If there are no fully cooked eggs, then the group with the most cooked egg wins.

Rules :

1. Before cooking the egg, groups should describe their proposed method to the judges.
2. Only 1 egg will be provided to each group.
3. An equal amount of calcium oxide will be supplied to each group – use it wisely.
4. No form of heating, other than chemical, is to be used for the cooking process.
5. **A cooked egg is one in which the white is firm. The yolk may or may not be runny – the judges will decide…and their decision is final.**

Good luck !

USEFUL REFERENCES SEMESTER 2

Combating Fish Disease
http://www.fishdoc.co.uk/treatments/malachite.htm
Atkins, P.W. ; *Physical Chemistry*, 5th Edition, Part 3, 25 – The rates of chemical reactions, section 25.2 and 25.3.
http://www.uni-regensburg.de/Fakultaeten/nat_Fak_IV/Organische_Chemie/Didaktik/Keusch/chembox_trph-e.htm
http://www.chm.davidson.edu/ChemistryApplets/kinetics/IntegratedRateLaws.html

Like Dissolves Like
Skoog, West and Holler; *Fundamentals of Analytical Chemistry*, 7th Ed.

Chapter 34, Separation by Extraction

Purification and Purity Determination
http://www.absoluteastronomy.com/encyclopedia/a/ac/acetaminophen.htm
Lab manual Pg 103 – 110
Dean, John R.; Practical Skills in Chemistry. *2002 (Pg 92-101)*
McMurry, John; *Organic Chemistry*, 1992 (or any other organic chemistry book)

Aspirin
http://www.shu.ac.uk/schools/sci/chem/tutorials/molspec/beers1.htm
http://www.chem.vt.edu/chem-ed/spec/beerslaw.html

Appendix 4.1: Initial Intake Survey

First Year SE1 Questionnaire for 2003/2004

Full Name: ____

Secondary School: ____

Physics Teacher's Name: _____________________________________

Chemistry Teacher's Name: ___________________________________

Which of the following activities did you attend or take part in?

Activity	Yes	No
Did you visit DCU prior to studying here?		
Did you attend the Open Day?		
Did you attend the Science Day?		
Did you attend the Higher Options Exhibition in the RDS?		
Have you had a visit from DCU to your school?		
Do you know anyone else who has studied this course?		

How did you hear about this course? ______________________________

____

Why did you choose this course? _________________________________

____

Any further information on your decision (e.g. locality, transport, friend/family): ___

____

What was your first CAO choice? _________________________________

What was your Leaving Certificate Grade for:

Maths	Physics	PhysChem	Applied Maths	Chemistry

What were the total points for your Leaving Certificate: [ ]

Thanks for taking the time to complete this questionnaire.
It is much appreciated

Appendix 4.2: End of Semester 1 Survey (Similar to one used in Semester 2)

End of Semester 1 survey for SE1 class: ‘03-‘04

Please complete this survey regarding the Problem Based Learning chemistry labs, thanks.

What do you feel was the most beneficial aspect of the labs?

____

What do you think was the least beneficial aspect of the labs?

____

Describe 3 things you liked about the labs?

1. ____
2. ____
3. ____

Describe 3 things you disliked about the labs?

1. ____
2. ____
3. ____

Rate your experience of 1st year Chemistry labs in relation to each of the following:

Fun	1 - Unenjoyable	2	3	4	5 – Very enjoyable
Learning experience	1 – Learned nothing	2	3	4	5- Learned everything
Understanding	1 – Understood nothing	2	3	4	5 – Understood everything
Competency in techniques	1 - Incompetent	2	3	4	5 – Extremely competent
Calculations	1 – Haven’t a clue	2	3	4	5 – Can do and get right
Tackling problems	1 – Haven’t a clue	2	3	4	5 – Sensible, researched, approach

Please tick box for preference for - traditional approach ☐

- problem based approach ☐

Have you studied chemistry before? ☐ Yes ☐ No

What changes could be made regarding how they are administered?

____

____

____

Any other suggestions/comments:

____

____

____

Appendix 4.3: Traditional vs PBL Laboratory Survey

Traditional versus Problem Based Learning – Your verdict

Last week, you did an experiment titled *'Dehyration of 4-Methylpentan-2-ol and Isolation of the Products by Distillation'.* This was the only lab done in the traditional way, i.e. you were not given any prior instructions before entering the lab, and followed a set procedure and did your write-up accordingly.

All the other weeks you have tackled experiments using a problem based (PBL) approach. The following questions are set to gauge any differences in the two methods from your point of view.

Thanks for taking the time to complete the survey.

1. Did you spend time preparing for the tradional lab ? □ Yes □ No
   If so, how long ? ___________________
2. Normally did you spend time preparing for the the PBL labs ? □ Yes □ No
   If so, how long ? ___________________

3. If you prepared for both the traditional and PBL labs, which preparation did you feel was the more beneficial ? □ Trad □ PBL
   Why ?
   ____
   ____
   ____

4. Experimentally, which labs did you find easier to do ? □ Trad □ PBL
   Why ?
   ____
   ____
   ____

5. Which lab did you enjoy more ? □ Trad □ PBL
   Why ?
   ____
   ____
   ____

6. Which lab did you feel you learned more from ? □ Trad □ PBL
   Why ?
   ____
   ____
   ____

7. Which write-up was easier to do ? □ Trad □ PBL
   Why ?
   ____
   ____
   ____

8. If given a choice, which approach would you choose to do ?
   □ Trad □ PBL

9. If given a choice, which approach would you choose to do in 2nd year ?
   □ Trad □ PBL

Appendix 4.4: End of semester 1 exam – 1st years

1st year general/analytical chemistry lab
Semester 1 – Assessment for non-academic purposes

ID Number ________________ Class _______________

Short questions :

1. Tick which of the following best describes typical units of concentration in analytical chemistry
   ☐ g/L ☐ mols ☐ molarity ☐ mls

2. Indicate in the boxes whether the following statements are true or false

‘Methyl orange is a good choice of indicator for a weak acid – strong base titration’ True ☐ False ☐

‘Potassium permanganate is a good reducing agent’ True ☐ False ☐

‘The end-point of an acid-base titration will always results in a solution with a pH of exactly 7’ True ☐ False ☐

‘The oxidising agent always gets reduced’ True ☐ False ☐

‘In the analysis of chlorine it is essential not to use tap water at any stage during the preparation and titration’ True ☐ False ☐

3. Write a balanced equation for an acid (excluding ethanoic acid) and base reaction, using chemical formulas.
   + → +

4. ‘Analysis of chlorine can be performed by reaction with silver nitrate, resulting in silver halides being quantitatively precipitated from solution’
   Explain what this statement means.
   ____

5. Give reasons why sodium carbonate can be used as a primary standard
   ____
   ____
   ____

6. The purpose of a ‘standardisation’ is (tick a, b or c)
   - ❑ a: to neutralise an acid/base solution
   - ❑ b: to determine the exact concentration of a solution
   - ❑ c: to make a primary standard solution

7. When doing the analysis of iron tablets, it was necessary to use decolorising charcoal, why was this an essential step in the procedure ?
   ____
   ____

8. The concentration of ethanoic acid, CH_3COOH, in vinegar is given as 5%w/v, convert this to molarity.
   ☐

Calculation question :

Given the following information, calculate the molarity of the ethanoic acid solution.

Ethanoic acid	Final titre volume (cm^3)
1	18.15
2	17.95
3	17.95
4	17.90

Answer :

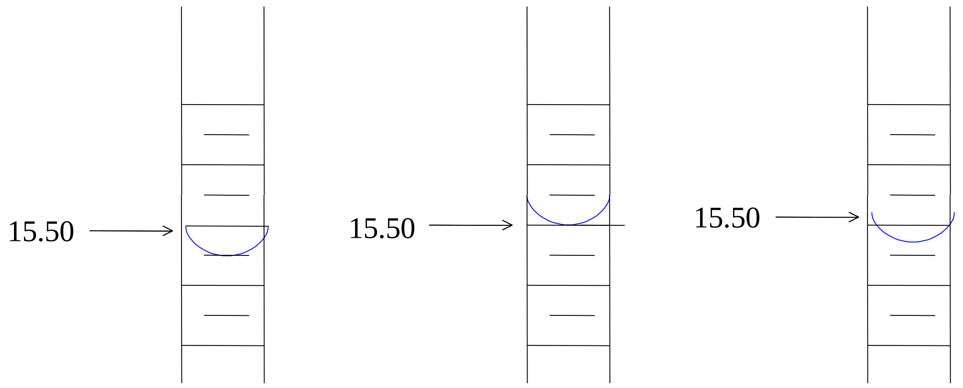
Sodium hydroxide : Molarity = 0.5107M
Pipette volume = $20cm^3$

Reaction equation : $CH_3COOH + NaOH \rightarrow CH_3COONa + H_2O$

Practical questions :

1. Tick which of the following burettes; A, B or C, correctly shows an end-point titre value of 15.50mls

A □ B □ C □



2. You want to weigh out approximately 1g of Na_2CO_3 to prepare 100mls of an approx. 0.1M Na_2CO_3 standard solution, do you use a top-loading balance (2 decimal places) or an analytical balance (4 decimal places) ?

Top-loading balance □ Analytical balance □

3. You want to prepare a 100mls standard solution for use in a titration, which of the following glassware do you use to make the final solution ?

A. Graduated cylinder □ B. Conical flask □ C. Volumetric flask □ D. Beaker □




4. You are doing an experiment to determine the Fe content in iron tablets, which balance do you use to weigh out your iron tablets ; a top-loading balance (2 decimal places) or an analytical balance (4 decimal places) ?

Top-loading balance □ Analytical balance □

Problem question :
Vitamin C in Orange juice

Vitamin C is found in many foods, especially citrus fruits and berries, and also in vegetables including broccoli, tomatoes, cabbage and potatoes. However, despite its wide presence in vegetables, many people do not acquire much Vitamin C this way. Why not ?
The air-oxidation of ascorbic acid is accelerated in the presence of heat, and light, thus many cooking methods destroy it.

Fruit juices are a significant source of ascorbic acid (vitamin C) for humans and their consumption in the last years has increased dramatically. However, ascorbic acid in fruit juices is also readily oxidised and hence, its concentration decreases over time. It is evident that the quality of any fruit juice and its value as a source of vitamin C depends on its content and on the rate of loss of vitamin C due to oxidation.

How would you determine experimentally the rate of loss of vitamin C over time in a sample of orange juice stored at room temperature and open to the air ?

**** Remember that there is also citric acid in orange juice****

Appendix 4.5: End of semester 1 exam – 2nd years

2nd year General/Analytical Chemistry Lab
Semester 2 – Assessment for non-academic purposes

ID Number ________________ Class _______________
Leaving Cert Chemistry □ Yes □ No Grade ___ Total LC points ____

Short questions :

1. Tick which of the following best describes typical units of concentration in analytical chemistry
   □ g/L □ mols □ molarity □ mls

2. Indicate in the boxes whether the following statements are true or false

‘Methyl orange is a good choice of indicator for a weak acid – strong base titration’ True □ False □

‘Potassium permanganate is a good reducing agent’ True □ False □

‘The end-point of an acid-base titration will always results in a solution with a pH of exactly 7’ True □ False □

‘The oxidising agent always gets reduced’ True □ False □

‘In the analysis of chlorine it is essential not to use tap water at any stage during the preparation and titration’ True □ False □

3. Write a balanced equation for an acid (excluding ethanoic acid) and base reaction, using chemical formulas.
   + → +

4. ‘Analysis of chlorine can be performed by reaction with silver nitrate, resulting in silver halides being quantitatively precipitated from solution’
   Explain what this statement means.
   ____

5. Give reasons why sodium carbonate can be used as a primary standard
   ____
   ____
   ____

6. The purpose of a ‘standardisation’ is (tick a, b or c)
   - □ a: to neutralise an acid/base solution
   - □ b: to determine the exact concentration of a solution
   - □ c: to make a primary standard solution

7. When doing the analysis of iron tablets, it was necessary to use decolorising charcoal, why was this an essential step in the procedure ?
   ____
   ____

8. The concentration of ethanoic acid, CH_3COOH, in vinegar is given as 5%w/v, convert this to molarity.
   [ ]

Calculation question :

Given the following information, calculate the molarity of the ethanoic acid solution.

Ethanoic acid	Final titre volume (cm^3)
1	18.15
2	17.95
3	17.95
4	17.90

Answer :

Sodium hydroxide : Molarity = 0.5107M

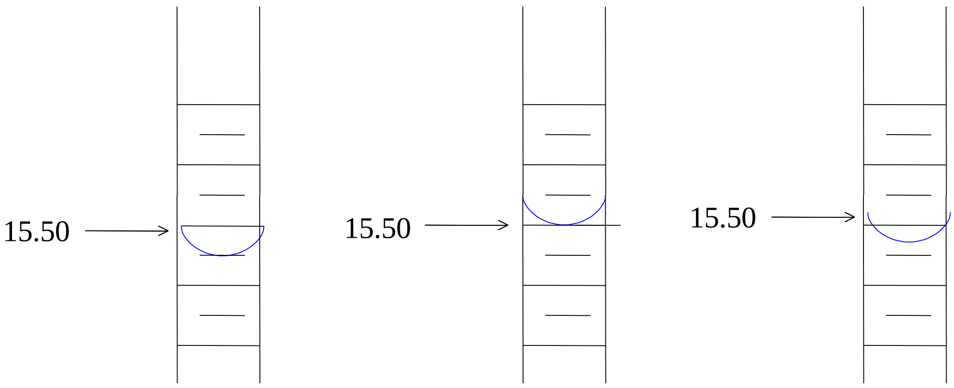
Pipette volume = $20cm^3$

Reaction equation : $CH_3COOH + NaOH \rightarrow CH_3COONa + H_2O$

Practical questions :

1. Tick which of the following burettes; A, B or C, correctly shows an end-point titre value of 15.50mls

A ☐ B ☐ C ☐



2. You want to weigh out approximately 1g of Na_2CO_3 to prepare 100mls of an approx. 0.1M Na_2CO_3 standard solution, do you use a top-loading balance (2 decimal places) or an analytical balance (4 decimal places) ?

Top-loading balance ☐ Analytical balance ☐

3. You want to prepare a 100mls standard solution for use in a titration, which of the following glassware do you use to make the final solution ?

A. Graduated cylinder ☐ B. Conical flask ☐ C. Volumetric flask ☐ D. Beaker ☐




4. You are doing an experiment to determine the Fe content in iron tablets, which balance do you use to weigh out your iron tablets ; a top-loading balance (2 decimal places) or an analytical balance (4 decimal places) ?

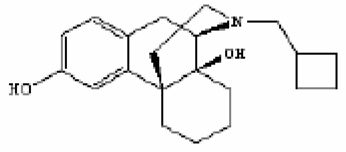
Top-loading balance ☐ Analytical balance ☐

Problem question:
As a trained analytical chemist, you have been given the task of analysing a number of urine samples belonging to several well-known race horses, including 'Kicking King' Gold Cup winner at Cheltenham and 'Hedgehunter' winner of the recent Grand National. The samples all appear to be clear until you come to the final one, which seems to contain traces of a pain-killing drug.

You manage to isolate a crude sample of the drug and you suspect it to be 'Stadol' – a narcotic analgesic, which acts on the central nervous system to relieve pain.

Background information - Stadol

Chemical name: Butorphanol, $C_{21}H_{29}NO_2$



What further steps would you take to determine if one of these famous racehorses is in fact taking this pain-killing drug?

Appendix 5.1: Extract from the Microscale Manual

Mandatory Experiment 4.6

To calculate the % of Iron in Iron tablets

Background

Iron compounds are essential to all life. For example, it is an iron atom in haemoglobin that is responsible for carrying oxygen around the blood stream. Iron is also found in the protein myoglobin and is stored in some organs such as the liver. Iron deficiency leads to anaemia and excess iron in the body causes liver and kidney damage. However, it is usually iron deficiency that is most common. Therefore there is a lot of iron supplements on the market. A healthy adult contains 4 grams of iron. In this experiment, we analyse a commercially available iron tablet for its iron content this is done to make sure that our body contains the correct amount. In the titration reaction, the Fe^{2+} ions react with permanganate ions, MnO_4^- and acid, H^+, according to the following equation:

$$MnO_4^- + 8\,H^+ + 5\,Fe^{2+} \rightarrow Mn^{2+} + 5\,Fe^{3+} + 4\,H_2O$$

The purple MnO_4^- ion becomes colourless when it reacts with the Fe^{2+} ions.

- **The potassium permanganate standardised in the previous experiment can be used for this experiment provided it has been stored correctly. (See practical notes 4.5).**
- **Unless enough sulphuric acid is added, there is a possibility for atmospheric oxidation of the iron solution to occur, giving inaccurate end-points.**

Practical notes:

- ⇨ **The iron tablets used in this experiment, have a red coating. If this red colour is not removed prior to doing the titration, the colour change will not be visible. To remove the colour it is necessary to use charcoal.**
- ⇨ **It is essential that when the iron solution is filtered that there is no trace of red, the solution should be colourless so add more charcoal if needed., and refilter the solution.**
- ⇨ **The iron (II) solution is made up in a $50cm^3$ volumetric flask and a common mistake is to use more than $50cm^3$ in the preparing of the solution, taking into account the washing of the pestle, mortar, beaker etc.**

Procedure:

1. **Rinse all glassware thoroughly with deionised water and the micro-burette and pipette with the solutions they are to contain, at least 2-3 times.**
2. **Pre-treatment of the sample is needed so accurately weigh out 1 iron tablet and crush with mortar and pestle. Transfer the powdered tablet to a beaker with washings from the mortar and pestle. Dissolve the solid as completely as possible in a mixture of 8cm^3 water and 8cm^3 dilute H_2SO_4. Add about 0.5g of charcoal (tip of a spatula) of decolourising charcoal. Stir the mixture and filter into the volumetric flask. Make up to the mark, stopper and invert.**
3. **Fill the pipette with the iron (II) solution and transfer to a clean conical flask. Add approximately 2cm^3 of dil H_2SO_4. In this reaction the manganate acts as the indicator.**
4. **Fill the micro-burette with the $KMnO_4$ making sure there are no air bubbles and record initial reading. When using $KMnO_4$ read the top of the meniscus and place a white tile or piece of paper on the base plate of the stand. This allows you to see clearly any colour changes.**
5. **Dropwise add the $KMnO_4$ to the conical flask with constant swirling, until the pink colour of the manganate just remains in the flask. Note the final reading and use this as a guide for your next titre. If a brown precipitate should form during the reaction, more H_2SO_4 should be added.**
6. **Repeat the titration until at least 3 consecutive titrations are within 0.01cm^3 of each other.**

Results and Calculation:

	Rough	Titre 1	Titre 2	Titre 3
Final reading				
Initial reading				
Volume used				

Using either method, calculate the concentration of iron sulphate and from that the % iron.

Sample calculation :

Calculate the % (w/w) of iron in iron tablets.

Mandatory Experiment 5.2

Preparation and properties of ethyne

Background

Ethyne (acetylene) is the only petrochemical produced in significant quantity which contains a triple bond, and is a major intermediate species. Ethyne is used as a special fuel gas (oxyacetylene torches) and also as a chemical raw material. It can be made by hydrolysis of calcium carbide. The reaction is:

$$CaC_{2(s)} + 2H_2O_{(l)} \rightarrow H\text{-}C \equiv C\text{-}H_{(g)} + Ca(OH)_{2(aq)}$$

Ethyne can be made industrially from hydrocarbons obtained by cracking petroleum. The thermal cracking of butane with steam as a diluent. Ethyne is also made industrially by the combustion of natural gas, which is mainly methane using insufficient oxygen.

- **It is highly recommended that this technique of gas preparation should be practiced first with a simple gas such as carbon dioxide. The following web site provides all the details:**
    - **http://mattson.creighton.edu/ThreeEasyGases.html**
- **The students should be comfortable with the apparatus and technique before attempting this experiment.**
- **A slight adaptation to the technique used above is that the sample holder is not lowered to the bottom of the syringe using floatation in this experiment, instead it is simply allowed to slide down the side of the syringe. The students should practice and become familiar with doing this prior to starting the experiment.**
- **Calcium carbide is a pyrophoric substance, meaning it reacts violently with water, therefore care must be taken in storing and using this chemical. Of course, it is this very property that is used in this experiment, with calcium carbide reacting with water to give the highly flammable gas, ethyne, or acetylene as it is commonly known.**
  NB : Do not use water if this chemical is involved in a fire

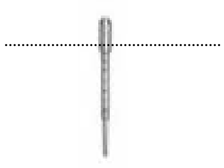
Application:

Ethyne is used:

- **Fuel for the oxyacetylene blow-lamp used in cutting and welding metals.**
- **To prepare ethanal (i.e. acetaldehyde),**
- **Important organic chemicals, including vinyl chloride monomer, which is used in the manufacture of the industrially important plastic polyvinyl chloride, PVC.**

Practical notes:

- **60ml syringe and appropriate cap should be used, making sure that the cap fits securely onto the tip of the syringe.**
- **The sample holder is made by cutting the end of a pasteur pipette along the dotted line, as shown below.**



- **The inverted pipette end can then act as a sample holder.**
- **It is possible to test the gas formed by burning the gas obtained, ethyne burns in air with a sooty flame. However, it must be done in a fume hood, and under strict supervision.**

Procedure: Part A

1. **Measure out approximately 0.2g of calcium carbide, CaC_2. Place the solid CaC_2(s) directly into the sample holder.**
2. **Lower the sample holder into the bottom of the barrel of the syringe by sliding it down the side of the barrel taking care to keep the holder upright.**
3. **Install the plunger while maintaining the syringe in a vertical position. The plunger has a plastic "rib" near the rubber seal that snaps past the "catch" — a small ridge just inside the mouth of the syringe. Usually it takes a firm push to move the rib past the catch. After that, the plunger should move smoothly.**
4. **Measure 5mls of water into a small weighing dish. Draw this solution into the syringe.**
5. **Put the syringe cap onto the syringe.**
6. **Generate the gas by shaking the syringe up and down in order to mix the reagents. Gently help the plunger move up the barrel if necessary.**
7. **To stop gas production, remove the syringe cap with the syringe held "cap-up" as shown. Assume contents are under positive pressure.**
8. **Discharge the liquid reagent into a waste beaker. Immediately recap the syringe to prevent loss**
9. **Ethyne filled syringes must be washed in order to remove traces of unwanted impurities before the gases can be tested. Follow the procedure summarized here.**
   a. **Remove the syringe cap**
   b. **Draw 5 mL of water into the syringe**
   c. **Cap the syringe**
   d. **Shake syringe to wash inside surfaces**
   e. **Remove cap**
   f. **Discharge solution only**
   g. **Recap the syringe.**
10. **To remove other impurities repeat step 9 above but use acidifed copper sulfate instead.**

Part B:

Test with acidified potassium permanganate for unsaturated hydrocarbons

1. **Measure 5mls of acidified potassium permangante into a small weighing dish. Draw the solution into the syringe and recap.**
2. **Shake the syringe vigorously, and monitor the change in colour of the pink potassium permanganate.**

Mandatory Experiment 6.2

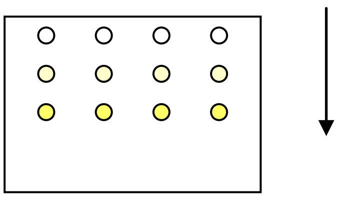
A study of the reaction between sodium thiosulphate solution and hydrochloric acid to determine the effect of (a) concentration and (b) temperature on the rate of a chemical reaction

Background

This experiment investigates the other two main factors affecting reaction rate, namely concentration of reactants and temperature. However, this time the reaction investigated is that between sodium thiosulphate and hydrochloric acid. This reaction has a very definite end-point, which makes it easy to measure the rate. This is due to the formation of a yellow solid sulphur precipitate. The reaction is as follows:

$$Na_2S_2O_3 + 2HCl \rightarrow S\downarrow + 2NaCl + H_2O + SO_2$$

The reaction is carried out in well plates, and an X is marked on a piece of paper underneath. When the sulphur is formed the X will 'disappear'.



Procedure:

Part (a) – the effect of concentration

Place page with x under the well.
Following the amounts outlined in the grid, on addition of the 2M Hydrocloric acid to the well, start the timer and wait for the x to 'disappear' from under the well. This is due to the formation of sulphur (yellow compound).

Cell	Drops of 0.2M $Na_2S_2O_3$	Drops of H_2O	Drops of 2M HCl	Time (min'sec'')
A1	20	0	3	
A2	16	4	3	
A3	12	8	3	
A4	8	12	3	
A5	4	16	3	

Part (b) – the effect of temperature

Place page with x under a well and put 0.5ml of 1M hydrochloric acid in it. Take 2mls of 0.1M thiosulphate and add it to the well. Start the timer and wait for x to 'disappear'. Monitor and record the actual temperature of the mixture in the well. The first measurement will be approx at room temperature (20°C). Then heat the thiosulphate solution to the next specified temperature (40°C) using a hot-plate or bunsen burner, take 2mls of thiosulphate and add it to a well containing 0.5mls of 1M acid. Start the timer and wait for x to 'disappear'. Monitor and record the actual temperature of the mixture in the well. Repeat for each temperature.

Cell	Mls of $Na_2S_2O_3$	Mls of HCl	Temp of $Na_2S_2O_3$	Actual temp	Time (min'sec'')
A1	2	0.5	20		
A2	2	0.5	40		
A3	2	0.5	55		
A4	2	0.5	70		
A5	2	0.5	90		

Results and Calculations:

Plot 1 graph of rate (1/time) against concentration and another one of temperature against rate (1/time).

Mandatory Experiment 7.4

Preparation of ethanal

Background

In this experiment ethanal, CH_3CHO, is produced from the primary alcohol ethanol, C_2H_5OH. Many aldehydes have odors and flavours, and this gives rise to their main use commercially. Examples include the use of ethanal to make perfumes and flavors, and the use of benzaldehyde as an artificial almond flavoring.

Primary alcohols can be converted to aldehydes using a strong oxidising agent such as sodium dichromate, $Na_2Cr_2O_7$. Other oxidising agents include $KMnO_4$ and CrO_3. They are easily oxidised at room temperature under acidic conditions. Precautions must be taken that the aldehyde is not further oxidised to the carboxylic acid. This is done by distilling the aldehyde as it is formed, and using an excess of ethanol over acidified dichromate.

$$\underset{\text{Ethanol}}{C_2H_5OH} \xrightarrow[H_2SO_4]{K_2Cr_2O_7,} \underset{\text{Ethanal}}{CH_3CHO}$$

Application:

Ethanal occurs naturally in ripe fruit and coffee, and is produced by plants as part of their normal metabolism. In the chemical industry, acetaldehyde is mainly used to produce acetic acid. It is made commercially by the oxidation of ethylene with a palladium catalyst

- **used as a reducing agent for silvering mirror,**
- **manufacture of synthetic resins and dyestuffs,**
- **preservative**
- **When treated with a small amount of sulfuric acid it forms paraldehyde, a trimer, which is used as a hypnotic drug.**

In the liver, the enzyme alcohol dehydrogenase converts ethanol from the alcohol consumed into acetaldehyde ethanal, which is then converted into the harmless acetic acid. Acetaldehyde is more toxic than alcohol and is responsible for many hangover symptoms. N-acetylcysteine (NAC) is known to assist in processing acetaldehyde in the body and therefore can help to relieve hangover symptoms.

Procedure:

1. **Set up apparatus as shown in figure 1 with sand bath as method of heating.**
2. **Place 3cm^3 of water and an anti bump granule into the flask. Slowly add 1cm^3 of conc. H_2SO_4. Swirl the flask gently and cool under running water.**
3. **Dissolve 2.5g of sodium dichromate in 2.5cm^3 of water and add 2cm^3 of ethanol. Place the mixture in the dropping funnel.**
4. **Heat the acid solution in the flask until it boils then turn off the heat.**
5. **Add the alcohol mixture slowly from the dropping funnel, at such a rate that the solution in the flask is maintained at its boiling point. Collect the distillate in a receiver surrounded by ice.**
6. **Replace the dropping funnel by a thermometer and redistill the distillate at a temperature of between 20 and 23°C, keeping the receiver surrounded by ice.**

Appendix 5.2: List of Experiments in the BASF Minilab Manual

Course *	Experiment
JCS	Sublimation
JCS	Filtration and Separation of Mixtures
JCS	Distillation of Red Wine
LCC	Distillation of Crude Oil
JCS	Preparation and Properties of Oxygen
JCS	Preparation and Properties of Carbon Dioxide
LCC	Recrystallisation of Aspirin
LCC	Preparation of Ethene
LCC	Preparation and Properties of Ethyne
LCC	Catalytic Cracking of Paraffin
LCC	Estimation of Percentage Ammonium in an Ammonium salt
LCC	Preparation and Properties of Ethanal
LCC	Laboratory Preparation of Ethanoic Acid
LCC	Preparation of Soap
LCC/TYS	Synthesis of Ethyl Benzoate (an Ester)
JCS/TYS/LCB	Osmosis through a Visking Membrane
JCS/TYS/LCB	Extraction and Analysis of Chlorophyll
TYS	Synthesis of Boric Acid Esters
TYS	Preparation of Acetyl Salicyclic Acid (an Aspirin)
TYS	Steam Distillation of Cloves

*

JCS – Junior Certificate Science

TYS – Transition Year Science

LCC – Leaving Certificate Chemistry

LCB – Leaving Certificate Biology

Appendix 5.3: Titre results obtained for each experiment described in Section 5.2.1

EXP 4.1	NORMAL SCALE			MICROSCALE		
Solution*	1	2	3	1	2	3
1	19.45	19.90	20.00	1.02	0.98	1.01
2	19.90	19.90	20.05	1.02	1.02	1.04
3	19.85	19.90	20.00	1.02	0.99	1.03
4	19.80	19.95		1.00	1.01	1.04
Average	19.85	19.91	20.02	1.02	1.00	1.04

* 3 standard solutions of sodium carbonate prepared for both the normal scale and microscale and then titrated against hydrochloric acid

EXP 4.2	NORMAL	MICRO
1	16.85	1.70
2	16.7	1.62
3	16.6	1.63
4	16.6	1.64
5	16.5	1.68
6	16.6	1.63
7	16.8	1.62
8	16.6	1.66
9	16.6	1.63
10	16.6	1.66
11	16.6	1.62
12	16.7	1.65
13	16.5	1.64
14	16.5	1.64
15	16.6	1.64
16	16.7	1.65
17	16.6	1.65
18		1.65
19		1.65
20		1.64
Average	16.63	1.65

EXP 4.3	NORMAL	MICRO
1	8.20	0.83
2	8.15	0.84
3	8.15	0.85
4	8.30	0.84
5	8.10	0.85
6	8.20	0.83
7	8.40	0.85
8	8.40	0.84
9	8.20	0.83
10	8.20	0.83
Average	8.23	0.84

EXP 4.4	NORMAL	MICRO
1	12.00	0.60
2	11.90	0.59
3	12.00	0.59
4	12.00	0.59
5	11.90	0.58
6	12.00	0.59
7	12.00	0.60
8	12.10	0.60
9	12.00	0.61
10	12.00	0.60
11	12.10	0.59
12	12.05	0.62
13	12.00	0.59
14	12.10	0.60
15	12.10	0.59
16	12.10	0.61
Average	12.02	0.60

EXP 4.5	NORMAL	MICRO
1	19.5	0.97
2	19.4	1.04
3	19.55	0.98
4	19.45	0.98
5	19.4	1
6	19.55	0.99
7	19.5	0.99
8	19.55	0.98
9	19.35	0.98
10	19.35	0.98
11	19.45	0.97
12	19.45	0.97
13	19.4	0.99
14	19.5	0.98
15	19.45	0.97
16	19.45	0.99
Average	19.46	0.99

EXP 4.6	NORMAL	MICRO
1	2.80	0.26
2	2.70	0.28
3	2.80	0.26
4	2.80	0.27
5	2.80	0.27
6	2.70	0.28
7	2.60	0.27
8	2.70	0.28
9	2.70	0.27
10	2.70	0.26
11	2.70	0.26
12	2.70	0.24
Average	2.74	0.27

EXP 4.7	NORMAL	MICRO
1	10.00	0.99
2	10.05	0.99
3	9.90	0.99
4	9.90	0.99
5	9.50	1.00
6	10.05	1.00
7	9.95	0.99
8	10.00	1.00
9	10.00	1.00
10	10.00	0.99
Average	9.98	0.99

EXP 4.8	NORMAL	MICRO
1	9.70	0.96
2	9.70	0.96
3	9.70	0.96
4	9.70	0.95
5	9.70	0.96
6	9.55	0.95
7	9.65	0.94
8	9.60	0.95
9	9.60	0.94
10	9.65	0.94
Average	9.66	0.95

EXP 9.3	NORMAL*	MICRO*	NORMAL**	MICRO**
1	6.35	0.68	19.90	1.00
2	6.40	0.65	19.85	0.97
3	6.30	0.64	19.70	0.98
4	6.30	0.63	19.80	0.98
5	6.30	0.63	20.05	1.00
6	6.35	0.61	19.75	1.01
7	6.45	0.67	19.80	0.98
8	6.30	0.62	19.70	1.00
9	6.35	0.64	19.80	1.00
10	6.40	0.66	19.70	1.02
11	6.30	0.63	19.8	0.98
12	6.50	0.66	19.60	0.99
13	6.40	0.63	19.60	0.99
14	6.35	0.63	19.75	0.99
15	6.35	0.62	19.90	0.99
16	6.35	0.62	19.85	0.98
Average	6.36	0.64	19.78	0.99

* Ballygowan Sample **Spiked Hard Water Sample

EXP 9.4	NORMAL	MICRO
1	6.60	0.66
2	6.50	0.67
3	6.50	0.66
4	6.60	0.66
5	6.60	0.67
Average	6.56	0.66