A BLENDED APPROACH TO PROBLEM-BASED LEARNING

In the Freshman Year

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Chemical Process Principles I (CPE 1002) is a core and compulsory course taken by approximately 70 students in the freshman year of a chemical engineering undergraduate degree program at the University of Sheffield, Sheffield, United Kingdom. The primary learning objective is to develop the students' knowledge and understanding of material balances, where the core learning content looks at material balances for single unit operations, such as mixers, splitters, separators, and reactors, and then various combinations of these single units in series. This allows for purges and recycles to also be considered.

This paper provides details of the chronological developments of the course, the issues emerging from student feedback, the actions taken based on this feedback, and the lessons learned by staff. Finally, some conclusions are provided.

COURSE DEVELOPMENTS

Historically, CPE 1002 had a relatively high failure rate (25% in 2003/04). Student feedback indicated that many of the students were finding that learning the content was challenging, and they were struggling to make the connection between the mathematical manipulations required and what a practicing chemical engineer does. Further, the number of students taking the course increased, from 28 in 2003/04, to 55 the following year, to about 70 in the past two years (see Table 1, next page). To address the problems of unacceptably high failure rates and increasing numbers of students, we decided to adopt a different style of course delivery to try to engage the students more effectively with the learning content and its application.

Despite the increased numbers of students in 2004/05, the failure rate improved to 16% with the introduction of small-group tutorials. This failure rate was still considered too high for such core content, however, so we decided to implement new pedagogical strategies that we hoped would improve student learning even with increasing student numbers.

The new mode of course delivery was a type of Problem-Based Learning (PBL). Our primary reason for this choice was the evidence available in the literature on the effective-

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TABLE 1
Chronological Course-Delivery Developments

Academic year	2003/04	2004/05	2005/06	2006/07	2007/08	2008/09
Student numbers	28	55	66	67	70	69
No. of staff	2	2	3	4	4	4
Lectures (per week)	2 hours	2 hours	1 hour	1 hour	1 hour	1 hour
Tutorials	2 per term 3 hours each Large group	3 per term 3 hours each Small group	weekly 2 hours each PBL-style	weekly 2 hours each PBL-style	weekly 2 hours each PBL-style	weekly 2 hours each PBL-style
Summative assessment	80% exam 20% course-work	75% exam 25% course-work	50% exam 50% assign-ments and test	50% exam 50% assign-ments and test	50% exam 40% assign-ments 10% online test	50% exam 40% assign-ments 10% online test
Failure rate*	7 (25%)	9 (16%)	15 (23%)	1 (2%)	4 (5.7%)	5 (7.2%)§

*Notes for Table 1: * The student must obtain an overall weighted average mark of 40% or greater from the combined summative assessment components. § Three of the five students who failed the summative assessment did not attend for the examination*

ness of PBL in motivating students to learn.[1] We also had good departmental links with the Department of Chemical Engineering at the University of Queensland, Australia—and in particular with Queensland's Professor Paul Lant. Lant's department has had national success with their students adopting a type of PBL, referred to as project-centered learning.[2] As part of his sabbatical at Sheffield, Professor Lant was willing to assist with its introduction within our course. At Queensland, this approach has been implemented program-wide, whereas we were looking initially to introduce it for only one course. Professor Lant visited Sheffield in the academic year 2005/06 and brought all his learning resources relating to his syllabus for Material and Energy Balances. This was the start of a major transformation for our course, and a catalyst for change within our department.

The initial transition was from traditional didactic delivery in the academic year 2003/04 (see Table 1), when students numbers were relatively low, to a two-hour weekly problem-based learning workshop with a one-hour-per-week supporting lecture from 2005/06 onwards. The idea was to shift the emphasis from the lecturer being the "sage on the stage" to "the guide on the side,"[3] with the students engaging in problems that required them to seek out information from the resources and supports provided, and construct their own knowledge. We anticipated that this would both improve content learning and, at the same time, help students gain key intellectual skills needed for continued success in their chemical engineering course.

This curriculum design aligns with the definition of PBL as "a conception of learning as an integrated process of cognitive, metacognitive, and personal development" as provided in Newman's review.[4] PBL has been introduced successfully into many professional fields of study including chemical engineering—see Woods,[1] who has carried out many detailed studies.

"Traditional" PBL Approach (2005-2007)

Firstly, the CPE1002 course content was extended to cover key personal and transferable skills such as group work, communication skills, independent and self-directed learning, and peer assessment, without losing any of the key technical material. This was done by introducing weekly group work, one industrial visit, and two major group assignments incorporating industrially relevant processes over the 12-week teaching term. The group assignments were carried out over a number of weeks.

The key to a successful PBL approach is the use of authentic problems[1] to engage the students while developing their core technical skills. Professor Lant provided several case studies relating to industrial processes, and the students worked in small groups of four or five to carry out the weekly assigned formative tasks and assignments. The industrial visit to a pulp and paper mill[1] was provided to enhance the students' understanding for one of the major assignments. Students were also encouraged to do weekly homework problems to support their learning and develop their problem-solving skills.

When the changes were first introduced in 2005/06, feedback from the students via the end-of-course questionnaire[5] was extremely positive, *e.g.*: "The tutorials were excellent, really hard work, but incredibly useful in cementing the course ideas." (student 1); and "The assignment group work was a new challenge compared to the usual academic work. This made the work more exciting and rewarding as well as reinforce the key concepts and knowledge." (student 2). As shown in Table 1, however, 23% of the students failed the summative assessment compared with 16% the year before!

1 *Unfortunately, the plant closed in January 2008 so for the academic year 2008/09 the students have had a "virtual" site visit using video resources from the Internet and a PowerPoint presentation provided by the company.*

A review carried out by Biggs[6] showed that those students who did not participate in PBL group work had not gained many of the associated summative assessment marks, and had relied solely on achieving very high marks on the exam paper. Since the exam paper was only worth 50% of the total course marks, however, and at least 40% was required for a pass, this was a high-risk strategy that usually failed. It is worth noting, however, that most of the students who did not participate in PBL group work also were not engaging with the rest of their degree program. Thus, the problem wasn't necessarily the PBL style of delivery, but these students' general lack of motivation and engagement.

In the following year (2006/07), two additional changes were made: 1) increased emphasis throughout the course by academic staff on the need for students to engage with the group PBL tasks and assignments to ensure success in the course, given the 50:50 split between exam and coursework; and 2) the weekly homework was marked so that the students got regular, timely, formative feedback. This had the desired effect of improving the overall summative assessment results: Only 2% failed the course that year (see Table 1).

The introduction of weekly homework marking and the size of the class, however, meant two members of academic staff and two teaching assistants were now involved with the course compared with the usual one member of academic staff on other traditionally delivered courses within our department. This had a significant impact on the running cost of the course, and as such it would not be practical for all courses to be delivered in this way without a major restructuring in the departmental teaching allocation. This was unlikely to occur in the short term. Hence, a different approach to providing effective and regular feedback to the students was needed to accommodate increasing class sizes and simultaneously to support the weaker students.

Another significant challenge was the need to find a teaching space to accommodate up to 70 students for a PBL-style tutorial. (Due to timetabling constraints it was not possible to split the cohort into, say, two smaller groups.) Recently, the University of Sheffield has had a major investment in Inquiry Based Learning (IBL), flexible learning, and teaching spaces (see CILASS[7] Web site). The University's largest collaboratory accommodated only 48 students, however. Hence, an alternative venue was sought that had a flat floor with moveable tables. Such venues proved to be very limited in number on our campus, although the construction of new teaching spaces for larger student numbers is currently in progress. As part of the PBL activities, it was also essential that the students could see the projector screen from anywhere in the space. This was solved by ensuring that the rectangular tables were positioned so that all four students in a group could sit with two facing the other two and also turn sideways to face forward toward the projector screen. These issues may seem trivial, but for PBL-style tutorials to be successful it is very important that the students are able to "huddle" in their groups and exchange ideas and information as well as come together as a whole class to discuss ideas and gain feedback. This is the essence of the communication and collaboration needed for PBL to take place.

By the end of 2006/07, the new course-delivery style of PBL was deemed a success, due to the improvement in the failure rate to only 2% and the continued positive feedback from students. Initially, it had been envisioned that further developments would involve rolling out the same format across other courses. The combined impact of the running costs and infrastructure limitations meant that this type of widespread rollout was not yet an option, however. But lessons learned from this course on how to deliver a PBL-style tutorial have been transferred to other small-group teaching in the department, such as modules in our process design strand throughout Years 1 to 3.

Blended Learning PBL Approach (2007-onwards)

Despite generally positive student feedback for the PBL style of delivery, there was evidence from the peer evaluation data that some students were being "carried" by the members of their groups. Since the summative assessment was 50% group assignments and 50% individual examination there was the danger that students could succeed in the course but not have the core technical skills required for courses later in their undergraduate program. Constraints on staff time and increasing student numbers (see Table 1) meant that providing additional remedial group tutorials and/or one-to-one support for developing the students' problem-solving skills were not practical options to support weaker students. It was necessary to find an alternative approach that would "blend" with the PBL approach.

It is noted by Woods[1] that students need to be skilled in problem solving before embarking on PBL. So, it was important to provide an effective mechanism for supporting the weaker students that was not staff intensive. The development of the computer-aided learning resources, particularly a set of online formative quizzes, seemed an ideal strategy to meet this need. The University's Centre for Inquiry-based Learning in the Arts and Social Sciences (CILASS) was approached for funding for development and evaluation of the online formative quizzes, and a grant was awarded in 2007.

The online resources were developed in time for use during the 2007/08 academic year, and were provided via WebCT Vista (managed learning environment).[8] The aim of introducing online self-assessment resources (or quizzes) alongside PBL was to enable the students to self-assess their weaknesses and strengths in the core chemical engineering principles and to practice their problem-solving skills. We expected that students who used these resources would come to PBL classes more prepared and better able to contribute to the group work.

The online formative quizzes allow students to get instant feedback on whether their answers are correct. If they select the wrong answer then additional feedback is provided directing

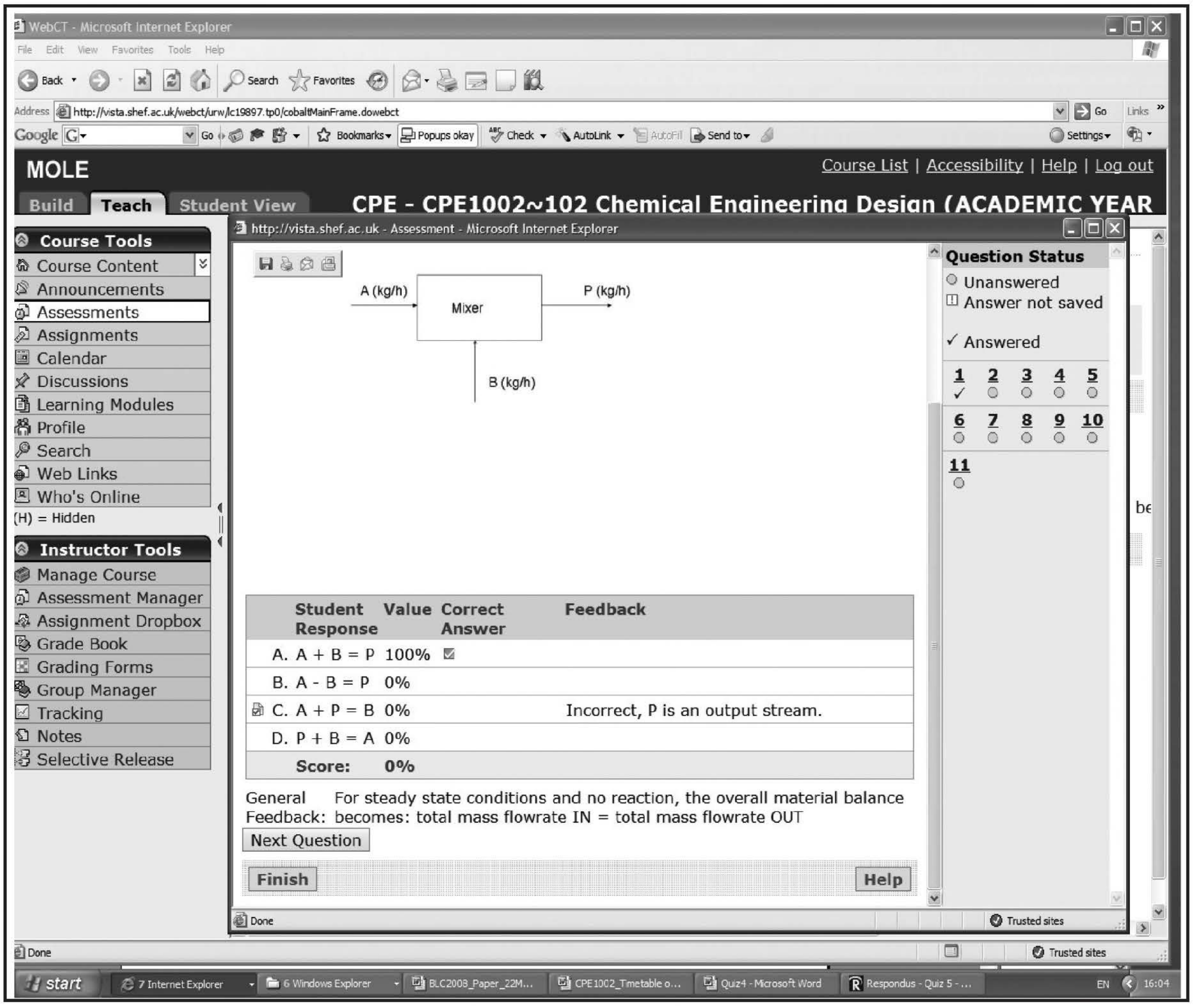

Figure 1. *Online formative quiz—multiple-choice question.*

them to the relevant part of the lecture notes and/or textbook by Felder and Rousseau[9] (see Figures 1 and 2). The computer aided assessment tool makes this possible without requiring large amounts of staff time. Although the quizzes were delivered within WebCT Vista,[8] some of the development work was carried out within Respondus,[10] a third-party tool for creating online assessments. (For detailed discussion of the development of the online quizzes see Rossiter and Biggs.[11]) These online quizzes cover five core technical skills:

1) *Unit conversions using the unity brackets approach*
2) *Mass to mole conversions*
3) *Calculations and definitions relating to material balances*
4) *Material balance calculations without reactions* (e.g. *Fig. 1)*
5) *Material balances with reactions* (e.g., *Fig. 2)*.

Figure 1 shows an example of a typical multiple-choice question for a mixer within the question databank of the online quizzes. The student here has selected the wrong answer so is given specific feedback on why their chosen answer is wrong, as well as being told the correct answer and being given more general feedback on what was required. Within the question databank, as well as multiple-choice questions, there are many calculation-type questions where a range can be specified for the variables so that a different set of values is presented each time the question is encountered. Thus, the students can repeatedly carry out the same calculation but with different number sets until they have mastered the problem (see Figure 2).

In the academic year 2007-08, for the first time, the examination for the course was held at the end of Semester 2[2] whereas the blended PBL approach was used in Semester 1. This meant that there was a gap of several months between

2 *The examination of the course content changed to being at the end of the year because a detailed program review by the Departmental Curriculum Committee concluded that the students were being over-assessed and developing a surface learning approach to their studies as they had 10 separate 1.5 hour examinations during the year. So to promote deep learning of the content the number of examinations was reduced to six separate 3-hour examinations . With the CPE1002 Chemical Process Principles-material balances being assessed at the end of Semester 2 as part of a 3-hour exam including the Semester 2 course content on energy balances. The timing of this exam meant the students had also engaged in a week-long PBL-style design study relating to mass and energy balances, thus reinforcing the course content delivered in Semester 1. Given only a slight increase in the failure rate for the summative assessment of CPE1002 (see Table 1), the change of timing of the examination does not appear to have had a detrimental effect on the students' outcome.*

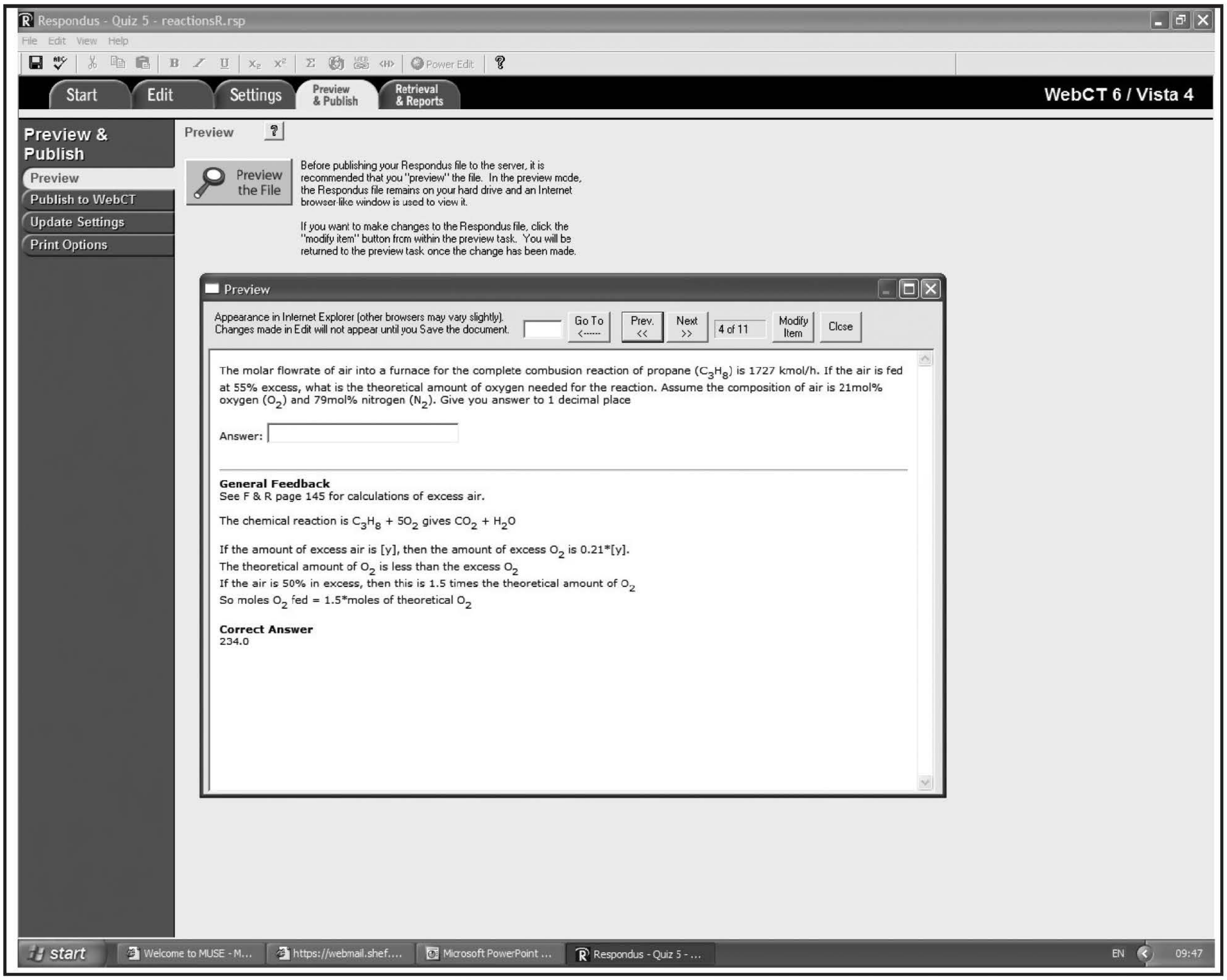

Figure 2. *Online formative quiz—calculation question.*

the material being delivered and the examination. So an added benefit of the online quizzes was that they were available throughout the year to assist students when they studied for the examination and carried out a detailed PBL-style design study in Semester 2 relating to mass and energy balances.

EVALUATION RESULTS OF BLENDED LEARNING APPROACH

As part of our CILASS-funded learning and teaching project during 2007-08, a detailed evaluation study was carried out to assess the impact of introducing the online quizzes within the PBL framework, on the students, the academic staff, their department, the university, and the wider community. This evaluation study provided a rich source of data. The data was collected via classroom observation by Petrulis, a focus group with students, interview with academic project staff, and a questionnaire to all students involved with the course. Some of this data is discussed in the following sections.

What Did the Students Say?

The students were asked in the questionnaire and the focus group about all aspects of the course including the PBL-style tutorials and their use of the online quizzes. The comments in Table 2 (next page) suggest that by working on the PBL group tasks and assignments the students were seeing the connection between chemical engineering practice and what they were learning in the course. This was reinforced by the questionnaire data[3] where:

- *93% of respondents found the PBL activities enjoyable and motivating. Student quotes: "Working as a group was fun and I worked extra hard because I did not want to let my group down," "Made me feel as if I was a 'real' chemical engineer and made me feel mature," "It was hard work but was enjoyable."*
- *98% of respondents found their experience of PBL helped them at least to some extent to develop confidence and skills in working collaboratively. Team working is an essential skill for engineers.*
- *96% of respondents found their experience of PBL helped them at least to some extent to develop confidence and skills in problem solving. Problem solving is also an essential skill for engineers.*

3 *Questionnaire, End of Semester 1 Feedback by Year 1 students, Feb. 15, 2008, 54 responses out of 69.*

TABLE 2
Extract From Student Feedback at Focus Group† on Their Learning (2007/08)

Interviewer: *Do you think the module (CPE1002) changed the way you approach learning or problem-solving activities?*
Student: "In the first semester, we were learning things and I could see why we were learning them because I could see how to apply them. This semester, we're learning a lot, but I'm not always sure why. I wish we had more practical group assignments throughout the course."
Interviewer: *If you had your choice between the group format and what you're getting now (predominantly lectures), which would you prefer?*
Student: "You actually felt like an engineer when you were doing the group assignments. Now I just feel like a student, learning a lot of things."

TABLE 3
Extract From Student Feedback at Focus Group† on Feedback in Quizzes (2007/08)

Student: "They (Quizzes) were beneficial because of the immediate feedback. With the homework, it took a week or so. The online quizzes also referred you to the book and page for more information. If you just get a grade, that's meaningless."
Student: "The online self-test quizzes gave INSTANT feedback. So if you didn't get the question right, I understood why and did not do the same mistake again. The quizzes were unlimited and this helped me practice."

TABLE 4
Extract From Student Feedback at Focus Group† on Use of Quizzes (2007/08)

Interviewer: *A couple of you said you didn't use the quizzes at all. Could you say why?*
Student 1: "I tried the quizzes a couple times, and they weren't very hard. The homeworks were more challenging, and you could talk to the teachers about them. That felt so much more helpful."
Student 2: "The examples in the quizzes weren't as difficult as the homework."

† *Eight students were present at the focus group. – Interviewer R. Petrulis (CILASS) on March 3, 2008*

In relation to the online quizzes, 81.5% of students who responded said the quizzes had helped them to some extent in developing their core technical skills for the problem-based learning activities. (The rest either didn't use the quizzes, didn't know, or didn't respond.) The comments provided in Table 3 show that the immediate feedback on the quiz answers was also found to be beneficial.

The online quizzes were provided to help the less-able students to develop their problem-solving skills and this seems to have been achieved judging by the quote from this student: "The homework made us work hard, but the quizzes really helped us learn how to do the homework." From the quotes in Table 4, however, students 1 and 2 don't seem to need this type of support. Biggs stated when interviewed[4]: "The point of the quizzes was to help those who needed the basics; not to challenge those who needed to be challenged, because the homework (and) assignments were there to do that. I think this shows that we were right to set this up in the first place." Rossiter commented at the same interview: "It reinforces that you could describe something in three different ways and it would have meaning to different people. It's not that the quizzes, assignments, and homework cover different things—they don't. They make it accessible to different types of learners."

What Did the Staff Say?

Overall, blending online formative quizzes with off line PBL-style tutorials has proved successful for this course. This has helped to provide a mechanism with instant feedback for the less-able students to get help in developing their problem-solving skills in preparation for the PBL group tasks and assignments. It has also resulted in helping all students to be more actively engaged in the group work.

Providing these online quizzes did involve significant development time; however, this was offset by a reduction in students' requests for remedial one-to-one support. Some time was also gained through some of the coursework (an online test worth 10%) being automatically marked by WebCT. Also, the homework sheets were modified since some of the questions formed the basis of the online quizzes. Hence, this led to some reduction in the weekly homework-marking load.

CONCLUSIONS

There have been several major challenges to address relating to this first-year chemical engineering course, such as increasing numbers of students, a widening range of student abilities and learning needs (including, in some cases, lack of well-developed problem-solving skills), constraints on provision of additional academic staff, and need for adequate learning spaces for PBL-style tutorials. Creative solutions had to be found to deal with these challenges, and this paper has

4 *CILASS Project leaders' interview of Catherine Biggs and Diane Rossiter by Robert Petrulis (Evaluator) carried out 20 March 2008. The interview was carried out as part of the CiLASS project triangulated evaluation study and its purpose was to have the academic project team comment on the collated student feedback from the questionnaire and focus group. Hence "close the loop" on the student feedback.*

outlined the blended-learning approach adopted for course delivery and support. In 2005, it was envisioned that the PBL approach in CPE 1002 would lead to major change in favor of PBL for the entire program. This has not occurred to the extent originally hoped. The process-design strand of the undergraduate programs has been influenced by the PBL approach, however, since we (Rossiter and Biggs) have both been involved in design-project supervision.

We originally set out to address the issue of student failure in this course, knowing that the high failure rate could be exacerbated by steadily increasing numbers of students. The innovations described in this paper—particularly the implementation of online quizzes—have indeed improved student learning and success. They have had ancillary benefits as well, including promoting student self-motivation and engagement, improving problem-solving skills among weaker students, and helping students develop transferable skills in such areas as teamwork and communication. We might also mention that the experience of teaching the course, despite the increasing class size, has become progressively more rewarding as student results have improved.

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