# Providing solutions through problem-based learning for the undergraduate 1st year chemistry laboratory

**Orla C. Kelly**[*a,b] **and Odilla E. Finlayson**[a]

[a] *CASTeL/School of Chemical Sciences, Dublin City University, Dublin, Ireland*
[b] *Faculty of Education, University of Plymouth, Exmouth, Devon, UK*
*e-mail: orla.kelly@plymouth.ac.uk*

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**Abstract:** A PBL laboratory-based module for first year undergraduate chemistry has been developed and successfully implemented. Its aim was to develop the students' practical and transferable skills, as well as their content knowledge and scientific understanding, and also to address the concern expressed in the literature over the effectiveness of the traditional laboratory courses to achieve these aims. The PBL module also encouraged students to prepare for their laboratory session in an active and collaborative manner through pre-lab exercises. By combining elements of group work, discussion, hands-on activities and alternative assessment methods, the students were provided with an environment conducive to meaningful, deep learning. We describe how the PBL module was developed by adapting the experience for the students rather than changing the experiments. Specific examples from analytical, physical and organic chemistry are given with a focus on the pre-laboratory exercises, associated group work, and the assessment methods, as well as on the actual practical work. [*Chem. Educ. Res. Pract.*, 2007, **8** (3), 347-361.]

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## Introduction

Problem-based learning (PBL), a teaching and learning method founded in the medical sciences and first introduced in 1969, is becoming increasingly popular in other academic disciplines such as education, psychology and business (Coombs and Elden, 2004), and also in science, for example Belt et al., 2002. This paper describes the development of a problem-based learning approach for a traditional chemistry laboratory module by looking at the traditional laboratory format to see why there might be a need to change and PBL will then be discussed to see how this might provide the solution. Finally, the development of the module will be described in detail.

### *Traditional labs*

Laboratory classes typically involve students performing teacher-structured laboratory exercises or experiments. Each step of a procedure is carefully prescribed and students are expected to follow the procedures exactly. Usually, little is left to the students' own thought or ingenuity.  This type of laboratory activity is often referred to as a 'recipe lab' (Domin, 1999). This requires little student engagement with the content, and as Johnstone et al. (1994) commented, "*students can be successful in their laboratory class even with little understanding of what they are actually doing*". However, the student may have little choice but to adopt this passive approach while they grapple with new techniques and equipment, especially when the preparation for the lab has involved no more than reading the laboratory manual. Johnstone (1997) reported that the laboratory is a place for information overload, which results in students having little ‘brain space’ to process information and therefore they blindly follow the instructions and seldom interpret the observations or the results made during the experiment.

At this stage, it is important to highlight the expense of running laboratory sessions in university. Firstly, specialised laboratory space is costly to build, equip and maintain. Secondly, it requires technical and academic staffing, as well as postgraduate demonstrators. Laboratory work is also time-consuming, and finally, there is ongoing expense of consumable chemicals and apparatus (Bennett and O’Neale, 1998). The question is raised as to whether the students are deriving maximum benefit from these laboratory sessions, and if the typical recipe lab format can be justified in the context of such expense.

In recipe labs the activity is predetermined, with demonstrators, technicians, and staff all clearly knowing what is expected to happen. Therefore, errors can be clearly identified by the teaching staff and rectified for the students before they continue with the laboratory work, with the result that students get little experience of problem-solving in the laboratory. Additionally, all the students are generally carrying out the same experiment and this can lead to students only being concerned with getting the same result as their laboratory neighbour. However, recipe labs have the great advantage that they allow the inexperienced student to take the same attitude to laboratory work as is taken by the professional scientist: the recipe allows the student to devote all his or her attention to the technique and not to worry at all about theory (Garratt, 1997). They get direct opportunities to develop manipulative and technical skills. This maximises the quantity of practical experience gained by students, and the quality of the results they can potentially obtain. Conversely, the students are not concerned with matching their learning in the laboratory to previous experience or as Johnstone (1997) put it “*consolidating their learning by asking themselves what is going on in their own heads*”, unlike the researchers and professional scientists who are doing the laboratory work for a particular purpose, which has meaning for them. The other problem with recipe type labs is that the actual practical aspect of any experiment represents only a small part of the whole process of experimental science (Garratt, 1997), while in recipe labs the practical aspect is all that is covered.

Hunter et al. (2000) suggested that the recipe lab “*omits the stages of planning and design*” and it encourages ‘data processing’ rather than ‘data interpretation’. Garratt (2002) developed this further by commenting on the various steps a research scientist would take before actually getting to the practical aspect of the experiment as follows:

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

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

It is clear that recipe labs have their advantages, and with modifications, could be much more effective in teaching and learning science. Incorporating student ownership, relating experiments to previous experiences, and getting students to use higher order cognitive skills would provide authentic investigative processes (Johnstone and Al-Shuaili, 2002). Laboratory sessions should provide students with the opportunity to hypothesise, explain, criticise, analyse, and evaluate evidence and arguments. Bailey (2001) highlighted the importance of transferable or general skill development in a UK context, with reports from both science graduates and employers in chemical industry suggesting that an emphasis on transferable skills at the third level is highly desirable.

With this as a motivation for enhancing the experience for our undergraduate chemists, our traditional first year laboratory course, a typical recipe-type laboratory module with written laboratory reports as the assessment, was analysed, adapted, and a PBL module developed.

### *Problem-based learning*

PBL sees a shift in educational focus from a teacher-centred approach to teaching and learning to a student-centred one, where students construct meaning for themselves by relating new concepts and ideas to previous knowledge. It is an alternative approach to teaching and learning, which encourages active involvement of the learner (Tan, 2004). As a learner-centred method that challenges the learner to take a progressively increasing responsibility for his or her own learning PBL is therefore consistent with the constructivist theory (Coombs and Elden, 2004). Furthermore, it also draws from another aspect of constructivism, which is to do with learning through social interaction, which recognises the impact of others' ideas on the way learners make sense of things (Harlen, 2006).

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), thus enhancing the chances of students emerging from University with some of the skills that are highly desirable in the work place. Furthermore, 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).

White (2002) stated that PBL provides an alternative to traditional education:

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

In PBL, the problem, as the focus of the learning, is typically an ill-structured, complex one, with no clear 'right answer'. This provokes extended collaboration among groups, leading to conceptual learning. Students automatically have to activate their prior knowledge in order to start thinking about the problem confronting them, and build it into new knowledge, which is the basis of constructivism. This has been shown to enhance learning (Norman and Schmidt, 1993 cited in Exley and Dennick, 2004). This is in stark contrast to traditional labs which use tasks with clear procedures and right answers, which is associated with limited exchange of information among students, leading to simple explanations and routine learning (Wilkerson 1996). Similarly, Belt et al. (2002) suggested that problems act as the context and driving force for learning, and that the acquisition of new knowledge is done through these contexts. PBL differs to the familiar case-based or problem-solving approaches since in PBL the problems are encountered before all the relevant knowledge has been acquired (Albanese and Mitchell, 1993).

However, there are a number of implementation issues that must be addressed. Woods (1997) listed the main issues with implementation of a PBL approach into a traditional chemical engineering lecture course as follows:

1. Preparing the students with the required skills
2. Students must be willing to take charge of their own learning and to cope positively with the attitudinal shifts that occur when they experience change
3. Empowering the students to be their own facilitators
4. Selecting and preparing teachers to operate in PBL courses (called the facilitators)

5. Student attendance and participation
6. Choosing and formulating the problem, preparing resources
7. Creating the student groups

With respect to point 4, in general the facilitator is not there to provide answers to students' questions but to guide the groups in their discussions. This can be a difficult activity to engage in, and PBL facilitators require training and continuing support to ensure that their role helps the group to function optimally (Exley and Dennick 2004). Additionally, facilitators must be willing to take risks as they give up their sense of 'control' that one is familiar with in a lecture setting (Woods, 1997). Furthermore, Albanese and Mitchell (1993) questioned whether the facilitator should be an expert in the discipline or not.

The purest form of PBL has just PBL tutorials and independent learning where problems can last for weeks or even semesters. However, this approach can require faculty level change and typically more time/staffing/training/resources, and there are often concerns of a trade-off between content and depth (Albanese and Mitchell, 1993). This pure form of PBL was not considered suitable within the constraints of resources and staffing in this study and the varied student backgrounds in terms of content knowledge and process skills on entering undergraduate level 1. Therefore the 'pure' PBL approach was adapted as discussed below. The authors however will use the PBL acronym throughout to describe their approach. Factors that were considered in the development of the PBL module by the authors of this work included:

- The problems developed were based on existing experiments
- The problems were designed to ensure that students covered a pre-defined area of knowledge, and to help students learn a set of important concepts, ideas, skills and techniques
- The form that the problems usually took were descriptive statements
- The students worked either in groups or individually
- The students took part in a pre-lab, where the students' initial answers to the problems were discussed with the lab instructor who provided further context and/or chemistry help, and who pointed out potential pitfalls and blind alleys before proceeding to the lab work

## Theoretical background

The development of skills, both general and technical, chemical concepts, knowledge and understanding were the core aims of the PBL module, and these were to be achieved through an alternative teaching and learning environment combining pre-labs, group work, discussion, practical work and alternative assessment.

### *Skills*

The first stage in the development of the PB laboratory was to reflect on the desired learning outcomes in terms of skills and scientific method that should be developed from laboratory work. Garratt (1997) and Bennett and O'Neale (1998) describe the range of skills that should be developed through laboratory work (Table 1). Laboratory work should also provide the experience of designing an experiment, consolidating subject knowledge with practical experience, and the process of science (Garratt 1997).

**Table 1.** Skills to be developed through practical work.

| **Garratt (1997)** | **Bennett and O'Neale (1998)** |
|---|---|
| Technical skill | Manipulation |
| Confidence in lab work | Lab know-how |
| Observational skills | Observation |
| Awareness of safety | Experiment design |
| Recording skill | Data collection |
| Data manipulation | Processing and analysis of data |
| Data interpretation | Interpretation of observations |
| Presentation skills | Problem-solving |
| Report writing | Team work |
| Oral communication | Communication and presentation |

There are obvious similarities between the ranges of skills promoted by these authors. Skills, such as technical and observation skills, confidence in practical work, and data collecting are integral parts of most laboratory sessions; however, what of skills such as data interpretation, problem-solving, team-work and communication of findings? On reviewing the traditional module, it was apparent that many of these elements were missing. Therefore, it was integral to the PBL module that students would have the opportunity to develop and use all these skills.

Having identified skills that were to be central to the PBL module, each of the traditional experiments was analysed to identify the main focus of each experiment in terms of chemical concepts, and techniques.

#### *Chemical concepts and techniques*

The three areas of analytical, physical and organic chemistry that were covered in the traditional module were studied to assess their suitability to develop students' understanding of the fundamentals of these disciplines. Also, the possibility of setting the experiments in relevant contexts was examined. A selection of these experiments was chosen for use in the PBL module which covered fundamental concepts and techniques, such as acid/base theory, titrations, mole calculations, rates of reactions, gas laws, Beer-Lambert Law, recrystallisation, and organic synthesis.

### Teaching and learning environment

Having determined the skills, concepts and techniques, the next phase involved designing the teaching and learning environment to include pre-lab work, group work, discussion and alternative assessment.

#### *Pre-lab*

The use of pre-lab session before the laboratory to 'prepare the mind of the learner' is not a new one. Johnstone (1997) described the elements of an effective pre-lab exercise as including:

- Revision of theory
- Reacquaintance with skills
- Planning the experiment to some extent
- Discussion with peers

When combined with elements of ownership and relevance for the students, the pre-lab can be very effective at preparing the mind of the learner (Johnstone 1997). Also, if students have had direct input into the laboratory experience, for example deciding the procedure or techniques to be used, and have an inherent interest in the experiments due to its relation to everyday life, for example, they will have a greater motivation and personal interest in actually doing the experiment.

Johnstone et al. (1998) reported on the use of pre-labs in physics: "*The aim of the pre-labs was to prepare students to take an intelligent interest in the experiment by knowing where they were going, why they were going there and how they were going to get there*". Also, Sirhan et al. (1999) commented on pre-lectures in chemistry being "*a useful tool in enabling students to make more sense of lectures, the effort being particularly important for students whose background in chemistry is less than adequate*". Allen et al. (1996) described how problems in PBL can be introduced with mini lectures, similar to the form of pre-lab session used in this research.

### *Group work*

Through small-group co-operative learning, individuals can pursue their own learning needs within the context of the group, referring to others for support, feedback, and validation. Much learning occurs from interactions between group members, provided it is appropriately structured to allow discussion and consideration of different points of view (McManus and Gettinger, 1996) Group work both in and out of the lab is an integral part of this PBL module.

### *Discussion*

Discussion can be defined in a broad sense as a wide range of informal situations where talk between people occurs. More specifically, it refers to a particular form of a group interaction where members join together to address a question of common concern, exchanging different points of view in an attempt to reach a better understanding of the issue (Bahar, 2003). Again, discussion both before the lab class and during the pre-lab session is encouraged in this PBL module. Nicol and Boyle (2003) have shown that students discussing concept questions in small groups not only enhanced their conceptual understanding, but it also proved to be a powerful motivating force. It was also reported that students showed a preference for thinking about the problem prior to the discussion; two reasons were offered for this. First, the requirement to make an individual response meant that they were forced to think about the problem, and to formulate their own reason for their selected answer, prior to the group discussion. Second, having constructed their own answer, students felt they benefited more from the subsequent peer discussion. They would be more likely to engage in dialogue and to provide reasons for, and defend their ideas and they would be more likely to be able to identify gaps in their thinking.

During the pre-lab session (no more than half an hour of the 3 hour lab time) discussion was initiated by the facilitator based on the pre lab task, from then on the students exchange ideas, explain and elaborate on their views, question and respond to each other and jointly derive a solution. The goal was to get students to think critically and creatively, and questions should be posed to promote these demands (Bahar, 2003).

### *Assessment*

Savin-Baden (2004) reported that assessment currently seems to be one of the most controversial issues in PBL. She went on to discuss how "*many of the concerns about assessment in higher education seems to relate to the unintended side-effects that undermine staff intentions to encourage students to learn effectively*". Her study reported that students had three main issues with assessment in PBL:

- Unrewarded learning
- Disabling assessment mechanisms

- Impact of assessment on group work

Though PBL does allow for more alternative and varied assessment tools, including oral and poster presentations, written reports, and peer assessment among others, the issue of unrewarded learning and undervalued learning in groups is a difficult one to solve. Overton (2001) reported on a variety of assessment tools which have been used in case studies:

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

Many advocates of PBL promote the use of oral presentations in various disciplines (Allen and Tanner, 2003; Cooper et al., 2003; McGarvey, 2004; Polanco et al., 2004; and Serpil Acar, 2004) and McGarvey (2004) and Wimpfheimer (2004) both reported the use of poster presentations in chemistry. Wimpfheimer (2004) described the benefits of posters, including the fact that it encourages creativity and it provides another platform for assessment, reaching students who perhaps have been overlooked in the traditional assessment formats. Also posters, because of their limited size, stress the importance of clear and concise information and can encourage collaborative work in a way than written lab reports cannot. Finally, he reported a positive attitude toward posters both by students and instructors.

Furthermore, the written report is still encouraged and has its advantages, including the fact that it draws together the method and results and enables students to report, analyse and draw conclusions in a concise and informative style. Therefore, written reports are an integral part of the PBL module, however, the emphasis is on the conclusions that the students have to draw from their results, and how these related to the original problem they were given.

## Development of the module

### *Skills profile of the students*

To identify what skills students felt that they were confident using, and which skills the students had little opportunity to develop, students who were to take the PBL laboratory module were asked to complete a skills survey, adapted from the Royal Society of Chemistry's Undergraduate Skills Record (Royal Society of Chemistry, 2006), at the beginning of their first year. Tables 2 and 3 summarise the skills that students felt most and least confident in. It is worth noting the limitations of this skills survey, as some students have limited practical experience when they start their university course and therefore limited understanding of the statements. Furthermore, approximately 43% of these students had previously studied chemistry at school, and within that group 22% took part in practical work less than once a month in school. Despite this, it was a useful tool to identify the strengths and weaknesses of students' perceptions of their own skills.

**Table 2:** Skills students feel most confident in.

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

**Table 3:** Skills students feel least confident in.

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

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

### *Keeping it real!*

Having identified important skills, concepts and techniques within the traditional experiments that were deemed important to the module, the next stage was to make the experiments appear relevant to the students. This meant finding a context to which the students could relate. For example, they were asked to apply the results of an iron tablet analysis to an anaemia case, where a female aged 20yrs is suffering from anaemia, and who needs to know how many tablets to take per day to keep her iron levels up, taking into account the amount of iron in the tablet that is actually available to the body. This also means having to do some reading around the subject. Other examples included environmental contexts, industrial analysis and food analysis. By brainstorming and simple internet searches, it is usually possible to devise relevant and interesting contexts that may engage the students.

### *Session outline*

This PBL approach was designed for a year 1 undergraduate general chemistry laboratory module, which runs over 2 semesters. The laboratory session lasted for three hours, the same as the traditional lab sessions, inclusive of the pre-lab discussion and/or oral/poster presentations, which were delivered during the lab time. In some cases the problems were run over two laboratory sessions, however, the majority of the problems were completed within one session. The students were given the task a week before the lab, and were expected to have some written evidence of having tried to solve the problem before starting the pre lab discussion. This included looking up resources to support the theory, and practical elements of solving the problem, as well as technical information such as a possible procedures and/or chemicals/apparatus needed. During the pre-lab discussion the students were encouraged either in their groups or individually to offer their ideas on the problem and how they might solve it. Before going into the lab, any safety or technical information was described clearly to the students by the demonstrator. Once in the lab, students set about solving the problem, again either in groups or individually. On completion of the problem, the students submitted a written report and in some cases gave oral or poster presentations to conclude their laboratory session. Throughout the duration of the PBL module, the resources needed were either the same as in the traditional lab or other basic glassware/chemicals which were readily available in the lab. Furthermore, the PBL module was no more labour intensive than the traditional lab with one demonstrator assigned per sixteen students.

## The PBL module

Elements of pre-lab work, discussion, group work and hands-on science were combined with alternative assessment in the development of the PBL module, as outlined above, to provide an environment in the laboratory, which supported student learning and skill development. It was decided that the problems would primarily focus on concepts, skills development or understanding. Table 4 gives two examples for each of the ‘concept driven’, ‘skills development’ and ‘understanding’ problems.

**Table 4:** Examples of ‘concept driven’, ‘skills development’ and ‘understanding’ problems

| Title | Description | Main aims |
|---|---|---|
| **Concept driven problems** | | |
| M&M’s | The problem was to use sweets such as M&M’s to demonstrate simple mole concepts | To introduce students to the concepts of moles and molarity |
| Apples and Oranges | The challenge was to investigate whether apples or oranges were acidic or not, and to determine their acidity. | To introduce acid-base chemistry, indicator theory, and titration as a quantitative method |
| **Skills development problems** | | |
| Clock reactions | The challenge was to find a series of reactions to change colour in time with a piece of music | To provide students with an opportunity to develop technical, observation and data manipulation skills |
| Hard-boiled or scrambled | The problem was to cook an egg without using a combustion-based source of heat | To provide students with an opportunity for group work and problem solving |
| **Understanding problems** | | |
| Old Wives’ Tale | The task was to determine if baking soda was effective at relieving indigestion, and to compare its effectiveness to that of a commercially available antacid tablet. | To provide students with an opportunity to apply their previous knowledge of titrations to a real situation |
| Gas behaviour | The challenge is to design a set of experiments to support the gas laws | To provide students with an opportunity to devise their own experimental procedures |

Furthermore, the problems are sequenced in such an order so that there is progressive development of key concepts and techniques. This is to maximise the potential for cognitive gain and development of process skills. For example, in the first week the students engage with a simple problem to support development of group working skills and problem-solving in a non-chemistry environment and with some simple practical tasks to develop their understanding of moles and molarity. Following on from this, they do a problem based on acids and bases and ways of testing for/measuring these. In the third week, the students do the Case of the Unlabelled Bottles problem (see below) which further builds on these concepts and techniques. The titration technique is only introduced when they have encountered some simple, less accurate ways of determining concentrations and therefore, have more of an appreciation for its use in quantitative analysis. Additionally, every effort is made to reinforce learning by putting things in other contexts to challenge the students to transfer their skills, knowledge and understanding.

### *Concept driven problems*

These problems were used to help students understand the major concepts of the first year programme, including moles and molarity, acid/base theory, use of indicators, the Beer-Lambert Law, polarity and purification. In the traditional labs, these concepts were only explained by a small introductory paragraph in the manual. However, students mostly ignore this information and even if the students attempt to read and understand it, according to Byers

(2001), effective thinking is inhibited because of information overload in the students working memory, leaving no room for information processing and hence understanding.

The concept driven problems aimed to give students a real opportunity to engage with the concepts both prior to the laboratory exercise through the pre-lab and discussion session and during the laboratory through relevant hands-on student driven investigative experiments.

### *Skills development problems*

This group of problems aimed to develop the skill-base of the students, both in terms of their transferable skills and their technical skills. Transferable or general skills developed include group working and communication skills and problem-solving within a chemistry domain, whereas the technical skills developed include improving accuracy and precision in:

- Making up solutions
- Selection of appropriate apparatus
- Carrying out titrations

### *Understanding problems*

Throughout the duration of the PBL module, there was an emphasis on group work, communication, problem-solving and researching skills. These were mostly developed through the pre-lab exercise and discussion. Through the pre-lab exercise the students were expected to go and actively research their problem using books and websites, and to solve the problem through collaboration with their peers in small groups. As well as developing the general skills mentioned, the aim of the pre-lab exercise was also to provide a platform for enhanced understanding by the students. The benefit of working in small groups has been discussed, with special focus on the enhancement of student learning and understanding through positive interactions with their peers. Suffice to say, that pre-labs are seen as integral in furthering students understanding and experience of the laboratory (Carnduff and Reid, 2003).

However, other methods can be used to enhance student learning in the laboratory, such as getting students to present their results in oral or poster presentations or to carry out real investigative experiments. Oral and poster presentation encourage them to ensure they understand fully what they have done, and hence can back up their argument. Also, investigative laboratories, where students have ownership over the design and implementation of the experiment, and the experiments have unknown outcomes, can give rise to real understanding. This set of experiments used the problem, pre-lab, discussion, experiment, and subsequent report to enhance students' understanding of their experimental results and hence of the experiment and its concepts.

## Sample problems

### *Problem 1. The Case of the Unlabelled Bottles*

This was adapted from an exploratory lab at Brigham Young University (Exploratory Lab, 2006). The PBL experiment asks students to label five solutions correctly, given five names and concentrations. The students are not given any other solutions, only indicators. Secondly, having identified the bottles, the students must accurately determine the concentration of one solution by titration. They must decide what other solution to use in the titration and what indicator. The solutions were acids and bases of varying concentrations, namely:

| | |
|---|---|
| Acetic Acid | 0.05M |
| Hydrochloric Acid | 0.05M |
| Hydrochloric Acid | 0.075M |

- Sodium Carbonate 0.01M
- Sodium Hydroxide 0.025M

This problem aimed to further the students' understanding of acids and bases, indicators and quantitative measurement. From the preceding week's experiments, they should be able to distinguish easily between the acids and bases, but the next level was to determine different strengths of acids and bases so as to distinguish between, for example, the sodium carbonate and the sodium hydroxide, and then also to distinguish between different concentrations of the same solutions, i.e. the 0.05M and 0.075M hydrochloric acid solutions. They could use a variety of techniques, from indicator theory to 'small-scale' titrations to solve this. Given the added challenge of using as little of the solution as possible, meant that they were discouraged from using the typical standard titration equipment, and instead encouraged to try well plates and small beakers to carry out small-scale titrations. This encouraged the students to think 'outside the box', thus developing a better appreciation of alternative methods, and adapting their previous knowledge of titrations to a new context.

This was instead of the traditional prescribed lab where students weigh out a primary standard ($Na_2CO_3$) and carry out a standardisation against HCl.

### *Problem 2. Gas behaviour*

In this PBL experiment, the students are given a variety of equipment and consumables to design a series of experiments to support the Ideal Gas Law, mainly using a gas chamber (syringe) and pressure and temperature sensors connected to dataloggers. The students were unfamiliar with the datalogging equipment; therefore it was necessary to give them some guidance and support at the beginning of the lab session. However, once they became familiar with the equipment they became more confident in their ability to design experiments and hence obtain acceptable results.

The very nature of this experiment required them to understand what each of the gas laws meant, and how they fitted into the Ideal Gas Law. To set up the experiments they needed to take into account what they wanted to measure, what had to be kept constant, how they were going to do it, and from there, develop a fair test. If for example they wanted to measure the effect of pressure on volume, then all the other variables needed to be kept constant i.e. the amount of gas, n, and the temperature, T. They then needed to generate data and manipulate it, to show the correct relationship between the two variables. Because there are no set procedures, the students really had to think about the experiments, and they were involved with all steps of the development, and hence involved in investigative experiments. Since some students were familiar with the laws and knew the expected outcome, having studied them for Leaving Certificate Chemistry or Physics, it was a surprise to them that designing effective experiments to prove the gas laws was not necessarily an easy task.

### *Problem 3. StateLab vs. LabAnalysis*

StateLab vs. LabAnalysis is another excellent example of a PBL experiment carried out by students in their first semester. It builds on the previous week's skills, concepts and techniques, including problem solving, group work, acid base theory, titrations and mole calculations. It is also an experiment which requires group work both during the lab session and before and after. Students are given a number of 'vinegar' samples taken from an alleged 'suspect' batch delivered to a local supermarket. Then, representing either the StateLab (on behalf of the consumer) or LabAnalysis (on behalf of the shop owner), they have to carry out an analysis of these samples to determine if the vinegar is suitable for resale. They must do their analysis over two lab sessions by two different methods and compare their results. The task concludes with an oral debate, where the groups 'defend' their results and make recommendations. The groups are encouraged to find potential mistakes (such as using a graduated cylinder to measure an accurate volume for a standard) and gaps in the other groups' arguments.

## Discussion

As this is an adapted form of PBL, some of the issues with PBL and its implementation, as discussed earlier, didn't arise here. For example, there was no sacrificing of the quantity of content and/or practical work for quality. Before PBL, in the traditional course students carried out 10 prescribed titration-based experiments in the first semester and 6 out of 9 physical chemistry experiments and 5 organic experiments in the second semester. In planning for the change-over the whole traditional module was reviewed to select the key skills, concepts and techniques to be covered. The PBL approach ensured that the students still get experience with all the key instrumentation and techniques, and cover similar chemistry concepts and, in fact, in most cases the actual experimental method employed in solving the problems is very similar to the procedure followed in the traditional laboratory.

Safety implications which can arise from students undertaking a PBL approach in the laboratory are also minimised by this adapted PBL approach. Though the students were encouraged to provide solutions to the problems, the actual laboratory procedures that the students had access to had already been limited by the PBL staff and were set out by the technical staff. Therefore, any safety implications were already identified and discussed with the students during the pre-lab sessions. Additionally, this meant that there were few extra resource or technical support issues.

Another issue with implementation of PBL is equipping the students with the skills to be successful in this alternative approach, especially in a context where the majority of their other courses and modules are taught in a traditional way, and where their previous experience most likely involved a minimum of 13 years of traditional schooling. The lack of experience with cooperative group working, taking responsibility for their own learning, searching for relevant information, communicating, etc. can place unwanted stress and worry on the students. Furthermore, there is an issue with prior knowledge, in that students need a certain amount of knowledge to be able to engage successfully with the problems. This is definitely an issue, especially considering the varied background of the students, where some have completed chemistry courses in second-level schools and others have not. The evaluation of this alternative approach showed that only 60% of the students indicated a preference for the PBL approach over a traditional approach after taking it for one semester, whereas 83% indicated a preference for the PBL approach by the end of the 2nd semester. This suggests that the students were better able to cope with these demands of both content and process, having gained more experience of it over the course of the year both within the PBL course and from the lecture-based chemistry module that runs concurrently with the laboratory module. There is further evidence to support this from the same evaluation, which specifically investigated the students' likes and dislikes of the PBL approach, where at the end of semester 1 some students reported a feeling a sense of frustration with the new approach. This was less prevalent by the end of 2nd semester.

Key issues, identified by Savin-Baden (2004) in her research on assessment in PBL, were unrewarded learning, disabling assessment mechanisms and impact of assessment on group work, and this is something that students in this study identified in some of their evaluations. They felt that the assessment mode, which was largely through their written lab reports, often did not reflect their level of engagement with the problem. However, where group work was assessed, the students' did not report any negative experiences about this.

On a general note, the students rated the pre-lab elements and the group work as the most beneficial aspects of the approach. With regard to the pre-lab element one student commented: "*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*". Furthermore, the students were very positive about the whole experience and one reason given by a student for enjoying the PBL labs was that it "*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*". However, there were elements the students disliked, such as having to do more work outside of the designated laboratory time than the traditional students, and some did not like oral presentations. On a personal note, the principal investigator enjoyed facilitating these PBL-laboratory sessions more than the traditional ones, and was pleased to see at first hand the higher motivation and excitement for learning that a PBL approach can invoke in the students.

## Conclusions

The PBL module aimed to develop students' practical and transferable, life-long learning skills as well as their scientific content knowledge and understanding in an environment where there is concern over the effectiveness of the traditional laboratory courses at undergraduate level. The PBL module also encouraged students to prepare for their laboratory session in an active and collaborative manner through the pre-lab element of the module, thus ensuring they were well prepared, thereby maximising the benefits of time spent in the laboratory. Furthermore, elements of group work, discussion, hands-on activities and alternative assessment methods, including oral and poster presentations, were combined to immerse students in an environment conducive to meaningful, deep learning.

The full PBL module has now been trialled over two years on 2 subsets of year 1 undergraduate students, and most recently (2005-2006) it was run without the presence of the principal investigator (O. K.) as a fully developed module in its own right. Following these developments, the traditional module has been redesigned for the whole 1st year cohort, encompassing many of the aspects of the PBL module (Lovatt et al., 2007).

In conclusion, both the PBL and traditional students cover all the same techniques and the same chemistry concepts within the same time frame and using similar resources. The PBL approach, however, provides more scope for skills development, and understanding of concepts and of the experimental process. The students get experience of the whole scientific process in a relevant and stimulating format. Furthermore, they seem to enjoy the experience.

## References

Albanese M.A. and Mitchell S., (1993), Problem-based learning: a review of literature on its outcomes and implementation issues, *Academic Medicine*, **68**, 52-81.

Allen D. and Tanner K., (2003), Approaches to cell biology teaching: learning content in context—Problem-Based Learning, *Cell Biology Education*, **2**, 73-81.

Allen D.E., Duch B.J. and Groh S.E., (1996), The power of problem-based learning in teaching introductory science courses, *New Directions for Teaching and Learning*, **68**, 43-52.

Bahar M., (2003), The effects of motivational styles on group work and discussion-based seminars, *Scandinavian Journal of Educational Research*, **47**, 461-473.

Bailey P.D., (2001), Teaching chemists to communicate? Not my job!, *University Chemistry Education*, **5**, 80-86.

Belt S.T., Hywel E.E., McCreedy T., Overton T.L. and Summerfield S., (2002), A problem-based learning approach to analytical and applied chemistry, *University Chemistry Education*, **6**, 65-72.

Bennett S.W. and O'Neale K., (1998), Skills development and practical work in chemistry, *University Chemistry Education*, **2**, 58-62.

Byers W., (2001), Using questions to promote active learning in lectures, *University Chemistry Education*, **6**, 24-30.

Carnduff J. and Reid N., (2003), *Enhancing undergraduate chemistry laboratories, pre-laboratory and post-laboratory exercises, examples and advice*, Education Department, Royal Society of Chemistry, Burlington House, Piccadilly, London.

Coombs G. and Elden M., (2004), Introduction to the special issue: Problem-Based Learning as social inquiry—PBL and management education, *Journal of Management Education*, **28**, 523-535.

Cooper A.J., Keen M. and Wilton J.C., (2003), The introduction of assessed group presentations as a novel form of in course assessment in neuroscience, *Bioscience Education E-journal*, **1**, available at http://www.bioscience.heacademy.ac.uk/journal/vol1/beej-1-5.htm (accessed December 2006).

Domin D.S., (1999), A review of laboratory instruction styles, *Journal of Chemical Education*, **76**, 543-547.

Exley K. and Dennick R., (2004), *Small group teaching; tutorials, seminars and beyond*, RoutledgeFalmer, London.

Exploratory Labs. The Case of the Unlabeled Bottles, available at http://www.chem.byu.edu/Plone/coursematerials/exploratorylab/EL06.PDF (accessed December 2006).

Garratt J., (1997), Virtual investigations: ways to accelerate experience, *University Chemistry Education*, **1**, 19-27.

Garratt, J. (2002), Laboratory work provides only one of many skills needed by the experimental scientist, *University Chemistry Education*, **6**, 58-64.

Harlen W., (2006), *Teaching, learning and assessing science 5-12*, SAGE Publications, London

Hunter C., Wardell S. and Wilkins H., (2000), Introducing first-year students to some skills of investigatory laboratory work, *University Chemistry Education*, **4**, 14-17.

Johnstone A.H. and Al-Shuaili A., (2001), Learning in the laboratory; some thoughts from the literature, *University Chemistry Education*, **5**, 42-51.

Johnstone A.H., Sleet R.J. and Vianna J.F., (1994), An information processing model of learning: Its application to an undergraduate laboratory course in chemistry, *Studies in Higher Education*, **19**, 77-87.

Johnstone A.H., Watt A. and Zaman T.U., (1998), The students' attitude and cognition change to a physics laboratory, *Physics Education*, **33**, 22-29.

Johnstone A.H., (1997), Chemistry teaching—science or alchemy? 1996 Brasted Lecture, *Journal of Chemical Education*, **74**, 262-268.

Lovatt J., Finlayson O.E. and Ramirez S., (2007), Modification of an expository laboratory for 1st year undergraduate chemistry, *Proceedings of the 2nd European Variety in Chemistry Education*, Prague, 150-155.

MacKinnon M.M., (1999), Core elements of student motivation in PBL, *New Directions for Teaching and* Learning, **78**, 49-58.

McGarvey D.J., (2004), Experimenting with undergraduate practicals, *University Chemistry Education*, **8**, 58-65.

McManus, S.M. and Gettinger, M. (1996) Teacher and student evaluations of cooperative learning and observed interactive behaviors, *Journal of Educational Research*, **90**, 13-22.

Nicol D.J. and Boyle J.T., (2003), Peer instruction versus class-wide discussion in large classes: a comparison of two interaction methods in the wired classroom, *Studies in Higher Education*, **48**, 457-473.

Overton T.L., (2001), Teaching chemists to think: from parrots to professionals, *University Chemistry Education*, **5**, 62-68.

Polanco R.; Calderon P. and Delgado F., (2004), Effects of a problem-based learning program on engineering students' academic achievements in a Mexican university, *Innovations in Education and Teaching International*, **41**, 145-155.

Royal Society of Chemistry, Undergraduate Skills Record available at http://www.rsc.org/images/USR_tcm18-41054.pdf (accessed December 2006).

Savin-Baden M., (2004), Understanding the impact of assessment on students in problem-based learning, *Innovations in Education and Teaching International*, **41**, 223-233.

Serpil Acar B., (2004), Releasing creativity in an interdisciplinary systems engineering course, *European Journal of Engineering Education*, **29**, 231-240.

Sirhan G., Gray C., Johnstone A.H. and Reid N., (1999), Preparing the mind of the learner, *University Chemistry Education*, **3**, 43-46.

Tan O.S., (2004), Students' experiences in problem-based learning: three blind mice episode or educational innovation? *Innovations in Education and Teaching International*, **41**, 169-184.

White H.B., (2002), Commentary: Problem-Based Learning and disciplinary boundaries, *Biochemistry and Molecular Biology Education*, **30**, 419.

Wilkerson L., (1996) Tutors and small groups in problem-based learning: lessons from the literature, *New Directions for Teaching and Learning*, **68**, 23-32.

Wimpfheimer T., (2004), Peer-evaluated poster sessions: an alternative method to grading general chemistry laboratory work, *Journal of Chemical Education*, **81,** 1775-1776.

Woods, D.R. (1997) Issues in implementation in an otherwise conventional programme in *The Challenge of Problem-Based Learning*, 2nd edn, D. Boud and G.E. Felleti, eds., Kogan Page, London, 173-183.