Embedding Enquiry-Based Learning in the First-Year Chemical Engineering Curriculum

Esther Ventura-Medina, Ted Roberts, Leo Lue, Arthur Garforth, Richard Holmes, School of Chemical Engineering and Analytical Science

Abstract

This work describes the introduction and implementation of Enquiry-Based Learning in the first-year Chemical Engineering undergraduate curriculum at The University of Manchester. Changes to the undergraduate curriculum have been implemented as part of the curriculum review project. However, the main focus of this case-study is the use of Enquiry-Based Learning in the problem solving sessions that substitute for previous traditional tutorials. Problem solving sessions were carried out in a small group work format. Groups had eleven to twelve students each and a postgraduate facilitator for each session. Two-hour sessions were carried out three times a week using a mix of different types of problems: close-ended, open-ended and integrated. Problems were selected and designed to be as realistic as possible, integrating topics from different areas of knowledge. The problem solving sessions were introduced in September 2006 with a cohort of one-hundred and forty students. An evaluation of the new curriculum and in particular of the problem solving sessions was carried out through different strategies. The feedback from the evaluation has been very positive and suggested that although some improvements are needed, the problem solving sessions and the enquiry-based learning approach have been successful.

Background

Engineering education has undergone major changes in recent years. These changes have been driven by the demand of employers wanting graduates being able to succeed in a constantly changing environment, as well as by the fact that students' backgrounds and culture have changed. In the area of Chemical Engineering education in particular these demands have been recognised. Many institutions have addressed this issue, as reflected in activities such as Massachusetts Institute of Technology's project on 'Frontiers in Chemical Engineering Education: a discipline-wide initiative to advance the undergraduate chemical engineering curriculum' (2003) and the current review at the University of Manchester of the Chemical Engineering curriculum.

The revision of the curriculum in Chemical Engineering at the University of Manchester has brought about changes in the content, structure and delivery. As suggested by Armstrong (2006), the changes address aspects of fundamental knowledge, skills and attributes and methods of student engagement. One of the major outcomes of the curriculum review has been significant adjustments to the methods of teaching delivery.

The increasing diversity of students going to universities in recent years has meant that changes in teaching methods are required (Biggs 1999; Felder 2006). In order to close the gap between the students from such diverse backgrounds, it is necessary to modify teaching methods so that students are more active and engaged in the learning process, which can be achieved by using Problem-Based Learning (Biggs 1999).

Problem-Based Learning, or Enquiry-Based Learning in more general terms, provides an environment were students can develop essential skills as they are required to obtain, communicate and integrate information in order to solve a problem (Duch *et al*. 2001). This idea is the main reason for incorporating Enquiry-Based Learning in the Chemical Engineering curriculum at Manchester.

Rationale

This project aimed to embed Enquiry-Based Learning (EBL) in the first-year Chemical Engineering undergraduate curriculum to provide students with opportunities to develop professional skills (e.g. teamwork, communication) and learn and use high-level cognitive skills (e.g. analysing situations, solving problems, applying concepts, interrelating ideas) from the very beginning of the course. The use of real world problems and small group work in EBL sessions was expected to allow students to be partners in their own learning and become independent, whilst enriching their experience and improving their engagement in the learning process.

The previous system of teaching delivery by traditional lecturing and large group tutorials presented difficulties in motivating the students and keeping them engaged during learning activities. In particular with large groups (over 100 students), the subject tutorial sessions have been identified as one of the learning activities where students easily lost interest and did not participate. As mentioned by Biggs (1999), the traditional method of lecture followed by a tutorial is no longer suited to the current student population with a wider range of backgrounds and abilities.

As part of its new, EBL-based delivery, the Chemical Engineering course at the University of Manchester introduced problem solving sessions and small group work as a means to provide the interaction and motivation students need to engage in their learning and to participate more actively. The proportion of the timetable taken up by traditional lectures has been significantly reduced, allowing more time to be dedicated to problem solving sessions. Consequently, the majority of student contact hours have changed from relatively passive lectures to active-learning sessions, which includes problem solving sessions, laboratory and IT classes.

The specific intended learning outcomes for the problem solving sessions using EBL are that students will be more easily able to:

- apply subject knowledge to everyday situations;
- analyse and make critical judgement about data and information presented;
- develop and apply effective and efficient problem solving strategies;
- evaluate situations and draw informed conclusions;
- use resources effectively and independently;
- work in teams;
- communicate well (both verbally and in writing).

Approach

The problem solving sessions are a fundamental part of the new curriculum structure. The main objectives of these sessions are the following:

- to reinforce what has been presented in lectures;
- to promote and develop critical thinking and problem solving skills;
- to develop working skills (e.g. teamwork, communication).

Each problem session lasted two hours, with three sessions taking place each week. Groups consisted of eleven to twelve students with one postgraduate facilitator per group and one member of the academic staff per session, acting as a 'floating facilitator' as in the model described by Duch (2001). Groups were formed with students of mixed abilities, based on previous performance. New groups were formed each semester to provide students with opportunities to work with different people. Each group also had different facilitators each semester. The groups worked in separate 'cubicles' within a large open-plan environment during each session.

The main role of the postgraduate facilitator was to encourage and moderate discussions, as well as to ensure adequate progress. At the beginning of each session, the facilitator described to the group the objectives and the problems that would be addressed. At the end of the session, the facilitator helped students to summarise their achievements. In some cases, these reflective instances occurred throughout the session as students moved from one problem to another.

Students were given a booklet with relevant questions at the beginning of the semester. Questions for each of the problem solving sessions were chosen from the booklet depending on the subject knowledge to be studied during a particular week. The question booklet contained a mixture of close-ended, open-ended and integrated queries. Questions were used in each session to reinforce subject knowledge from lectures; however, some questions required students to investigate new topics and link them to prior knowledge. Questions with an EBL approach were selected and, in some cases, designed to target particular fundamental concepts and encourage the integration of different ideas. In general, the questions used were as realistic as possible. The use of different types of queries was designed to make the students think; discuss and find possible solutions by integrating different ideas and concepts; and reflect on the learning process itself.

Feedback from facilitators regarding progress and difficulties encountered by the students was collected by the problem session co-ordinator after each session. This feedback, along with that obtained from the PASS (Peer Assisted Study Scheme) leaders, was used by the first-year teaching team to clarify issues during lectures and to plan the weekly Plenary Lecture, where difficulties and misconceptions were addressed.

Evaluation

The introduction of the problem solving session in the first-year curriculum was evaluated through a range of strategies: student attendance figures; feedback from facilitators, PASS leaders and staff; focus groups; and a students' experience questionnaire.

Attendance was monitored in each session in order to assess the impact of the new approach in the overall course and to compare with previous experiences of traditional tutorials. Figure 1 shows the attendance at problem solving sessions for the first semester of first-year students.

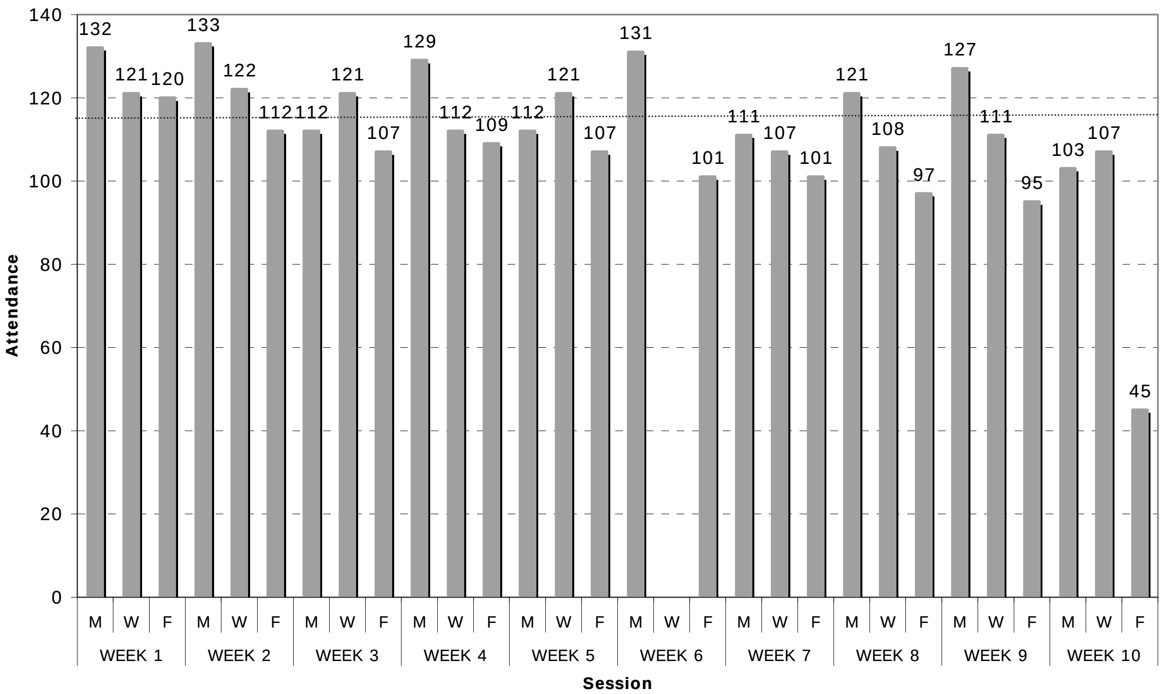

Figure 1 Attendance at problem solving sessions for 2006-07 student cohort (140 students). Sessions during semester one of the first year took place over ten weeks on Mondays (M), Wednesdays (W) and Fridays (F).

The average attendance at problem solving sessions in semester one was one hundred and fourteen (114) students per session (81%) which represents a significant improvement in attendance when compared to the traditional tutorials used in previous years.

Attendance was correlated to overall performance for each student as shown in Figure 2. Although attending problem solving sessions does not necessarily guarantee good exam and course performance, it can be seen that in general there is a positive correlation between the two. Most of the students who regularly attended the problem solving sessions obtained high scores in their exam marks. Data on attendance and performance in the second semester has been collected but has yet to be correlated.

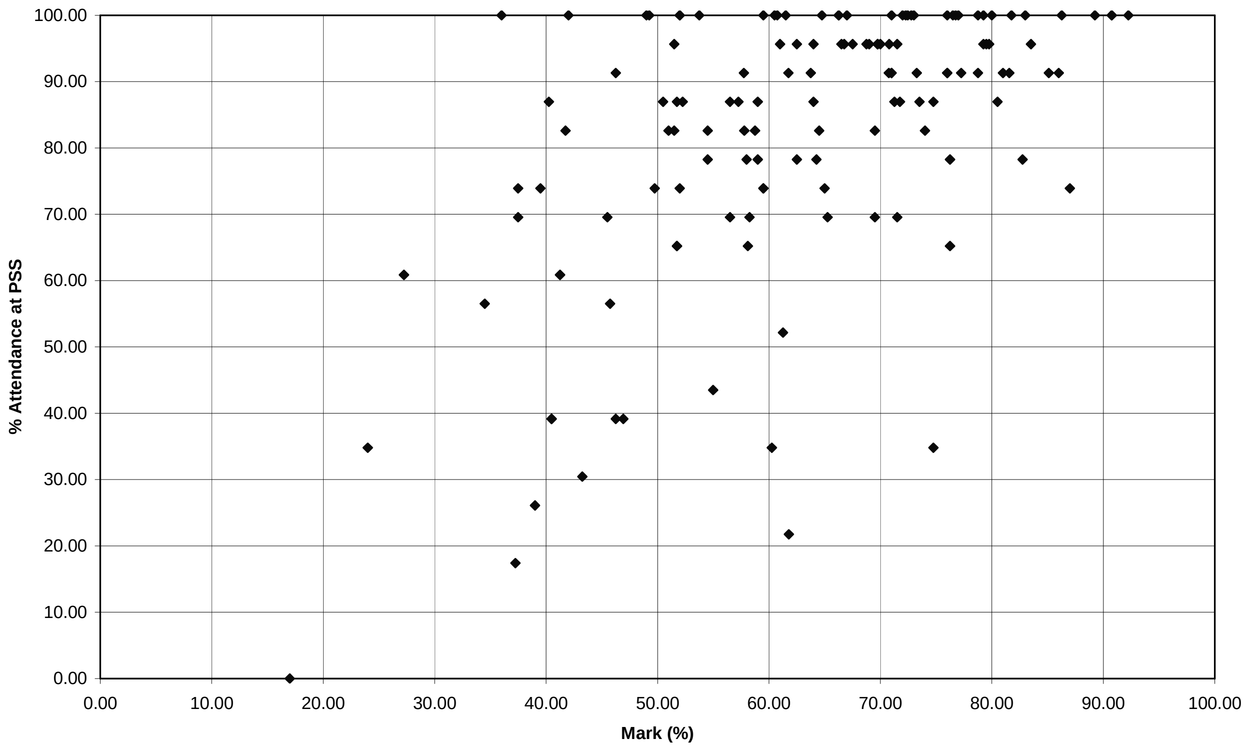

Figure 2 Correlation of attendance at problem solving sessions to average exam marks for the 2006-07 student cohort (semester one, first year).

Feedback was obtained from facilitators after each session regarding difficulties, issues and misconceptions that may have arisen during the session. Additionally, feedback from the PASS leaders was obtained on a weekly basis regarding aspects of the course that the students found particularly difficult. This feedback allowed the first-year teaching team to address issues and adjust teaching activities appropriately.

At the end of each semester, a students' experience questionnaire was issued. The questionnaire aimed to gather students' comments on their experience of the problem solving sessions and the course overall. The feedback from students has been very positive in general. Eighty-six students responded to the first semester questionnaire, with 73% ranking the problem sessions as good to very good in terms of a learning activity. Of the respondents, 94% said that they attended the problem solving sessions and 86% found them useful.

In the questionnaire, students were asked what they liked about the problem solving sessions. Some of the quotations were:

I can discuss problems with friends.

I am able to concentrate and consolidate what lectures have taught.

I do questions that I would not do on my own accord.

I can get others' perspective on questions.

When asked what they did not like about the problem solving sessions, some of the responses were:

some demonstrators cannot help

they are crowded

they are noisy

too early in the morning

nothing

It has been encouraging to realise that most of the major issues students have with the problem sessions are related to the space and settings. Difficulties regarding the space and facilitators will be discussed in the next section.

Feedback from the teaching staff involved in the problem solving sessions was in general very positive. Staff found that the problem solving sessions were a very good way to engage students. The opportunity to have interactive discussions of problems with groups of students was found to be invaluable. The sessions were also considered to be very effective for obtaining rapid feedback on student progress. The sessions were found to be more enjoyable for both staff and students, leading to improvements in the learning environment and in student performance.

Further Development

The introduction of Enquiry-Based Learning in the first-year Chemical Engineering curriculum has been successful not only in terms of enriching the students' experience, by means of increased engagement and involvement in their own learning, but also in terms of their performance and the development of professional skills from an early stage in the course. However, there are still areas that require improvement. One of the major issues is the need for adequate space and facilities for small group work. Ideally, groups would have consisted of only five to six students for EBL activities; however, in our case, this has not been possible owing to lack of space and resource limitations. The issue of adequate space is one that needs to be addressed urgently, especially with the prospect of an increasing student intake in the coming years.

Furthermore, there is the increased demand on resources that this method of delivery imposes. Enquiry-Based Learning is, without a doubt, an excellent teaching method; however, it is heavily demanding in terms of resources—not only in staff time but also facilitators' training, teaching materials and support. In our case, the issue that requires immediate attention is the need for consistency in facilitating groups in problem solving sessions; this may require a more formal and structured induction for postgraduate facilitators.

References

Armstrong, R., 2006. A vision of the Chemical Engineering Curriculum of the future. *Chemical Engineering Education*, 40 (2), 104-109.

Biggs, J.B., 1999. *Teaching for quality learning at university: what the student does*. Buckingham: Open University Press.

Duch, B.J., 2001. Models for problem-based instruction in undergraduate courses. *In*: B.J. Duch, S.E. Groh and D.E. Allen, eds. *The power of problem-based learning: A practical "How to" for teaching undergraduate courses in any discipline*. Stirling, Virginia: Stylus Publishing, 39-46.

Duch, B.J.; Groh, S.E. and Allen, D.E., 2001. Why problem-based learning: a case study of institutional change in undergraduate education. *In*: B.J. Duch, S.E. Groh and D.E. Allen, eds. *The power of problem-based learning: A practical "How to" for teaching undergraduate courses in any discipline*. Stirling, Virginia: Stylus Publishing, 3-12.

Felder, R.M., 2006. Teaching engineering in the 21st century with a 12th century teaching model: how bright is that? *Chemical Engineering Education*, 40 (2), 110-113.

Massachusetts Institute of Technology, 2003. *Frontiers in Chemical Engineering Education: a discipline-wide initiative to advance the undergraduate chemical engineering curriculum* [online]. Massachusetts Institute of Technology, Cambridge. Available from: http://mit.edu/che-curriculum/index.html [Accessed July 2006].