Developing practical chemistry skills by means of student-driven problem based learning mini-projects

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Abstract: Problem-based learning mini-projects ('PBL mini-projects') are used as an alternative to the traditional 'recipe-style' laboratory teaching method with the aim of enhancing students' experience of chemistry laboratory practicals. Small groups of students (3–4) in the second year of their degree are assigned a project title and they must devise the experimental protocol to carry it out. This teaching method better reflects real-life problem solving situations. The students responded favourably in their feedback on these laboratory classes. Class attendance and general class morale were found to be noticeably higher than in previous years. This paper describes the implementation of the PBL mini-projects in our teaching laboratories and examines some feedback obtained from the students (42 in total) and teaching staff involved over a two year period (2004/5 and 2005/6). [*Chem. Educ. Res. Pract.*, 2007, **8** (2), 130-139]
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Introduction

Traditional practical classes for undergraduate chemistry students where they follow a prescribed experimental procedure over a set time are the backbone of most chemistry degree courses. These practical classes are designed to complement material dealt with in lectures and give students practical experience, which will be invaluable in their future careers as chemists. However, there is much discussion on the merits of such a system (Meester and Maskill, 1995, Johnstone and Al Shuaili, 2001). Among the arguments against is the claim that the level of learning is limited, and that students are unclear of the aims of a practical and unsure of what the results mean or how they are applied to the theory provided in the lecture programme (McGarvey, 2004). In addition, the traditional style practicals often leave little room for creativity or contextualisation, and are often a verification of a known quantity or a testing of a theory that has been presented in lectures.

Several different types of laboratory-based teaching exist. Domin listed four descriptors that can be applied to the different laboratory teaching methods (Table 1) based on the expected outcome of the laboratory session, the student's approach and whether the procedure was supplied (Domin, 1999). By far the most common among these is the *expository* or 'recipe-style' laboratory class. Students in our institution rarely perform any other type of laboratory work, except for that involved in their final year project.

Table 1: Descriptors of the laboratory instruction styles (from Domin, 1999).

Style	Descriptor		
	Outcome	**Approach**	**Procedure**
Expository	Predetermined	Deductive	Given
Inquiry	Undetermined	Inductive	Student Generated
Discovery	Predetermined	Inductive	Given
Problem-based	Predetermined	Deductive	Student Generated

In a major review on the role of laboratory teaching in science education, Hofstein and Lunetta (2004) detailed some of the factors that inhibit students' learning. Among these are the following:

- the recipe-style laboratory practicals used in most institutions do not allow the student to think about the larger purpose of their investigation and the sequence of tasks they need to pursue to achieve those tasks;
- assessment is seriously neglected, resulting in the impression that laboratory work does not need to be taken seriously;
- educators are not informed about what is best practice;
- resources for more appropriate laboratory teaching styles are limited.

PBL mini-projects allow for a lot of these issues to be addressed. The shifting of the responsibility for devising the experimental procedure onto the student means that students must now be aware of **whether** a particular experiment they devise is suitable, **why** it is so and **what** it will tell them. Hence, the students are now beginning to examine the usefulness of an experiment and think about it in the context of an overall problem solving scenario. This contrasts significantly with recipe-style laboratories, where students can complete an experiment and produce a report without ever really understanding or thinking about the experiment involved. The PBL mini-projects are assessed in part by examining the students' individual research diaries, where they report any work they did (background reading, laboratory work, follow up calculations). In addition, students give a presentation on their laboratory work and are asked questions about the project after the presentation as well as during the laboratory sessions. They also submit a short individual reflective piece summarising what they learned and how they found the mini-project, including any benefits and any difficulties. This provides a more holistic form of assessment as compared to traditional laboratory teaching, where only students' reports are assessed.

There are some reports of the use of PBL mini-projects as alternatives to expository practicals. Dunn and Philips (1997a, 1997b) describe PBL mini-projects for analytical chemistry. In the excellent book *Teaching in Laboratories*, Boud, Dun and Hegarty-Hazel (1986) discuss laboratory practicals where students develop their own procedure. According to Domin's descriptors (Table 1*)*, problem-based laboratories have a pre-determined outcome (but only the instructor knows of the outcome) and, significantly, the procedure is student generated. It is this alteration in laboratory teaching style that changes the entire emphasis of the laboratory class and which, we believe, has a significant impact on the students' learning.

In our own studies at the Dublin Institute of Technology we have examined the use of PBL mini-projects for the past two academic years. Students completed their laboratory work in groups and completed their projects over four to five sessions of three hours each. Students were assigned contextualised problems that show the applications of chemistry, similar in style to those suggested by Mc Garvey (2004). Some examples of mini-project titles are shown in Table 2.

This paper describes the implementation of PBL mini-projects in a second year chemistry degree course. An extensive student mini-project system was developed, which involves students completing their PBL mini-project over five 3-hour laboratory sessions. This runs concurrently with 'traditional' laboratory sessions, which students complete at other times during their week. In this paper, the operation of these PBL mini-projects alongside the traditional laboratory practicals is described and the additional benefits that result from combining this new approach with the existing system are examined. It has been recognised that the implementation of laboratory practicals where the student generates the procedure for the practical presents a number of significant challenges (Edelson 1999). This method requires more laboratory time than would normally be assigned to a pre-determined practical, but we believe the benefits observed make the time investment worthwhile.

Method

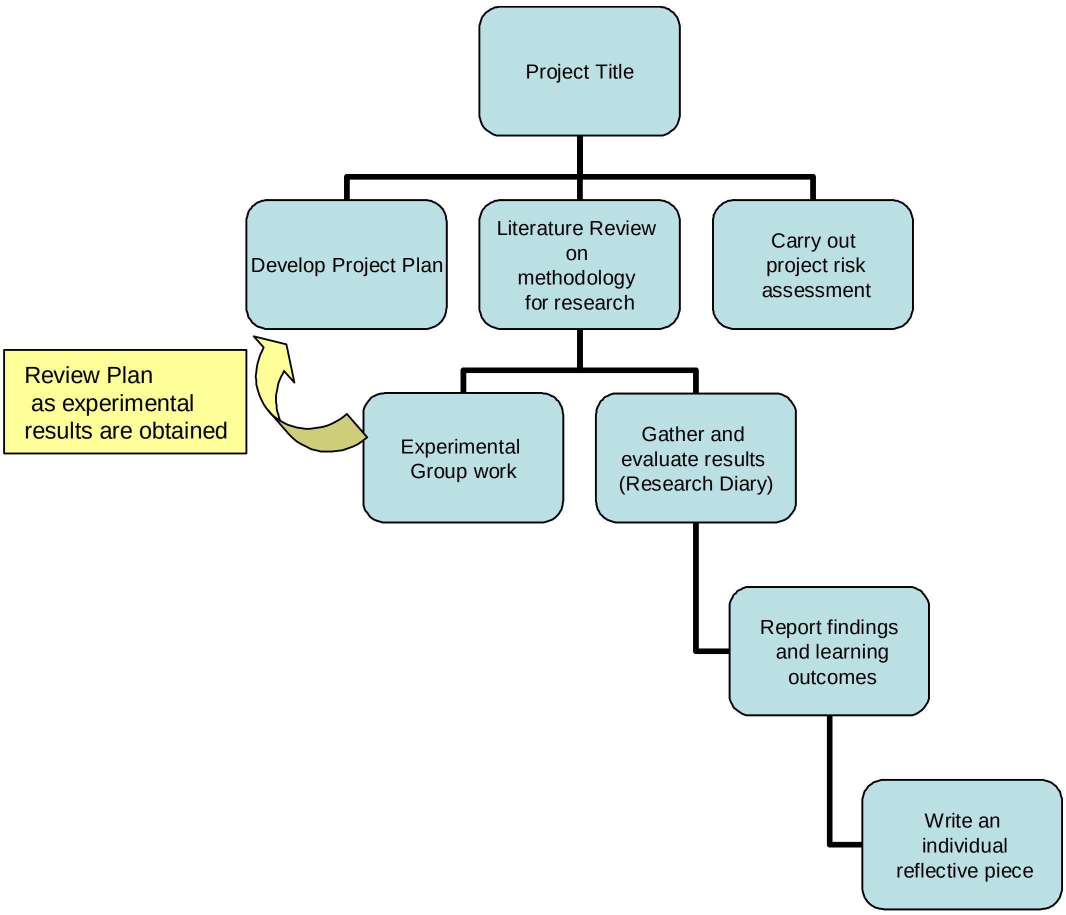
Student Group

The PBL mini-projects were implemented in place of traditional laboratory practicals for a module taken by a group of our Year 2 students studying for an ordinary degree in Physical and Life Sciences (Chemistry option). This degree is designated as a Level 7 degree (National Framework of Qualifications, 2006).

Implementation

Figure 1 shows the general project outline. Students were divided into small groups (3-4) and each group was assigned a member of academic staff as project supervisor.

Figure 1: Schematic flowchart outlining implementation of PBL mini-projects and requirements from students at each stage.



Groups were presented with a project title. The project supervisors could devise a project themselves or select from a list of provided titles (see Table 2). Details of some of these projects are provided in the Supplementary Material. Projects were devised so as to be at an appropriate level, with most of the required theory having being covered in lectures, or readily accessible to the students. The students were given a pre-project talk where the learning outcomes and project plan were explained to them. Each group then met with their supervisor for guidance on the project.

Table 2: Examples of PBL mini-project titles and their relationship to the syllabus.

Project Title	Topics Covered
"Do the forensic tools on CSI* really exist?"	TLC, microscopy, forensic methodology
"Investigation of sunscreen and sunglasses protection" (Abney and Scalletar, 1998)	UV-Analysis methods, Beer-Lambert Law
"Investigation of the calorific value of crisps"	Calorimetry, thermochemistry
"Who killed Mrs. Bernhard Schreider?" (Grove and Bretz, 2005)	Colligative properties, solubility, microscopy, flame photometry, chemical tests
"Can the active pharmaceutical ingredients in a range of analgesic products be extracted, separated and characterised?"	TLC, solvent polarity, recrystallisation, drug formulation
"Can the lipids in cheese be extracted and analysed?"	Saponification, TLC, extraction
"Fluorescent chemicals: analysis and applications"	Spectroscopy (UV-Vis and Fluorimetry), Beer-Lambert Law, Confocal Microscopy
"How are analyses of trace metals, dissolved oxygen and fluorine content in natural and potable water performed?"	Atomic Absorption, volumetric analysis, COD & BOD tests, Ion selective electrodes.
"What are the chemicals in cosmetics?"	Light microscopy, extraction methods, TLC, fluorescence

*CSI (Crime Scene Investigation) is a popular US television series dealing with forensic science.

One of the main aims of this initiative was to encourage student independence and 'ownership' of projects. Supervisors gave the groups an outline of the problem, in essence what the objective of the project was. Groups had to investigate what experiments they would need to do to complete the task. All groups were required to devise a project plan, do a short literature review on the topic and carry out a chemical risk assessment on materials they would be using. These were presented to the project supervisor before experimental work could begin.

Assessment

Students were required to keep individual project diaries for the duration of the project, which were used in the assessment of the projects. These were worth 40% of the individual's mark. Supervisors looked for evidence that the student had kept records of background information gathered, together with references and had kept detailed records of their work in the laboratory. Importantly, we also looked for evidence that the students used both their background reading and experiences/results in the laboratory to modify or expand their experimental work as necessary to help with solving the problem. The project plan submitted at the beginning of the project counted for 15% of the mark. In this, we expected students to outline some of the initial experiments that they wished to carry out, and how they hoped those experiments would help to solve their problem. Risk assessments for any planned practical work were also submitted with the project plan. It is unfair at this stage of the project to expect a lot of detail, as these students were used to the 'recipe-style' labs, and one of the overall aims of the project was to encourage reflection on work completed at each stage, and subsequent modification of experimental procedures. On completion of the project each group was required to give a 15 minute PowerPoint presentation on their project, which was assigned an assessment weighting of 25%. The important criteria looked for were capability in presenting scientific data, along with of the ability to answer questions on their analysis, and to provide suggestions for further experiments/analysis. As this was a group presentation, coherence of the presentation was evaluated. The project statement, a summary and reflection by the student of their project work, was awarded 20%. These statements allowed students to comment on their experience of completing these type of laboratory classes, their experience on working in a group (together with a self-evaluation of their contribution to the group) as well as a reflection on the project and how they would approach it if given the same scenario again. These student reflections were refreshingly honest, and provided very useful feedback for evaluation of the PBL mini-projects. The outline of the assessment structure is shown in Table 3.

Table 3: Breakdown of assessment marks.

Element	Marks
Project Plan	15
Presentation	25
Reflective Project Statement (individual mark)	20
Project research diary (individual mark)	40

It should be kept in mind that the design of the assessment should drive the learning outcomes of the PBL mini-project (Biggs, 2002). On reflection, it would be a useful feedback exercise for the supervisor to identify the individual's strengths and weaknesses to each student in terms of their contribution to the project.

Evaluation

Evaluation of the effectiveness of the PBL mini-projects and extent to which they improved student learning was by means of post-lab questionnaire, examination of student reflections, staff interviews and informal feedback from students.

Results and Discussion

Pre-Experimental Work

All groups used the Internet extensively for several aspects of the project: to find information on the background to the projects; to find Material Safety Data Sheets (MSDS) data for risk assessments and, if possible, to find experimental procedures for their experiment! As reported by McGarvey (2004), students quickly realised that a certain level of critical evaluation of the material downloaded from the Internet was required, which in itself was a useful learning exercise. In several cases, they found that a textbook or reference book was a more useful source of information than the Internet.

Experimental Work

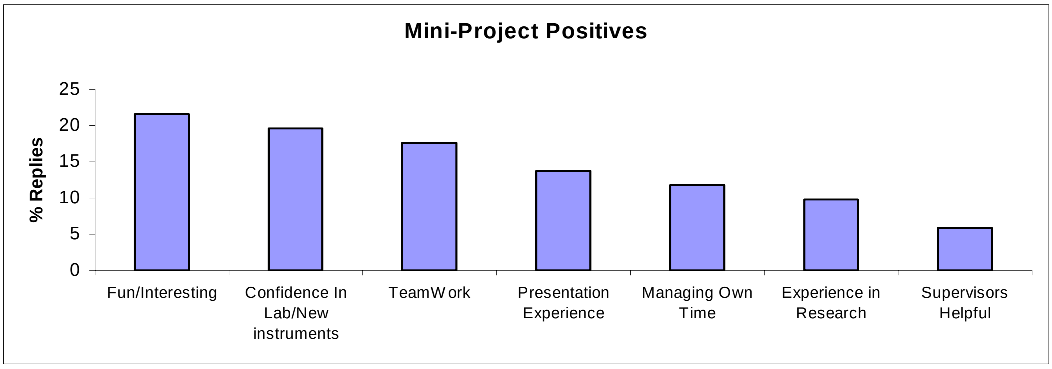
Experimental work began after about 3 hours (one session) of background research and project planning. During the initial practical sessions, most students found daunting such tasks as making up solutions, weighing out solids, or indeed any tasks that they attempted, as they weren't following direct instructions. Some students initially interpreted '*R*' and '*S*' phrases (risk and safety phrases) in the MSDS for the reagents being used without adjusting for quantity and the exposure involved. This made them appreciate the importance of considering these factors when interpreting and applying safety information in risk assessments. In the first few practical sessions, students were also very frustrated by the trial and error experiments or dry runs required for some projects. Also, some students were so used to the concept of recipe style laboratories that they would not have prepared any material prior to the laboratory practical. This was dealt with by telling students that the responsibility to produce an experimental procedure was theirs and hence they would have to spend their laboratory time devising the experimental work plan. Usually, these students had work prepared for the following week. However, mid-way through the study it became apparent that students were, in the main, taking control of their projects, and using their initial 'failures' to re-evaluate their project plan and devise better procedures. This emphasised the fact that students were beginning to think about whether experimental results obtained were useful to them and what role they had in solving the final 'problem'. This was undoubtedly one of the most positive aspects of these laboratories. The students kept a project diary, which they found very useful in this regard.

Student Evaluation

At the end of the projects, students were provided with feedback forms to allow them to give their views and reflections on the project. This questionnaire asked students to list five positives and five negatives, rank what they felt were difficult aspects of the project from a given list and respond to some 'Yes/No' questions on what they gained from the project. The details of these responses are listed below.

1. Positives and Negatives

Figure 2: 'Positives' and 'Negatives' perceived by students on completing PBL mini-projects.



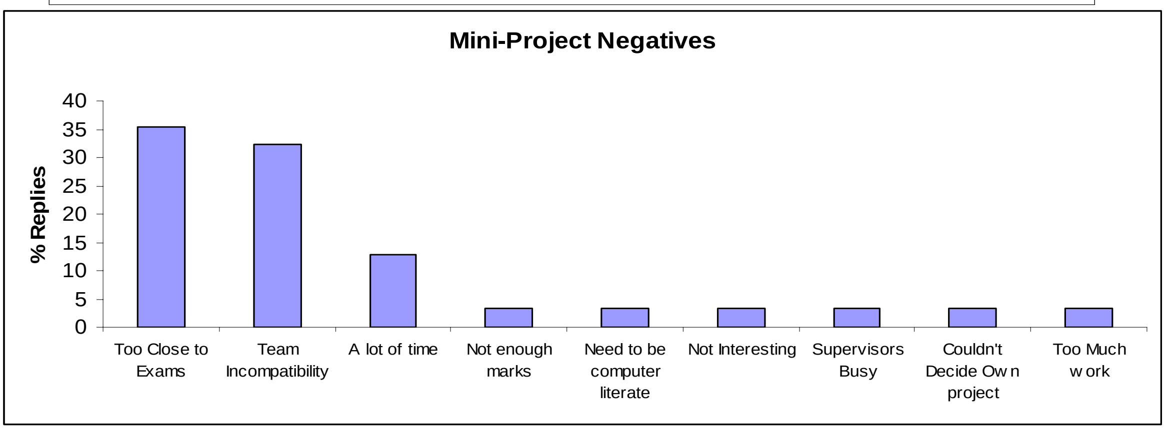


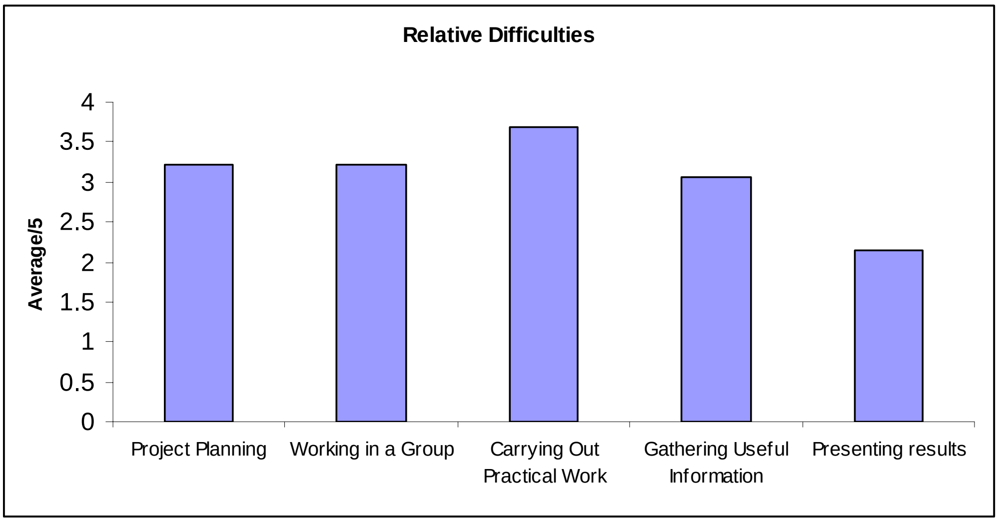
Figure 2 shows the positive and negative aspects of the PBL mini-projects in the opinion of the students. One of the most encouraging responses was that students found the projects 'Fun/interesting', seemingly having forgotten their initial frustrations with the projects. In addition, 'Confidence in the laboratory/use of new instruments' ranked highly, again a stark contrast to the situation observed at the beginning of the project. However, when asked in a separate question whether their confidence in the laboratory has increased, while almost all students (94%) answered 'Yes', there was still some reticence about how prepared they will be for their 3rd Year Individual Projects. This is attributed to a fear of the unknown, and we are confident that students do feel more at ease in the laboratory than they would having only completed traditional practicals. Indeed, as discussed below, we observed that classes who completed these projects settled in to their third year individual project much more readily than classes from previous years who had not.

Among the negatives, two featured predominantly. The first point, that the project was too close to the exams, is a fair criticism, and in future years we plan to run this module at the start of Semester 2 instead of in the second half of that semester. The second, '*Team incompatibility*' proved to be a major issue for some students, but it reflects a common situation that must be overcome in the real-life work environment. In future projects, we plan to use teams of mixed ability. In addition, this is the first time the students have undertaken a major project in a group. Future questionnaires will ask students to reflect in detail on their experience of working in a group.

2. Relative difficulties

For the relative difficulties question, (Figure 3) students were asked to grade on the scale 1–5 the extent to which they found a particular component of the project difficult. Carrying out practical work was perceived as the most difficult part of the project. However, we believe that this only emphasises the fact that students were really thinking about their practical work, and whether their experimental results were useful – which is the ultimate aim of laboratory work in science. Presenting results was, perhaps surprisingly, ranked as least difficult. Students were generally found to be very nervous and anxious about presenting. This had a positive side effect by generating general camaraderie among the class.

Figure 3. Relative difficulties encountered during a mini-project, on a scale of 1-5.



3. Student Comments

Student comments were generally positive. As already stated, team incompatibility and proximity to exams were the most contentious issues. Some of the student comments are listed below.

- *It was nice to have more time in the lab*
- *Got to use equipment we wouldn't normally use*
- *Learned to do more by myself without direct supervision*
- *Looks good on CV*
- *Better than writing up labs*
- *Change team members!*
- *It was nice working more closely with people from my class*

Students repeatedly stated that they used a wider range of equipment than they would normally use. In general, this wasn't really the case and the experiments students carried out were usually similar to the ones they would perform in traditional laboratory classes. What did become very clear is that students gained a much greater understanding of the principles and procedures for using particular instruments or carrying out specific experiments than they would normally do in traditional laboratory practicals (see staff comments, below). It is more interesting for students as they are working on a 'unique' project, as opposed to the traditional laboratory sessions where everyone does the same experiments. This new approach requires more time than traditional practicals. Nevertheless, we believe it reflects real-life problem-solving situations better.

Staff Evaluation of the PBL Mini-projects

We acknowledge that this project system placed an extra burden on our colleagues in relation to their supervision of groups. We were keen to examine if they felt the effort on their part had any extra benefits for the students. Some of the staff comments are listed below:

- *Students were planning their own experimental procedures instead of following a recipe*
- *Worked well, but would suggest a deadline for the project plan so that the experimental work is not unduly delayed*
- *Considerable support required initially, but as project progressed, students became more independent and took more ownership*
- *Found there was better engagement in the course in general*
- *Relies on goodwill of staff*
- *Would like to adopt this approach in other programmes*

The general feeling among academic staff involved was that the bulk of the work was involved in the initial stages – giving students the outline of the project, giving general guidance on how to proceed, assessing the project plan and help with general laboratory procedures. Some members of staff involved in teaching the students in lectures observed a greater enthusiasm among the class for chemistry and enhanced engagement generally after initiation of the PBL mini-projects. Tangible evidence of this is that the class attendance, which traditionally had declined slowly as the academic year progressed, increased after initiation of the mini-project programme.

To examine student understanding of their practical work and related theory after completing these labs, we discussed the impact of the PBL mini-projects with other members of staff assessing the students who have had many years experience in traditional style laboratories. Their comments indicated that, when compared to students who completed traditional 'recipe-style' practicals, students who completed these PBL mini-projects could describe why they were carrying out a particular experiment, what that experiment would tell them and why. In addition, understanding of the theory behind the laboratory work was assessed at the group presentation stage (in their ability to explain and answer questions), in the reflective piece by students, and in their project diary. Therefore staff had several opportunities to assess student understanding of the projects, and compare this understanding with students from previous years who would have completed "recipe-style" practicals. Another benefit worth considering was the class performance in their third year project. We observed that the students who had completed the PBL mini-projects in year 2 in 2004/5 adjusted themselves to the independent project in year 3 much more readily than was usually the case.

Sourcing Ideas

Given the success of this study, it is intended to continue with this PBL mini-project system in future years. The biggest preparatory task is sourcing suitable ideas for projects. Obvious sources are extensive laboratory descriptions in the primary literature (*Journal of Chemical Education*, *The Chemical Educator*), in laboratory textbooks (*Journal of Chemical Education Chemical Resources Shelf*) and on the Internet. We are currently developing several projects that are spectroscopy themed, which are being piloted at present. Details of these projects will be published following evaluation.

In order to implement these practicals on a wider basis, we have decided to eliminate the need for an advisory supervisor, and set up the laboratory sessions so that one laboratory supervisor can control all of the projects. To this end, we are currently developing and compiling some materials that outline the problems to be presented to the student together with support material (sample spectra, suggested pathways to solving problems) which will provide the laboratory supervisor with all of the material required to run the class.

Conclusions

Problem-based learning mini-projects have been used successfully as an alternative laboratory learning experience with second year Chemistry undergraduates over two years (2004/5 and 2005/6). The programme complements the existing traditional laboratory approach and provides students with stimulating 'real-life' problems (PBL mini-projects) to tackle in small groups. Increased class participation and engagement and improved class morale were observed as a result of this change in approach. This observation was confirmed by feedback obtained in an evaluation survey that the students completed. It was also the opinion of the authors that the students were better prepared for their individual research project in their third year as a result of participating in the PBL mini-projects the year before.

Note added in proof: after the submission of the paper the authors became aware of another example of a similar implementation of project-based work in physical chemistry (Tsaparlis and Gorezi, 2007).

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