Centre for Excellence in Enquiry-Based Learning

Project Case Study

Innovative Student Assessment in Engineering Mathematics

Esther Ventura-Medina, Paul Grassia, Grant M. Campbell, Benjamin Embley, Julio Sacramento and Konstantinos Tseronis
School of Chemical Engineering and Analytical Science

Abstract

This report describes the results of a project which aimed to make students full partners in the teaching and assessment of an Enquiry-Based/Problem-Based Engineering Mathematics course. Students worked in small groups using Problem-Based Learning (PBL) to specialize in a particular part of the course syllabus. They then taught their specialist part to their peers, and designed a suitable assessment by which their peers' learning was gauged. The desired outcome was to empower students' learning through having them experience the entire 'life cycle' of a taught course module, from preparation, through delivery to final assessment. The student-assigned assessment was the most innovative aspect of the entire project. The assessment results obtained were robust compared to more traditional lecturer-assigned assessment procedures.

1. Background

This report describes an innovative course module developed to teach Engineering Mathematics to fourth-year (i.e. final) students in the Chemical Engineering programme delivered by the School of Chemical Engineering and Analytical Science at the University of Manchester.

1.1. Module Aims and Syllabus

Chemical Engineering students in Manchester take standard Engineering Mathematics throughout all years of their programme. Specifically the fourth-year Mathematics module deals with teaching partial differential equations and techniques for their solution.[1]The aims of the course module, however, are wider than merely training students to manipulate mathematical tools. The intention is that students should develop physical intuition about the equations and solutions studied. Hence there is a strong emphasis on understanding the derivations of the underlying equations studied, and on interpreting the results.

In order to make the interpretation of results as straightforward as possible, particularly simple model equations are selected for study. These have an analytic solution (i.e. an exact algebraic formula), and as such are simpler to interpret than more complicated numerical (i.e. computer generated) solutions. The partial differential equations that students deal with subsequently in their professional careers will almost certainly be more difficult than the ones covered in the module, and will generally require numerical solution. However, the overall physical behaviour of the solutions of the complicated equations is expected to have parallels and analogies with the simpler equation solutions.

[1] In the interests of making this report as general and widely accessible as possible, mathematical details of the equations are suppressed. For the benefit of readers from outside the discipline, who may be unfamiliar with the concept of partial differential equations, it suffices to note that such equations describe the behaviour of a physical system in terms of local variations in one or more spatial dimension(s) and/or time. By obtaining solutions to the equations, the global system behaviour can be deduced.

1.1.1. Classification Scheme

These parallels and analogies can be bound more tightly by exploiting a classification scheme for partial differential equations. The equations which arise commonly in Physics and Engineering can be categorized mathematically into one of three classes: so called hyperbolic, elliptic or parabolic (Kreyszig 1983, chapter 11, p. 519). The origin of this nomenclature is irrelevant to the present report. It is sufficient to know that (regardless of whether very simple or very complicated equations are being considered) hyperbolic equations deal with wave phenomena, elliptic equations deal with steady state physical fields (such as a steady electric field), and parabolic equations deal with diffusion. These general physical features of the different classes of equations can be exploited mathematically in the solution techniques applied to each.

In hyperbolic systems (Lighthill and Whitham 1955a, sections 1-2; Lighthill and Whitham 1955b, sections 1-3) it is sufficient to compute where waves (formally known as 'characteristics') are moving: a physical property is often conserved along a characteristic wave and, if not, changes in some well-prescribed fashion. Thus a solution technique called the 'method of characteristics' presents itself.

In elliptic systems the variation of a steady state field in one direction can often be effectively decoupled from the variation in another direction. A solution technique (James 2004, section 9.5) called 'separation of variables' can be applied. Moreover, fields often display spatial oscillation to enable them to be fit into some confined geometry. Thus oscillating mathematical functions (such as the familiar sine and cosine functions) frequently arise in separated solutions (Stroud 1996, p. 825, p. 953), meaning that separation is often intimately linked with another mathematical topic ('Fourier series' which expresses general functions in terms of sums of various sines and cosines).

Diffusive (parabolic) systems have the property that they respond exceedingly rapidly over short distance scales, but diffusion is extremely inefficient and slow over long distance scales. While the length scale of a diffusive cloud grows over time, it often happens that the shape of the cloud is more or less constant (Batchelor 1967, section 4.3, p. 188). This suggests that a simple solution should somehow be obtained by continually rescaling the length. The shape of the cloud is said to be 'self-similar', the rescaled length is said to be a 'similarity variable' (Ockendon *et al.* 1999, section 6.5), while the solution in terms of this variable is called a 'similarity solution'.

1.1.2. Reduction to Simpler Systems

All three solution techniques described above have a common feature: they reduce partial differential equations (in terms of one or more spatial dimensions and/or time) to yet simpler ordinary differential equations (in terms of one variable only). However, the way in which the resulting ordinary differential equation is expressed and the physics of what it describes are method-dependent (and hence ultimately dependent on the underlying equation class). In the 'method of characteristics' the ordinary differential equation represents a wavefront position with respect to time. In 'separation of variables' it describes field variation with respect to a decoupled spatial direction. Meanwhile, for 'similarity solutions' the ordinary differential equation is written in terms of the similarity variable.

1.2. Module Objectives

The objectives of the fourth-year Engineering Mathematics course module are that students should become adept at all three solution techniques, and thereby be exposed to the behaviour of the solutions of all three classes of equation. The overall aim of the module, as stated above, is to develop students' physical intuition about systems described by the equation classes, by obtaining and interpreting the solutions to particular equations. This intuition will stand them in good stead in their future careers when they encounter (more complicated examples of) equations from the familiar three classes.

After some years of teaching the course in a traditional lecture format, it became apparent that innovations were required in the teaching style. In what follows, the rationale for introducing innovation is described (section 2), along with the actual approach adopted in the most recent incarnation of the course module (section 3) and the implications of this approach for assessment (section 4). Evaluation of the innovations (section 5) and suggested improvements for further developments (section 6) are described next. Conclusions are offered at the end of the report (section 7).

2. Rationale

As mentioned above, the course module had been taught for a number of years in a traditional lecture format, with the lecturer covering the various classes of equations (hyperbolic, elliptic and parabolic), and the background to the mathematical tools required to solve them. Examples were also worked through on the blackboard, both during lectures and in tutorials.

Assessment was via a traditional exam, usually with some questions taken from the lecture/tutorial examples, and some other questions applying the course mathematical tools to unseen problems.

Typically students performed very well on the former type of problem, but very poorly on the latter. This seemed to indicate that they were learning the problems covered in lectures/tutorials, but not really the underlying tools. This was serious, as to a large extent, if the students could not apply techniques and especially intuition to previously unseen equations arising in previously unseen physical systems, the module had totally failed in its primary aim.

2.1. Teaching Style Innovation

An innovation was called for in the teaching style. The decision was taken some years ago that students would be divided into three groups, one called hyperbolic, one called elliptic and one called parabolic. Each group was assigned a physical problem from the respective equation class. They were told to research a solution technique appropriate to their problem, and then to come back and teach both the technique and the problem to their peers.

Student groups met with the lecturer (module leader) in charge of the course once per week. Early meetings were mainly to ensure that the students had selected the 'correct' solution technique for their problem (i.e. the one the course syllabus was actually intended to cover), the module leader providing hints where necessary. Subsequent meetings were to check up on progress, correct misconceptions, and advise students on preparation for teaching the course material to their peers.

The view taken was that, even if students did not learn any more deeply the two techniques taught to them by their peers than they would have done in a traditional lecture setting, at least they should learn one of the three techniques (i.e. the one appropriate to their assigned class of problem) in considerably more detail (this view is indeed borne out in section 5.2 below).

2.2. Special Features of the Student Cohort

Fortunately, there were a number of special features of the cohort taking the Engineering Mathematics course which made the decision to innovate some years back rather easier. These features, as listed below, mitigated the potential risks of allowing students to teach each other.

- It was a small cohort. The size of the cohort in the 2005/06 academic year (13 students) is typical of previous years also. Thus it could be divided sensibly into three manageable groups.
- It was a relatively cohesive cohort. The students had been together for the previous three years of the course, and so knew one another well. Students reported that they felt a sense of responsibility to each other.
- It was a cohort of above average academic ability compared a 'typical' chemical engineering student. The University of Manchester runs both three-year and four-year programmes in Chemical Engineering. Permission to remain on the four-year programme is conditional on performance in earlier years of the programme. Indeed, the vast majority of the students reaching fourth year have maintained year averages of above 60% throughout their studies. The composition of the groups was selected by the module leader to have a range of abilities (from exceptional to good to barely above average) in each group.
- All students had been exposed to group working and Problem-Based Learning (PBL) activities in earlier years of the programme.

2.3. Problem-Based Learning (PBL) Plus Peer Teaching

The course was thus operated in a PBL plus peer teaching format for a number of years. The assessment, however, was primarily traditional[2], i.e. the module leader prepared an exam, typically involving applying one or more of the mathematical tools covered by the course to a problem or problems incorporating some unseen element. Students were required to answer all parts of the paper: they were not allowed to choose solely questions dealing with topics that they personally had been involved in teaching.

As alluded to above, students generally performed well in questions involving the tools they themselves had researched during the PBL phase of the course, and, in other problems, performed no worse than would have been expected in a traditional lecture course. However, the variation within groups (which were of mixed ability by design) was larger than the variation between groups of group averages. This helped somewhat in that the assessment system was perceived as fair: a particular student being assigned to one group over another was not seen to convey any special advantage or disadvantage.

Nonetheless, in course questionnaires distributed to students during the 2004/05 academic year, one student came up with an interesting challenge to the module leader:

> We learn about the topic. We deliver the teaching.
> Why can we not set the exam?

The current project running in 2005/06 and incorporating significant assessment innovations, as described in the remainder of this report, was a response by the module leader to this challenge.

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[2] Under the PBL plus peer teaching format, the lecturer-assigned exam counted for most of the module marks, but a small fraction of the assessment was also reserved for how well students taught each other, according to a specified set of guidelines. This provided a strong incentive to teach well. When the assessment innovations to be described in section 3 were introduced, this direct assessment of teaching was eliminated, in the interests of simplicity. However the module leader noted that teaching seemed to be of a slightly lower quality compared to previous years as a result. Students have also requested that direct assessment of teaching be reinstated (see section 5.1).

3. Approach Adopted

Each student group was permitted to write an assessment question to be answered by the other two groups (obviously groups did not take their own question). These assessments were taken by the students in a course exam held in the final week of the teaching semester (rather than in the subsequent official assessment period of the university). Allowing students to prepare assessment questions for their peers in this fashion raised three separate issues. These were:

1. **Logistics**. Students could not prepare assessment questions at least until they learnt their PBL material, and preferably not until they were preparing to teach (or possibly even, already actively teaching) that material. If the students only met the module leader briefly just once per week, as had happened previously, their learning of the PBL material would have been too slow to permit them to prepare timely assessments.
2. **Quality**. Degree programmes will only be recognized as valuable to the extent that the degree awarding institution maintains quality in delivering them. This, of course, extends to maintaining quality in assessment. Quality assessment questions need to be accurate (error free), appropriate (neither too easy nor too difficult, and differentiating a range of abilities) and clear (not open to misunderstanding). Members of academic staff generally already have the training and experience necessary to ensure that they produce accurate, appropriate and clear assessment questions: the same cannot be said *a priori* of fourth-year students.
3. **Robustness**. If students are asked to prepare assessment questions for each other, a great deal of trust is being placed on them. Procedures need to be put in place to encourage them to maintain that trust. In the event that an abuse of trust occurs, alternative and even more robust assessment procedures need to be available. This linked back to the logistics issue mentioned above, since the student-prepared assessment questions had to be not only ready, but also taken, in sufficient time for alternative arrangements to be made in the event that the integrity of the process was compromised.

3.1. Dealing with Issues Arising

These issues arising were dealt with as follows:

1. **Logistics**. Trained postgraduate demonstrators were assigned to each student group. During the PBL phase of the course the demonstrator-student contact time was three times as much as the module leader-

student contact had been previously. This served to accelerate the PBL phase of the course.

The demonstrator training consisted of attendance at an intensive mathematics module delivered to postgraduate Chemical Engineers who had arrived from abroad. The syllabus was very similar to the fourth-year Engineering Mathematics module, but the module delivery was more intensive over a shorter period of time. The module leader facilitated PBL sessions during this course, with the trainee demonstrators present. Thus demonstrators thereby learnt an appropriate level of intervention for PBL sessions. Each demonstrator was required to become an expert in one of the three equation classes (hyperbolic, elliptic and parabolic): this proved relatively easy as the equation classes turned out to be directly relevant to the demonstrators' postgraduate research projects. Demonstrators were also required to formulate an assessment question relevant to their equation class themselves, so that they would be able subsequently to assist fourth-year students with formulating questions. This was a vital part of the demonstrator training, as students found preparing assessment questions comparatively difficult (see section 5 later).

The module leader still attended a part (but not all) of each timetabled demonstrator-student PBL session to check on student progress. If progress seemed stalled, the module leader would offer hints to possible lines of enquiry. The module leader also questioned the students if there appeared to be important issues they were overlooking. Interestingly, demonstrators commented that students participated much more actively in the PBL sessions when the module leader was not present. In particular, quieter students who participated less than average in a PBL session in the module leader's absence, were almost completely silent when the module leader arrived. Throughout the PBL phase, demonstrators maintained weekly log books of the PBL sessions which enabled the module leader to verify that the sessions were progressing at a reasonable pace.

2. **Quality**. The academic School in the University of Manchester hosting the Chemical Engineering programme (of which the Engineering Mathematics module forms an element) has a member of academic staff designated as the Director of Assessment. The Director of Assessment oversees all student assessment within the School, and thereby helps to maintain assessment quality. The Director of Assessment also doubles as examinations secretary for the Chemical Engineering programme, and in this latter role, his duties extend to reading through all draft exam papers for that programme produced by academic staff members within

the School.

Feedback from the Director of Assessment on proposed exam questions is a valuable component of the training received by members of academic staff newly arriving in the School. When plans to use student-assigned assessment questions in the fourth-year Engineering Mathematics module were proposed, the Director of Assessment was consulted regarding what training would be appropriate for the students to ensure they could produce questions of a similar quality to those from an academic. The training programme consisted of a seminar held by the Director of Assessment (considering several exam papers in various modules from previous years and noting what was good - or bad - about them), plus a written guide with tips for good practice in preparing exam questions. Interestingly (see section 6), the seminar was not perceived by the students to be of much use, while the written guidance was perceived to be more helpful.

Another quality assurance procedure employed by the University of Manchester is to have one or more external examiner(s) assigned to all degree programmes. The external examiners have the opportunity to see and comment upon assessment questions (after the Director of Assessment has done so). Given the novelty of the proposed assessment system for the Engineering Mathematics module, it was thought important (especially the first time the module was run) to seek the opinion, in advance, of the external examiners on the student-assigned questions.

This decision unfortunately led to a large number of issues concerned with the course time-scale and deadlines (see sections 5, 5.1 and 5.4.1). As such, it is no longer proposed to follow exactly the same procedures in the future. Instead, assessment materials for the module (student-prepared questions and their peers' attempts at answering them) will be made available after the exam for review by the external examiners. Since the Engineering Mathematics module is taken in the penultimate semester of the degree programme, in the event that the externals are dissatisfied, students could still be recalled for an additional lecturer-assigned exam in their final semester.

3. **Robustness**. This is probably the issue which caused most concern to the module leader and Director of Assessment. Students had to be given strong incentives to avoid cheating (e.g. to avoid circulating copies of assessment questions to their peers in advance of the exam). Incentives also had to be in place to stop students setting questions which were either ridiculously easy or impossibly difficult.

It is worth remembering that the students on this course module are fourth-years, only several months short of graduating and embarking upon professional careers. From that point of view, it would be hoped that they are mature enough to be entrusted with confidential information. Indeed they could, in principle, have opted to leave the university with a three-year degree, and therefore already have been in professional employment, where they presumably would have managed sensitive commercial information.

It is also worth noting that they are all of above average academic ability. It is unlikely that (confident of obtaining their degrees by honest means) they would wish to put their entire degree progress at risk very close to finishing by being involved in accusations of serious academic malpractice. The fourth-year Engineering Mathematics module contributes only 3% to the overall weighted average mark received for the entire degree programme: a slightly higher or lower mark in this course module is unlikely to make a material difference to final degree outcomes for most students, suppressing the temptation to cheat. A related point is that the vast majority of the students in the cohort have already maintained year-on-year averages above 60%: any marking scheme which brought one's own mark below 60% if sensible assessments were not assigned would provide a strong driver for them. These special features of the student cohort were exploited when attempting to devise a suitable assessment system for the course module, as section 4 explains.

4. Assessment

It was decided that assessment would be 50% by individual student exam performance and 50% by group performance. The group performance mark contained a small element (10 marks out of 50) associated with delivering their proposed exam question along with a marking scheme and model answers. However, the bulk of the group performance (40 marks out of 50) came from how *other students* performed on the questions set by any particular group.

This reflected an important shift in the viewpoint of where evidence of learning should be demonstrated. Students certainly demonstrated their learning by answering exam questions correctly as in traditional assessment; however, they also demonstrated learning by *setting* suitable/appropriate questions in their specialist topic.

4.1. The Question Drafting Process

Students took their questions through a process of two drafts with demonstrators and the module leader reviewing these drafts. The general form of the questions was apparent in the first draft, but typically first drafts still contained technical inaccuracies that needed to be corrected. The module leader also advised on parts of questions he perceived as potentially too easy or too difficult. By the second draft, many errors had been eliminated, but there were still numerous style and layout issues to be addressed, and questions also needed rewording to improve clarity. It would have been useful to return the questions to students at this stage for a third draft, as this would have helped develop the clarity of the students' technical writing, but unfortunately time constraints (for sending papers to external examiners) intervened. Thus the module leader took it upon himself to make the required changes and produce the final version of the exam paper.

One interesting feature (pointed out by the module leader to the students) arose in the process of students drafting questions and model answers. The model answers that students prepared did not always correspond precisely to the question they asked: occasionally the model answers omitted the answer to the very last part of a question, or they answered a question very closely related to, but not identical to, the one actually asked. Had the module leader set the paper, and had the students submitted that same answer in a traditional exam, they would have received most of the marks assigned, but certainly not all of them. It is possible that the exercise of asking students to prepare questions and model answers in this module has drawn their attention to the importance of answering questions more fully and/or more precisely in traditional exams.

One student group showed particular flair when developing their proposed exam question. They took the initiative in deciding to base their question on a novel physical system, relevant to both Chemical Engineering and to the mathematical tool they were exploring, but which had never been used as an example before in the Engineering Mathematics module. Through drafting their question, they learnt a considerable amount of new material. The other two groups showed less creativity: their questions had some overlap with past exam questions, albeit with some unseen material added on.

There was, unfortunately, nothing envisaged in the assessment criteria for the module to reward creativity, novelty and initiative in preparing questions. This will, however, be introduced in future years. Giving students a remit to be creative, novel and innovative in preparing questions is expected to have a twofold advantage. Firstly, students will push themselves to learn more while preparing questions. Secondly, they will be expecting other groups to set novel questions in the exam: they will therefore be obliged to revise material they are taught at depth, not merely work through past questions at a superficial level.

4.2. The Marking Scheme

When drafting questions, student groups were told to make the marks sum to a total of 25 (each student sitting the questions from two other groups for 50 marks total). The exam scripts were ultimately marked by the module leader, but employing the model answers that the students had prepared. Students were given a remit to devise a question for which their peers would average 15 out of 25. If the average was exactly 15, the question set was deemed to be highly appropriate (and the group had demonstrated a good ability to assess their peers): they were rewarded with a high group mark. The extent, if any, to which their peers' average deviated from 15 marks reduced the group mark component according to a transparent formula. The penalty for making a question slightly too difficult was less than that for making a question slightly too easy: hence student groups were encouraged to err slightly on the side of difficulty. This was felt to be appropriate, as the groups themselves would learn more by formulating a difficult question rather than an easier one.

Variants of the marking formula were possible, e.g. a target standard deviation as well as a target mean could be set for the exam questions: this rewarded groups that differentiated their peers' abilities. However, whichever precise formula was used, an important principle was adopted. The formula should ensure that groups setting a question either so extremely easy or so extremely difficult that their peers averaged respectively 25/25 or 0/25 were penalized with zero marks via the formula. Since the formula-driven component of the group mark was worth 40% of the total module mark, no student in such a group could score above 60%, a mark with which (as already stated) students in this fourth-year cohort would be very dissatisfied. By making other groups' assessment inappropriately easy or inappropriately difficult, a group would therefore simultaneously punish itself. The onus was therefore on students to take the setting of assessment questions very seriously. Moreover, circulating copies of assessment questions to peers prior to the exam was strongly discouraged: if detected, it would leave students open to serious accusations of academic malpractice; even if undetected, it could serve to skew averages well above target levels, and thus penalize the group circulating the question in the first place.

Although extremely inappropriate exam questions were penalized heavily, the marking scheme for the group mark was designed to ensure that any group preparing a reasonably fair question should score highly. This was borne out in practice: the average group mark was 38/50, while the average total exam score was 27/50, giving an overall module average 65/100. This is in line with expectations for this cohort, and in fact the module average was identical to that in another (more traditionally examined) module taken by this same cohort in the same academic semester delivered by the same module leader and dealing with a similarly mathematical subject.

The relatively generous group marking scheme provided students with an incentive to cooperate with the innovative assessment process. The alternative put forward by the module leader (an exam set by himself worth 100% of the module mark, if at any point he suspected that the innovative assessment process was being compromised) was intended to be a less attractive option.

The exercise of asking (and trusting) students to prepare exam questions had an unforeseen consequence which reach fruition well after the module had finished. During job interviews many students were asked by interviewers to give examples of times when they had been placed in a position of trust or of responsibility to others and/or had managed confidential information. Students report that referring to the assessment of the Engineering Mathematics module created an extremely good impression with interviewers. Much more detailed student opinions about the module are described in the next section.

5. Evaluation

Evaluation was carried out through semi-structured interviews with three groups of students, which were the same groups as those that had worked on the module. The purpose of the evaluation was to determine how the modifications to module structure, delivery and assessment criteria affected both the learning experience of the students and the outcomes of the course. In particular, the evaluation aimed to determine the impact on learning and outcomes that arose from the main innovation introduced, namely the preparation of the assessment by the students. What follows compiles the impressions of students regarding their learning experience.

Students thought that the module was a very good learning experience. They considered that the PBL element provided them with opportunities to work independently, to explore different routes of enquiry and to be innovative. They enjoyed the small-group work and the challenges associated with teaching their peers. Students also appreciated the trust that the School has placed upon them to deliver the module’s assessment. They liked to work at a professional level with a high level of expectations. They found that preparing an exam question helped them to reinforce their learning and further develop transferable skills. What students liked the most was the teaching preparation and delivery. They felt that they learnt much better by teaching than by being taught, partly because of the disparity in the quality of what was taught. They found that proposing and preparing an exam question was the most difficult aspect of the module. Most students appreciated the assessment guidelines provided for the module and their transparency. Students have suggested the following areas for improvements:

- Time-scale: deadlines; balancing the time for PBL and preparation of teaching vs time for delivery of teaching, time for preparation of assessment and time for revision: the time-scale of some parts of the course was very compressed owing to deadlines for sending material to the external examiners for review.
- Quality of teaching: making the teaching element a more formal requirement and assessing it directly, as well as providing guidelines for a delivery with a wider scope, instead of delivery focused on a single narrow problem.

5.1. Actions to be Implemented in the Module in Future Years

The main actions taken by the module leader for implementation in future years are:

- Revision of time-scale. A new time-scale has been proposed to allow a better balance in the time allocated for the PBL element, the teaching preparation and delivery, and the time allowed to prepare the assessment. The fact that the assessment material will no longer need to go to the external examiners before the end of the semester (it will be sent the following semester instead) will help to have a more fairly distributed time allocation for different activities.
- Changes to the assessment criteria. Changes have already been made to have direct assessment of the teaching element and also to reward students' creativity and innovation in the preparation of exam questions. It is noteworthy that direct assessment of the teaching element according to a definite set of criteria had already been used in the past with this module, during the period when it was run as a PBL plus peer teaching course. This was prior to the more recent innovation with the students developing the exam assessment questions themselves. In the interests of simplicity, direct assessment of teaching was suppressed upon introducing the latter innovation, as it was felt that the students now had another incentive to teach well, albeit an indirect one (namely their performance is tied to their peers' achievement in material that they teach their peers). Reintroducing direct assessment of teaching is a straightforward matter.

A more detailed list of suggestions from students for improvements in the delivery of the module, as well as comments upon these suggestions, can be found in section 6.

The following sections collate in detail the main ideas from the students' experience in terms of the overall module organization (section 5.2), their teaching and learning experience (section 5.3) and the preparation of the assessment (section 5.4). Finally, section 6 enumerates the areas for possible improvement in the delivery of the module and comments upon the suggestions for changes.

5.2. Overall Module

Students thought that the module overall was very good. Most of them found that it was quite different from what they are used to in terms of teaching, even when compared to other previous PBL experiences. The module provided them with opportunities to experience learning from a different perspective. The fact that they had to teach, not just simply give a short seminar, and also prepare an exam question was new to all of them.

Most of the students liked the independence and the involvement that this type of teaching and learning experience brings. Some of them mentioned that they were involved in the learning process continuously throughout the module, much more than they usually are in other modules.

A few students commented that they learnt very well the material they had to teach but considered that their learning of the other topics, which they were taught by their peers, was rather shallow. Only one student felt that Mathematics should be taught with a more formal and traditional approach through lectures and tutorials.

As mentioned earlier, all students liked and appreciated the trust that the School had placed on them to deliver the assessment in a professional manner. However, they recognised that the measures in place (a possible exam after the end of semester prepared by the module leader) were a good way to ensure the successful outcome of the assessment. They liked the fact that they could work at a professional level and handle confidential information.

5.2.1. Module Requirements and Resources

All students agreed that the course requirements were clear from the beginning, including deadlines, level of expectations and in particular the assessment criteria in which the allocation of marks was very transparent. Also, most students agreed that the clear requirements of the course and their level of involvement were the main drivers for having a good and productive learning experience.

Students agreed that the resources available for the course (references, demonstrators and notes) were good. References and textbooks were recommended, although the course did not follow a particular textbook. They all agreed that their main references were the problems set, the notes that they made during sessions and the demonstrator, although they had access to other resources as well (e.g. library and internet).

All students said that demonstrators were an essential resource for the progress and success of the course. They also recognised the importance of the support and input from the module leader during each session, especially in terms of guidance and ideas for exam questions. Students had the demonstrator as the first port of call but knew that the module leader was also available.

Some quotations from students were:

> I liked learning how to teach. Writing an exam paper was quite interesting. I have more respect for lecturers now, it is lot harder than what I thought.
>
> ...I really enjoyed it, it was a different spin of things.
>
> I think that because it is making us do things, I quite like this course instead of 12 weeks of lectures...

Although the general view was very positive, students perceived that there are aspects that could be improved (see suggested improvements in section 6).

5.3. Teaching and Learning

Teaching was what students enjoyed the most in this module. The few students who did not fully participate in the delivery of the teaching, however, liked the small group work and learning by doing instead of passively receiving information.

All students agreed that the fact that they had to teach the subject meant they had to learn it well. Although most students have delivered seminars, presentations and in some cases micro-teaching sessions previously, they acknowledged that the preparation in this module was more demanding in terms of knowing the material well and producing handouts.

5.3.1. Comparison with Traditional Teaching and Learning

All students found that PBL was much better than the traditional lectures and tutorials because it kept them engaged throughout the whole learning experience. This allowed them to learn the material in depth and deliver the teaching confidently later on. They also found that the workload was fairly distributed between all students because the teaching was divided into three topics, one per group.

Most students preferred the PBL approach to traditional lecturing because it led to deeper understanding. However, they felt that if all modules were to be taught using PBL it would be very time consuming for them. In courses like this where PBL techniques were employed, they also thought that the assessment strategy of the learning needed to be considered more carefully (compared to traditional lecture courses) to ensure both learning and progression.

All students agreed that the time allocated to learn the topic by PBL and prepare the teaching was sufficient. However, they also agreed that some more time in the preparation of the assessment would have helped them to produce an exam question of higher standards.

As alluded to in section 5.2, although all students found that they learnt and understood their own topic quite well, they did not feel so comfortable with the topics they were taught. In that respect, they felt that the course was very similar to any other topic that they learnt through lectures and tutorials.

5.3.2. Teaching Preparation

Every group had the freedom to organise and decide upon the teaching preparation and delivery. Only in one group did everyone teach a section of the material. In the other two groups, everyone participated in the preparation but only two people in each group delivered the material. One group thought that the material that they had to teach was not sufficient for everyone to do some teaching.

All groups prepared handouts and most of the students found that the preparation of these actually reinforced their learning of the topic. All students in each group were involved in the preparation of the handouts. One of the groups prepared handouts only after they had delivered the teaching (perceived as less useful), whereas the other two groups prepared them beforehand and distributed them in their teaching session. Only one of these latter two groups sought feedback from the module leader regarding the material in their handout prior to distribution. The handout produced by the other group contained errors that had to be corrected later on.

One group covered the relevant background of the problem at hand, as well as solving the problem itself. They thought that it was a good idea to provide other students with some background information of a more general case. They taught using a deductive approach: after covering the background information they moved onto solving the particular problem with which they were dealing.

The other students mentioned that it seemed rather difficult to generalize the methods to make them more widely applicable just from being taught with a specific example. They claimed that this is because they are more used to learning by deduction than by induction.

All students found teaching their peers useful because not only did they learn the material and understand it well, but they could also relate better to their peers than to the module leader. Through being at the same level of experience, communication was much easier.

As mentioned in section 5.3.1, all students agreed that the time allocated for learning the material and preparing their teaching was enough for the tasks set: they did not need to work outside sessions.

Some students also thought that they learnt better their own topic, partly owing to the new and different learning style (PBL) and partly because of the amount of time allocated for that period of their learning (compared to that for learning from their peers during the subsequent period of teaching delivery). Indeed, some students felt that the teaching they received from some of their peers was not of a good standard because (as mentioned above) it did not necessarily cover any background material for general cases and it was not always well organised.

5.3.3. Teaching Delivery

Most students found delivering the teaching an interesting challenge, as it meant not only knowing and understanding the material well but also communicating it effectively and clearly and being able to answer questions. Although delivering the teaching required a good level of understanding, students pointed out that any group members not directly involved in the delivery could potentially not achieve the same level of understanding, as they will not subsequently be examined on their own topic.

All students agreed that they learnt much better by teaching than by being taught. Some of them felt that the teaching of their peers was very similar to what they would have obtained from a lecturer. However, the facts that there were more than one person teaching (and thus a greater variety of teaching styles), and that they were at a very similar level of experience helped (see also section 5.3.2).

All students commented that the teaching delivery (as opposed to the prior teaching preparation) could have benefited from more time. The learning that occurred during the teaching period was referred to as shallow (see also section 5.2) partly because of time constraints.

Most students enjoyed the experience of teaching, although not everyone was fully involved in the delivery. Some of the students who were not involved in the delivery felt that, had they become more involved, it could have improved their learning experience. Some of them enjoyed the direct contact and communication with other people, whereas some other students preferred the experience of solving a problem and showing the solution to others more informally. Each group had a different teaching experience and found different areas to improve it. Some students would have liked to have been able to have different ways of explaining an idea; indeed some of them found it frustrating not being able to have different approaches at hand to address questions from their peers. This might be because, in general, they focused on solving one question only, and less on background material. Some other students would have liked to have developed more material to allow everyone to be involved in delivering the teaching. Finally, some other students felt nervous and under pressure during the teaching sessions, which affected their delivery. Indeed, some students found it difficult to deal with the anxiety of making mistakes when writing on the board, but most of all answering the questions from their peers and the module leader. In general, however, they found that preparing the teaching material and doing the delivery were fairly easy.

5.3.4. Developing Skills through Teaching

One student felt that the methods were not all learnt in depth and that the teaching and learning experience was not related to ‘real’ Chemical Engineering problems. However, it is noteworthy that the Chemical Engineering discipline is currently undergoing a period of rapid change, and that, as a result, there is a consensus amongst educators that a curriculum based solely on traditional Chemical Engineering problems is in need of revision (Shaeiwitz and Turton 2006; Armstrong 2006; Pekdemir *et al.* 2006).

Moreover, most students taking the module agreed that its aims were not only about acquiring knowledge and technical skills, but also about developing transferable skills. Indeed, all students agreed that they had in fact developed transferable skills through this module. The skills they developed further were principally communication (both oral and written), analytical and interpersonal skills, as well as doing research and working as a team.

5.4. Assessment

Students thought that setting an exam question was challenging. However, once the preparation process started they felt more confident. As mentioned in section 5.2, they also appreciated the trust that the School had placed on them to deliver the assessment of the module. They thought that the process was quite transparent and clear from the start.

5.4.1. Exam Question Preparation

Students found that preparing an exam question helped them to reinforce the material that they had just learnt via PBL.

Students most enjoyed finding out the kind of thought that goes into exam paper preparation and procedures. Some of them also enjoyed very much the independence and freedom to be innovative and produce a question based on a completely new physical situation.

Most students liked the challenge of aiming for their marks based on what they thought their peers will answer correctly in the exam. Moreover, most of them found that predicting what their peers would answer correctly was relatively easy.

Some students did not like the fact that by setting an exam question they could influence their peers' marks. In a traditional setting the outcome of the exam would not be affected by the students' own decisions. Some other students were worried that the time allocated for answering the question was not enough, leaving the possibility of people not finishing the exam paper.

Students found that pitching the exam question at the right level was quite difficult, in particular being able to discriminate students by ability. Specifically, although they could readily predict their peers' performance given a particular question, it was a challenge to find a question which some of their peers would find easy and others would find difficult. The need to discriminate abilities was also linked to the course assessment criteria, since groups had both a target average mark and standard deviation for the results.

Each group identified a different aspect as the most difficult part of preparing the assessment. One group found that decoupling the different parts of the question and having a well balanced question that both filled the allocated time and spread the level of difficulty was quite hard. Another group found that finding an idea of a physical system that could be described with their type of equation was hard. Another group found that allocating marks within the question was quite difficult and they had to iterate through that process as there were different approaches to arrive at the answer to the question (a short method and a long method, with different weightings to the marks being appropriate depending on the method selected).

Most students thought that more time to prepare the assessment could have been translated into a better quality exam question, especially since the preparation of the teaching was parallel to the preparation of the assessment. Also, they felt quite rushed at the end of the module and with little time to revise. They perceived that the time required to prepare the teaching was much less than that to prepare the exam question. Indeed, only one group found that they had enough time to prepare the exam question. As mentioned earlier, the reason for the tight deadline imposed on the question preparation was a wish to have questions ready to send to the course external examiners for review. Incidentally, the externals commented that the exam paper compiled from the questions submitted from each student group was a 'good paper'. No distinction was noted between this paper and those prepared by academics.

Support and Resources

The students felt that they received very good support from the module leader when preparing the assessment, not only in terms of giving feedback about the quality, relevance and adequacy of the written question but also when they were looking for ideas at the beginning. All students did the recommended changes to the question, although one group objected that their question underwent further edition without their knowing the reason for it. (In fact, the reason was to remove some minor errors and ambiguities. As the question needed to be sent to the external examiners that same week, there was unfortunately no time to consult the students).

All students thought that the session with the Director of Assessment to obtain guidance on how to prepare exam questions was not very useful. The session seemed to have covered what the demonstrators and the module leader had already mentioned to the students. Also, the session was done at a late stage when most of them had almost finished preparing their exam question.

Developing Skills through Assessment Preparation

Some students found that they actually had the opportunity to develop further their writing skills by preparing the exam question. They recognised that the task required more precise and clear writing than, for instance, writing a report. Had there been time for further drafts of questions, the clarity of their writing should have improved even more. Some of them also learnt how to use a new scientific document preparation software. Some students also found that preparing and planning an exam question helped them to target their revision in other modules.

5.4.2. Comparing Quality of Assessment and Teaching

The quality of teaching and how well it prepared students for the exam was perceived differently in each group. Two groups thought that the teaching from their peers was not really relevant to their exam question. One group mentioned that the teaching lacked sufficient background information about general cases. Another group, however, was satisfied with the teaching, as it was well related to the exam questions.

Most students found the exam paper slightly long as they could not finish all the questions. They thought that this might be mainly because the questions were not benchmarked in terms of time.[3] Two groups of students found a question they had to answer particularly hard, as they did not consider that it was related to any of the material taught by the group and involved a physical situation that they were studying during the semester in another module. It was in fact related to the underlying mathematical tool, but not to the problem the students were taught as an example of the tool. The importance of the underlying tool may not have been emphasized sufficiently in the teaching.

Some students perceived the exam more like an in-class coursework or a test than an actual exam for the module, partly because it was done during term time, rather than in the official assessment period. This was beneficial as they felt under less pressure than in a formal or official university exam. They also knew that if the overall class performance was exceedingly poor compared to expectations, to the extent that the new assessment innovations were considered compromised, there was a possibility that an official exam could still be held later on.

[3] The time permitted to attempt the exam was 90 minutes, which is the same time period as was allowed in previous years for a lecturer-assigned exam.

6. Suggested Improvements & Further Development

As mentioned in section 5.3.1, all students found that PBL was much better than the traditional lectures and tutorials because it kept them engaged throughout the whole course. They also found that active learning was much more effective than receiving information from someone else (passive learning).

However, students found that some aspects of the module could be improved. By way of summary, areas of improvement suggested by the students and comments upon those suggestions are described here.

1. **Overall Module**

(a) Having an introductory lecture with a stronger focus on the engineering relevance of partial differential equations, as well as potential industrial situations and applications in which they could encounter similar problems in the future. Students felt that the first lecture was more an introduction to the way in which the module would be managed, than to the subject.

COMMENT: Partial differential equations are of course central to Physics and Engineering, as they describe the behaviour of a physical system in terms of local spatial and temporal changes within it. By finding the solutions to such equations, the global system behaviour can be found. Certainly an introductory lecture of the nature suggested (or even a briefing document containing the relevant information) would help to dispel any claims (see section 5.3.4) that the course may be unrelated to ‘real’ Chemical Engineering.

(b) Adjusting the time-scale for deadlines so that there is enough time to produce and, if necessary, correct proposed exam questions. They all agreed that it is better to have the exam before the official university assessment period, as they tend to be overloaded with assessments in other modules during the official assessment time.

COMMENT: The time-scale for question preparation was tight since the questions were to be sent to the external examiners. However, this constraint will be removed in future. Instead, assessment material (consisting of the questions prepared by the students and their peers' attempts at answering them) will be made available to the external examiners in the following semester.

2. **Teaching and Learning**

(a) Making teaching compulsory for everyone to improve understanding and to enhance their experience.

COMMENT: Teaching delivery is undoubtedly a valuable learning experience for all those involved in the delivery. However, insisting that delivery is compulsory may be incompatible with the innovative assessment style employed in this particular module. By and large, the students taking this module are academically competent, but they are not all equal in terms of oral presentation skills. A weak teaching delivery by a particular group member may disadvantage students in other groups, if an exam question is subsequently based on that particular presentation. If the assessment for the course had been more traditional (i.e. an exam prepared by the module leader) there would be scope for making the teaching compulsory, since the module leader could base the assessment on those parts of the course which were well taught. Alternatively if the students had been given the opportunity to deliver teaching, but not prepare assessment, in an earlier stage of their programme, one could operate the current module, where they are involved in both teaching and assessment, with a higher degree of confidence in uniformly high teaching standards.

(b) Assessing directly the teaching element of the course to ensure good quality teaching. Some students also suggested introducing an element of peer assessment in the delivery of the teaching.

COMMENT: This change has already been made. As mentioned in section 5.1, direct assessment of teaching was used previously when the module was run in a PBL plus peer teaching format. Moreover, marks for quality of teaching delivery were always decided in consultation with the recipients of the teaching. It is a simple matter to reinstate this type of assessment.

(c) Providing guidelines for the teaching preparation and delivery and also making handout preparation compulsory.

COMMENT: The assessment guidelines for direct assessment of teaching clarify the requirements for good performance in teaching delivery. The guidelines state that the remit for the teaching is not merely to present the solution of the PBL problem originally assigned, but also to cover background mathematical tools and physical interpretation of solutions: this addresses concerns about perceived shallowness of the teaching (see sections 5.2 and 5.3.3). Moreover, preparation of high quality handouts is specifically rewarded by the guidelines.

(d) Providing references for all topics. Although some textbooks and references were available, some students felt that it would have been useful if these had been given at the beginning of the course so that everyone could benefit when revising. Students also suggested having at least one reference per topic.

COMMENT: Students should include reference lists in their handouts (again this is specifically rewarded by the guidelines assessing teaching delivery). Giving a list of references at the beginning of the module will impede the PBL element of the module.

(e) Making the learning of all the topics available early on. Some students suggested that to allow the learning to be spread across the whole duration of the module, each group could prepare a summary sheet at the end of each session that could be distributed to the other students so that they could become familiar with the topics before the actual teaching sessions occur. This would increase the time for students to be exposed to new ideas and provide opportunities for self-directed study.

COMMENT: This suggestion will not be implemented. The content of the module can be conceptually difficult, and during the PBL phase of the course students frequently need some time to come to terms with it. It is unlikely students could produce a useful summary sheet for their peers until such time as they are forced to order their thoughts in preparation for their teaching sessions. There is nonetheless an issue that students in receipt of the teaching sessions should be engaged as early on as possible in practising the techniques their peers are teaching them. This will reduce the perception that they were rushed at the end with little time to revise for the exam (see section 5.4.1). However, item 2(g) below offers a resolution of this issue, without the need for a weekly summary sheet during the PBL phase.

(f) Providing access to photocopying facilities to help the teaching delivery (e.g. overhead slides and handouts).
COMMENT: The demonstrators have access to such facilities. Requests should be channelled through them.

(g) Including a tutorial question in the teaching. Some students suggested that having an extra question delivered as part of the teaching could help others to practise the methods that they have just learnt.
COMMENT: Several past exam questions are available. One possibility is for students to use these as tutorial/practice questions, handing them out, collecting them and reading through them to provide feedback to their peers: high quality feedback should help their peers to learn taught material at depth. As mentioned above, setting tutorial/practice questions will help students to start revising earlier. It is proposed that no mark weight should be assigned to these tutorial questions: instead they should be optional. The students are believed to be of sufficient maturity that most of them will wish to take advantage of such a revision opportunity, even without a direct mark incentive. Similarly, in the first instance, no mark weighting will be assigned to the quality of feedback provided by groups to their peers. However, in the future, it may be valuable to incorporate this into the assessment of teaching delivery.

3. **Assessment**

(a) Providing written guidance about how to write exam questions. Students felt that written guidelines would be more useful than having a session about exam preparation.
COMMENT: These guidelines are already available. Indeed, the Director of Assessment produced them in response to the innovations proposed for this module. However, the guidelines are useful not

only to the students undertaking this course, but also to newly arriving academics within the School.

(b) Benchmarking the time required to answer the exam paper. Students felt that the exam paper was too long for the time allocated.
COMMENT: Student groups should check the time required when preparing the exam question. The guidelines prepared by the Director of Assessment state that the person preparing the exam paper should be able to complete the question in about half the time allotted!

(c) Providing students with more feedback for their proposed exam questions so that changes can be agreed. Some of them felt that their exam question underwent heavy editing, which made it less easy for the other students to understand, potentially affecting their mark. They proposed that if further editing of the exam question occurs without the group knowing they should not be subjected to penalties. However, they acknowledged that this is related to time-scale and deadlines issues.
COMMENT: Removal of the time constraint associated with sending papers to the external examiners should resolve this problem.

(d) Rewarding creativity and innovation for proposed exam questions. Some students felt that their effort at being innovative was not rewarded.
COMMENT: The assessment criteria for the course now contain an element rewarding the creativity and novelty of exam questions, and the initiative students display whilst preparing them.

7. Conclusions

An Engineering Mathematics course module has been taught using a Problem-Based Learning (PBL) plus peer teaching approach. Students were divided into groups, each group specializing in one part of the Engineering Mathematics syllabus via PBL. Groups then came together to teach their peers. An innovative assessment approach was employed: student groups prepared exam questions for their peers to sit. Students were assessed not only on their individual exam performance, but also on the suitability of the assessment they set. The latter assessment was via a transparent formula based on their peers' performance relative to a target. Overall, the module marks were entirely appropriate to the student cohort in question, and the students managed the assessment process with a high degree of honesty and professionalism. Special features of the particular cohort (its size, cohesiveness, level of academic ability, previous PBL/group working experience, and maturity) are believed to have helped ensure the broad success of the teaching and assessment innovations. The main areas suggested for future improvement of the module concerned time-scale issues (students need time and support to produce quality assessments) and direct assessment of the peer teaching sessions (to ensure the quality of teaching remains high).

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