Incorporating Enquiry-Based Learning in Experimental Laboratory Projects in Chemical Engineering

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Abstract

This report describes a project to embed Enquiry-Based Learning methods into the experimental laboratories (CHEN 30002: Laboratory Projects 3) in the third year of the undergraduate Chemical Engineering programme at The University of Manchester. Experimental projects offer tremendous possibilities for developing problem statements that enable students to learn, not only practical laboratory techniques and safe working practices, but a broad range of transferable skills, such as group and project management and communication. We have redesigned the module so that the problem statements given to the students are less prescriptive. In addition, we provide a more supportive environment that permits the students to actively research, plan, design, perform and report their experimental work. This allows the students to take greater ownership over the project, thus enhancing their learning experience. Overall, we found that the project was successful in making the students more independent learners.

Background

The School of Chemical Engineering and Analytical Science offers BEng (three-year degree) and MEng level (four-year degree) undergraduate (UG) programmes in Chemical Engineering. It also offers additional specialisations in environmental technology, biotechnology, chemistry, business studies, industrial experience and study in Europe. All these courses are fully accredited by the Institution of Chemical Engineers (IChemE).

The School has already run three projects funded by the Centre for Excellence in Enquiry-Based Learning (CEEBL): two to incorporate Enquiry-Based Learning (EBL) in the first year of the UG curriculum (see E Ventura-Medina *et al*. 2007; Curtis and E Ventura-Medina 2007) and one project for a fourth year mathematics module (see P Grassia and G Campbell 2006).

This project aims to reinforce EBL in the UG programme by incorporating it into CHEN 30002: Laboratory Projects 3, an experimental laboratory-based module. This is a 15-credit module that is compulsory for all undergraduates in the School and runs in the autumn semester. A total of 110 students were enrolled in the module. Eighteen of the students were in the MEng with Industrial Experience course; these students undertake an industrial placement in the third year of their studies and take this module in their fourth year, upon return from their placement. The other 92 students were in the third year of the BEng or other MEng Chemical Engineering courses. This case study takes place from September to December 2008.

Rationale

Chemical Engineering is an extremely broad discipline, concerned with the operation and development of processes, such as those used in the production of bulk and fine chemicals, pharmaceuticals, food, electronics and energy (*e.g.*, oil and gas, biofuels, etc.). It integrates aspects of physics, mathematics, chemistry, biology and economics, as well as many other disciplines. The rapid advance, development and usage of new technologies (such as the emergence of bio and nanotechnology) have increased the number of fields with which the chemical engineer must be familiar. Consequently, there has been a growing challenge in trying to prepare chemical engineering graduates for the increasingly wide range of topics they might encounter in the workplace.

Due to the diverse range of careers that our graduates pursue, it is not possible to anticipate the specific skills and knowledge they will require in the future. Therefore, it is crucial that they are comfortable with unfamiliar situations or problems (*e.g.*, designing a new process or operating a new piece of equipment). It is also important that they can identify and acquire the necessary skills and knowledge to tackle these issues. The use of EBL methods within CHEN 30002: Laboratory Projects 3, an experimentally-based module, is expected to significantly enhance student learning, because this course directly offers practical 'hands-on' experience which involves the use of real equipment. It not only teaches the students the particular aspects of the experiments with which they are involved, but gives them the ability to 'independently' acquire the knowledge, skills and understanding they need for themselves. Experimental projects offer challenges, as well as opportunities that are not found in projects driven mainly by computation, writing or library research. In addition, there are many other indirect learning benefits that working with experimental equipment offers. These include the practical involvement with procedures regarding health and safety; experimental design; group and project management; library skills; and communication skills. The use of EBL is expected to improve delivery of these learning outcomes because the students are more motivated by a greater level of ownership over the project.

Approach

The module was introduced in Week 1 of the semester through a one-hour lecture to all the students. This consisted of a 30-minute presentation that included an overview of the expectations of the module, the timetable and assessment elements and criteria. The students were also directed to the Blackboard site for further details of this information. The students were then given their group assignments. The 110 students were randomly divided into groups of approximately six members; the students on the Industrial Experience course were kept in separate groups. The students would work together within these groups for the entire duration of the module.

Each group was given a problem statement, which formed the basis of the Enquiry-Based Learning. The problem statements involved resolving some technical issues with respect to a particular piece of equipment, which would require not only experimental work but also theoretical modelling; they were fairly open-ended to allow the students to explore ideas that they might want to pursue. Note, however, the projects needed to be completed within the rigid constraints of time and resources (*e.g.*, technician time). The groups were assigned to one of the following eight pieces of equipment:

- Refrigeration
- Tomography in a mixing tank
- Flotation tanks
- Tank level control
- Thermosiphon reboiler
- Mixing tank
- Liquid ring pump
- Paper production and testing

After the introductory lecture, the students were introduced to their academic supervisors and postgraduate demonstrator, who introduced the experimental equipment and then discussed their particular problem statement in more detail. The first assignment for the group was to develop a properly researched experimental project plan. This task involved undertaking a critical review of the literature, proposing an experimental design, establishing the associated budget and conducting a risk assessment. The project plan needed to be approved by both the academic supervisor and the School Safety Officer before the group was allowed to perform any experimental work. After the initial meeting, the groups had formal one-hour meetings with their academic supervisor every week. A sample timetable for a group is given in Table 1.

Week	**Activity**
1	Meet supervisor and demonstrator Equipment familiarization
2	Meet supervisor: Discuss initial project plan
3	Experimental work
4	
5	Experimental work
6	
7	Experimental work
8	
9	
10	Seminar
11	Submit final report. Submit self-assessment marks
12	

Table 1. A sample timetable for a group.

Additional material was also delivered through lectures. Table 2 provides a summary of the lectures given during the semester. Each of the lectures was nominally one hour. In addition to the introduction lecture in Week 1, the students also attended a one-hour lecture on safety and a one-hour lecture on library methods. The safety lecture was mandatory for all the students taking the module. It covered a wide variety of issues, including safe working practices in the laboratory and regulations of the Health and Safety Executive (HSE). The library methods lecture taught students how to use various catalogs and on-line databases to search for scientific and technical information. The data analysis lecture covered the treatment and quantification of uncertainties in measurement, as well as general approaches to modeling data mathematically. The report writing lecture covered the basics of technical writing and the various assessment elements of the report.

Week	Lecture
1	Introduction
1	Safety
1	Library induction
5	Data analysis
6	Report writing

Table 2. Lecture timetable.

The students needed to perform a risk assessment before any experimental work would be allowed. In addition, they had to complete the necessary Control of Substances Hazardous to Health (COSHH) forms, in compliance with the regulations of the HSE. These documents needed to be approved by the academic supervisor and the School Safety Officer.

The groups had three sessions with their experimental equipment. Prior to each experimental session, the students submitted a detailed experimental plan to their academic supervisor for approval. Each session lasted five hours. During that time, the students were supervised by a demonstrator (typically a postgraduate student) and aided by a laboratory technician. These experimental sessions were spaced apart by two weeks to allow time for the students to reflect upon the results they had obtained and to plan carefully their next course of action for the following session.

Students were expected to arrange their own group meetings to discuss the progress of their project and to plan and assign tasks. Minutes of all meetings were expected to be kept, which included the attendance and the action points. The academic supervisory was copied into these minutes. After completion of their experimental work, the students had three weeks before they had to give an oral presentation on their project. Following the seminar, the groups submitted their final reports.

Assessment

There were five components to the assessment of the students' performance in the module. The components are summarized in Table 3, along with their relative weight in the overall module mark. The assessment was meant, not only to evaluate the students' performance, but to provide them with a guide to what was expected of them, in an effort to motivate them to achieve the intended learning objectives.

Task	Weighting
Seminar	10%
Self-assessment	10%
Supervisor appraisal	10%
Project management	10%
Technical report	60%
Total	100%

Table 3. Assessment elements.

The seminar consisted of a 20-minute presentation given by each group to peers and academic supervisors (including supervisors of other projects), which was, in turn, followed by a five-minute period for questions, which could be asked by both supervisors and other students in the audience. The marks were assigned to the quality of the presentation (good use of visual aids, keeping to the time, clarity and pace of the speech, etc.) and the responses to the questions posed.

The self-assessment mark was, in part, used to differentiate between the contributions of the individual students within a group. This was an opportunity for the students to assess their own relative contributions, as well as the other members of the group. Each student was asked to assign a mark to every member of the group, including himself or herself, according to his or her performance against a set of specific marking criteria. These included attendance and participation at meetings and taking responsibility for and completing tasks. All of these marks were sent directly to the academic supervisor, who then compiled the marks. The supervisor's appraisal was also used to differentiate the individual performance of the students within the group. The academic supervisor assigned a mark to each of the students according to the same marking criteria used by the students for the self-assessment.

The project management mark assessed the manner in which the groups planned and executed the necessary experiments. It was based on the quality of the project and experimental plans. It also considered the ability of the group to work together to overcome any difficulties, as evidenced by the project plan, experimental plans and minutes from group meetings.

The major contribution to the assessment was a 35-page technical report. The main part of the marks was based on the technical content of this report. This was evaluated according to their experimental technique and ability to make accurate measurements, which are relevant to the problem statement and to estimating the uncertainties in their measurements. In addition, the students were expected to analyse and interpret their data with respect to the problem statement. Particular attention was paid to whether the students attempted a theoretical analysis of the data, based on the previous taught modules, and the information collected as part of the literature review. Finally, the ability to draw meaningful conclusions from their work was also assessed. The presentation and style of the writing also formed a significant part of the final score for the technical report. This included the students' abilities to summarise their work; to convey the motivation and the procedures that they used to achieve their aims; and to present clearly their major conclusions.

Evaluation

Three different questionnaires were used to evaluate the project: 1) the School's evaluation form; 2) the University's standard module evaluation form; and 3) an EBL-related questionnaire. Two of these were the module evaluation forms from the School and from the University, which are distributed to students for all modules delivered in the University. These assessed such topics as the communication of the course material, the quality of the notes/handouts, the identification and achievement of the learning outcomes, the interest of the subject matter and difficulty in comparison to other modules. The responses were on a scale from one to five. In addition, the students were given the opportunity to provide more general written feedback. An additional questionnaire was also distributed, which focused more specifically on issues regarding the Enquiry-Based Learning style used in the module. The first section of the questionnaire asked for responses on a scale from one to five, while the second section prompted more in-depth written responses.

Overall, the module scored well in comparison to other modules within the undergraduate Chemical Engineering courses. In general, the students felt that they were given the opportunity to establish their own research interests; encouraged to find information by themselves (as opposed to simply being given information by their lecturers); and more involved with analysing and evaluating information rather than just memorising it. In addition, they wanted more time with the experimental equipment. Based on this feedback, the project appears to have been successful in making students more independent learners.

However, the questionnaires did reveal large variabilities with regard to how the students felt their group worked as a team and how much they had learned from each other. There were also difficulties in the consistency among groups assigned to different academic supervisors. For example, there were issues with the level of supervision groups received, the quality of feedback given on the initial drafts of the technical reports and the assignment of the supervision mark.

Further Development

During the course of the semester, several groups explored the use of software tools for collaborative group work. Several freely available on-line resources were examined, *e.g.*, GoogleDocs (http://docs.google.com) and Zoho (http://zoho.com). These tools provided a means to share and allow the common editing of text documents and spreadsheets among individuals. While these tools worked quite well for creating basic text documents and spreadsheets, they lacked advanced capabilities needed by the groups (*e.g.*, typesetting mathematical equations and handling references). However, these tools are always being improved, so this issue needs to be revisited in the future.

In addition, the assignment of the self-assessment mark was not consistent across the various groups. While some groups assigned marks to each of their members according to the assessment criteria, many groups simply assigned all members the maximum possible marks. Consequently, all the self-assessment marks needed to be moderated to make them more consistent. As a result, there is a need to change the manner in which the self-assessment mark is determined. Various options are being investigated.

Furthermore, variations in the supervisor appraisal were difficult to mitigate, as only the individual academic was in close contact with his/her particular group. Thus, the mark could not be second marked. Again, various options are being investigated to resolve this issue.

References

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