Educational design and online support for an innovative project-based course in engineering design

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A new course in Engineering Design and Innovation used a project-based learning approach to facilitate learning the design process, the development of design thinking and the skills required to solve open-ended design problems. The course involved over 950 first year students, in the Faculty of Engineering at the University of New South Wales. Students were enrolled in nine schools of engineering in the faculty. A WebCT Vista course was used to support student learning in design teams and to integrate and manage the course. Online facilitation methods were used to support student learning during several phases of the design process. Online peer assessment and review processes were used to encourage reflective learning and be time-efficient for academic staff. The paper includes survey data from the first offering of the course.

Keywords: design, engineering design, project-based learning, online facilitation, student peer assessment, student peer review

Introduction

The Faculty of Engineering at the University of New South Wales introduced a new course in Engineering Design and Innovation for first-year engineering students. This involved running a faculty wide course for over 950 students enrolled in 9 different schools of engineering. The aim was to take a project-based approach, with students working in teams to do a design project. The course was administered centrally through the Faculty with each School offering one or more projects aligned to various disciplines. This placed a heavy focus on the need for a coherent pedagogical framework upon which learning outcomes and assessments could be uniformly measured. A common conceptual focus on the engineering design process was critical so that students would learn the same process for resolving open-ended problems regardless of the specific design project they were working on. To create a unified course, the students were all brought together for the first two weeks and given an impromptu design task modelled on an activity previously introduced by one school (Reidsema, Wilson, & Netherton, 2004). Additionally they all used the same engineering design textbook (except for a small number doing an environmental project). An online course in WebCT Vista was set up to provide a common access point, support and communication framework for all students and staff. The online course played a key role in coordinating and supporting key learning activities for project groups with large numbers of students.

The School of Mechanical Manufacturing Engineering had over 240 students doing its design project. The school had previously pioneered a design course taking the project based approach with similar numbers of students. The previous course was a major influence on the faculty-wide course design and development. Due to the large number of students, the online support from a WebCT course was seen to be critical. The staff member involved (CR) wished to introduce a greater emphasis on written reflection to reinforce learning for several stages of the design process as well as addressing perceived shortcomings in written communication and critical analysis skills. As this would involve the assessment and prompt feedback of written work for a large number of students, a student peer review and assessment process, enabled by online technology, was required. The Calibrated Peer Review system (Chapman, 2001) was implemented to address these issues. Due to a significant proportion of the student's final mark being attributed to group performance, the iPeer system (iPeer, 2006) was also used to support student peer review and assessment of individual students' contribution to the final group mark. These became major parts of the online design and development for this research project.

This paper focuses on the educational design of the course and the online technologies to support learning and teaching. Most specific processes and evaluation data are based on the students doing the project offered by the School of Mechanical and Manufacturing Engineering, as this school had the largest number of students, identified the requirements for, and made the greatest use of online technologies to support and enable learning activities associated with the design project and reflection. The project aims, issues in educational literature, a description of the course and evaluation data from an end of course survey are all included. The paper ends with a discussion of key issues and suggestions for further development.

Project aims

Key aims for the project and online support include:

- Design and implementation of a project-based learning approach to a new Engineering Design and Innovation course. Project-based learning includes group work, individual reflection, student peer review and assessment.
- Design and development of an online course in WebCT Vista that will assist staff to manage the course and support key learning processes associated with:
  - the phases of the engineering design process,
  - group work on design projects,
  - individual reflection on learning design, group process and project management capabilities,
  - student peer review and assessment.

Learning outcomes for students in the new course included:

- Familiarity with the process of engineering design and the use of design methods for defining an open-ended design problem, generating alternative and innovative conceptual solutions and evaluating these solutions.
- Understanding the dynamics of collaborative teams and how to work effectively within a team to accomplish tasks within given deadlines.
- Understanding the basic elements of managing a design project and being able to plan and schedule work activities in accordance with standard practice.

These aims and outcomes defined the project as they clarify the focus of learning and the learning process required of the student and the requirements for the online course design. A range of findings from educational literature were influential in shaping the detailed educational design and online support provided to enable the project aims and learning outcomes to be attained. These are discussed in the next section.

Literature review

There is a strong rationale for introducing engineering design courses into the curriculum. Design is considered to be a distinguishing feature of the engineering profession, and both the US and Australian professional bodies have identified the need for courses that develop the flexible thinking, teamwork, and communication skills associated with working in teams on open-ended problem-solving tasks such as a design project (Dym, Agogino, Eris, Frey, & Leifer, 2005; Felder & Brent, 2003; IEAust, 1999). These skills are often seen as 'soft' skills by staff in engineering schools, as engineering courses tend to place a critical emphasis on analytical skills associated with scientific reasoning, logical and convergent thinking, all of which are important to engineers (Shah, 2005). There is a growing recognition, however, that design thinking is complex problem-solving that is important to the profession and practice of engineering (Dym et al., 2005) and that the communication and teamwork skills associated with design projects are capabilities that lead to graduate attributes that are important for an effective professional.

Design thinking involves generating ideas and evaluating their potential, using lateral thinking as well as scientific reasoning, visual thinking and generating novel solutions as well as analytical processes. It means bringing creativity into a process that still requires engineering analysis and precision to realise the project – a combination of divergent and convergent thinking that is specific to the discipline (Shah, 2005). The thinking processes required for engineering design are different, and possibly more complex than those required for analytical courses.

Project-based learning is the method of choice for many design courses as design tasks fit well with this approach (Dym et al., 2005). Criticisms of design courses as being soft and fun as opposed to serious engineering may be made in ignorance of the rich possibilities for developing student capabilities that are inherent in the project-based approach when it is effectively applied. These include the capabilities that lead to graduate attributes, and processes, such as group projects, that may help to socialise students into the university environment and develop the flexible thinking needed for more advanced design courses as well as the so-called 'hard' engineering courses to come. Project-based learning has strong similarities with the problem-based learning (PBL) approach that has been widely used to foster high-level learning outcomes in many professional courses. The problem-based approach is an experiential learning approach to enable students to develop capabilities required to solve complex 'real-world' problems during a professional education program (Savin-Baden, 2000). The approach involves students working in small teams to consider the implications of a problem and how they will resolve it. They need to generate hypotheses, identify the deficiencies in their own knowledge that must be overcome to resolve the problem scenario, decide how they will investigate the knowledge required to learn the necessary skills and techniques. Finally they need to apply new and existing knowledge and capabilities to a resolution of the problem. Problems should be ill-structured and open-ended (Hmelo-Silver, 2004). One identified difference between the two approaches is that project-based science uses a variety of computer-based tools to scaffold students' problem-solving, while PBL uses simpler tools (Hmelo-Silver, 2004).

Research into effective learning using the problem-based approach has shown a key role for facilitation to ensure that students focus on the key learning issues, discuss them and follow them up in later stages, and that lessons are learned and reflection on new learning occurs at each stage of the problem-based learning process. An important role for the facilitator is to ensure that students understand the implications of the problem and identify what they need to learn, and to reflect on what they have learned. Giving the students a visual focus for learning by creating a structured whiteboard to direct the students' focus on the key learning issues and record them is one of the simple PBL tools that have been effective in the facilitation process (Hmelo-Silver, 2004). A critique of design education in Engineering is that the required facilitation and support is too labour-intensive and that design courses are too expensive to be sustainable (Dym et al., 2005). Research and development on PBL has identified ways of embedding parts of the facilitation process in online technologies so that the time demand on academic staff can be reduced. Facilitation can be aided by guides that students can use themselves to facilitate group learning process during specific stages of the PBL process, online 'whiteboards' that can be monitored by a facilitator who is not present when the students are meeting or working on the project independently and communicating online (Steinkhuehler, Derry, Hmelo-Silver, & Delmarcelle, 2002). These processes have a potential application to project-based learning in Engineering to aid the sustainability of design courses.

Reflection and peer review

Online supports have been developed in many Engineering Design courses to aid reflection using peer review and assessment processes (Campbell & Colbeck, 1998). These are used to encourage students to fully engage with the design process and group work, and to reflect on these processes to reinforce learning. Student peer assessment has been used to assess individual student assignments, enabling students to see and review the work of other students and to reflect on their own (Hanrahan & Isaacs, 2001). It has also been used to review and assess contributions to group projects by the team members (McGourty, 2000). Some advantages of student peer review of group processes are that the process of completing feedback improves awareness of group processes and the need for effective contribution, and that staff receive valuable data on contribution from those best placed to perceive it – the other students. These data can be used for assessment (McGourty, 2000). Miller (2003) found that introducing a wider range of rating scales and criteria improved the qualitative discrimination that could be obtained from peer review, which consequently improved the overall value of the process. The use of 'behavioural anchors' – additional guidelines for students to use to aid interpretation of criteria was found to improve rating reliability (Ohland, Layton, Loughry, & Yuhasz, 2005).

Staff time can be a critical issue when student peer review is applied, as the process can be difficult to manage if the anonymity of raters is to be preserved while still carefully tracking the process. Hanrahan and Isaacs (2001) found student peer review with large numbers of students (200+) to be feasible but very time consuming for academic staff. From their study of peer review of individual assignments they recommended providing exemplars of good work to aid the assessment process. A solution to the time demands of peer review can be to use online systems to manage the process. These have been developed for both forms of student peer review. The Calibrated Peer Review system provides an automated process that presents the exemplars that Hanrahan and Isaacs (2001) suggested as being an important support, and effectively trains the student to carry out peer reviews of individual work from other students through a calibration process. It then asks the students to review and assess three other assignments and then review their own (Chapman, 2001). Esechenbach and Mesmer (1998) describe an online system for managing peer review and assessment of contributions to group projects.

The outcomes of research in these areas were used to inform the learning design for the course and the online materials to support it. Key considerations were student-focused support for project-based learning and group facilitation, and peer review and assessment processes. The online support for the course needed to support or enable these learning processes to foster high levels of engagement with the group design project, and reflection and peer review to reinforce deep learning. The next section describes the course design.

Course design

Students attended lectures and practical laboratory sessions. They had some structured group meeting times with staff mentors but were also expected to (and did) meet with their project groups more frequently to complete the project. Online group discussions were also set up to allow groups to interact flexibly. Project-based learning included an impromptu design activity (start to finish in two hours), and a major design project that took the remaining ten weeks of semester to complete. Lecture time was cut back and additional time in the laboratory was allowed when students were building and testing their prototypes. All final prototypes were performance-tested against the criteria in the design brief on one day. Design projects included making a mechanical hand, a solar powered device that would climb a vertical pole and come back down again, and an air powered vehicle using the battery, motor, and fan from a handheld battery-powered vacuum cleaner. Assessment was based on the group report, testing the project, individual reflections on phases of the design process, and an individual report on the impromptu design experience.

The online course, in WebCT Vista, played an important role in supporting the course and maintaining cohesion and a single faculty-wide course identity with a wide range of design projects being offered by different schools. The online course was structured with introductory material, information on all projects, and an online question and answer discussion for students answered by the course coordinator. This was needed to aid orientation for the 950 students. Organisers within the online course were set up for each school project. After the first two weeks that included the impromptu design activity, students divided into subgroups around school projects. Students then worked in small groups on the design project. The detailed design of the online course described below was to meet the needs of the largest school group, with 240 plus students. Other school groups used some of the online resources, but each school operated independently, and made different use of the online course.

The most critical need for online support for learning processes was to facilitate students to learn the design process individually and to apply it to the project design in groups. The design process was divided into the following phases:

- Phase 1. Formulating the problem to identify the range of aspects of the task that may be investigated further. This leads to a statement of the design problem.
- Phase 2. Conceptual design – generate a range of design concepts for solving the problem.
- Phase 3. Evaluation – critique and evaluate the proposed concepts to select the best solution.
- Phase 4. Detailed design – refine the solution and consider implementation issues.
- Phase 5. Implementation – building and testing the design prototype.

These phases are similar to the stages of the PBL process (Hmelo-Silver, 2004). Each phase is critical to learning the overall process of design. As large numbers of students had to be facilitated through the project based learning process by one academic staff member, and a small group of mentors who were inexperienced in facilitating design projects, the online support materials included instructions for individual work on each of the first three design phases, and activities to be done as a group following individual preparation for the phase. Students were then asked to reflect on what they did in the phase, what they experienced, and what they learned. This was done individually as a portfolio reflection, and submitted for assessment. The same process was repeated for phases two and three.

Facilitation processes adapted from those described in Steinkhuehler et al. (2002) and Hmelo-Silver (2004) were applied in this course. With few academic staff, the emphasis was on self-facilitation. To aid the process a 'Group Facilitation Guide' was created for each of the first three phases. This was designed so that a student could use it to facilitate the group activity for that phase. The guide has directions for facilitation, types of questions to ask to clarify issues during group discussions, and a model 'whiteboard', so that ideas from the group can be displayed and further learning activities identified and defined. The combination of individual work, student-facilitated group work with some support from a mentor, and individual reflection encourages students to focus on each design phase and to identify their own learning. The online support enabled a large part of the facilitation role to be taken by the online technologies while still ensuring that focused learning and reflection occurred. As there was no compulsion for students to use these guides the developers were interested in the extent to which they would be used, and how effective they would be.

Hmelo-Silver (2004) stresses the importance of reflection on learning at the end of each stage of the PBL process to reinforce the key points and identify further learning. To further enhance the value of the students' reflective portfolios the Calibrated Peer Review (CPR) system was implemented (Chapman, 2001). CPR is an online system that effectively trains a student to review and assess other student's work using good, medium, and poor exemplars, with questions and feedback. The students then assess three other papers using the same criteria and reassess their own. This process is consistent with the solution proposed by Hanrahan and Isaacs (2001) above. It is manageable for large numbers of students as manageability is not contingent on numbers. Using CPR students had the opportunity to see a good example of the portfolio reflection and to reflect again on their own. They also receive three sets of feedback on their own assignment from other students. Once the exemplars were written, using the system took little time to manage by academic staff.

Reflection on contribution to group process is also a valuable learning opportunity. Using marks from the peer review system to moderate the marks for the overall group assessment marks provides additional incentive for students to contribute effectively to the group project. As one of the most common complaints from students about group work is the non-contribution from some other students this incentive is important (Gibbs, 1995). Additionally, first year students are generally ill-equipped in dealing with non-contributors early enough for intervention by staff to be effective. The iPeer (2006) system was used to provide peer feedback and assessment on individual contribution to the work of the group. Criteria given in the text book for the course (Voland, 2004, p. 21) were set up in iPeer for student feedback. As this contained a wide range of criteria (ten), the benefits of greater discrimination described by Miller (2003) could be realised. Use of this online system placed minimal demands on academic staff time while providing data for assessment, and gave the students a valuable additional opportunity for reflective learning.

The overall course design provided the students with flexible access to a range of resources and used online systems to support and enable key learning activities. Resources included notes from important lectures. Online support, other than the systems referred to above, included:

- An online discussion for all students involved in a school project. This was unmoderated but staff monitored the discussion and contributed when this was warranted.
- Online discussions for members of project teams. Students were free to decide whether they would use these. Some groups used them extensively and others very little.
- Guidelines on working in teams on group projects.
- Guidelines on study skills.

The overall design was entirely focused on the learning activities associated with the design project and the associated systems, described above, to enable and support the process.

Evaluation

Students in the School of Mechanical and Manufacturing Engineering project group were asked to complete an online survey for evaluating feedback on the project at the end of first semester 2006. 124 out of 240 students completed the survey – a response rate of 52%. The survey covered a range of issues relating to the educational design of the course and the online support systems used to enable learning activities. These include:

- student learning from the design project
- applications of online support
- group work related to the major project
- reflective tasks and peer review.

Survey data on each of these is included below.

Student learning from the design project

Questions on the cognitive aspects of project-based learning are shown in Figure 1. These were included to see if the students saw the level of challenge as appropriate, that they saw themselves as building new knowledge on existing structures, and that they felt they developed a problem-solving capability – a major goal of the project based approach.

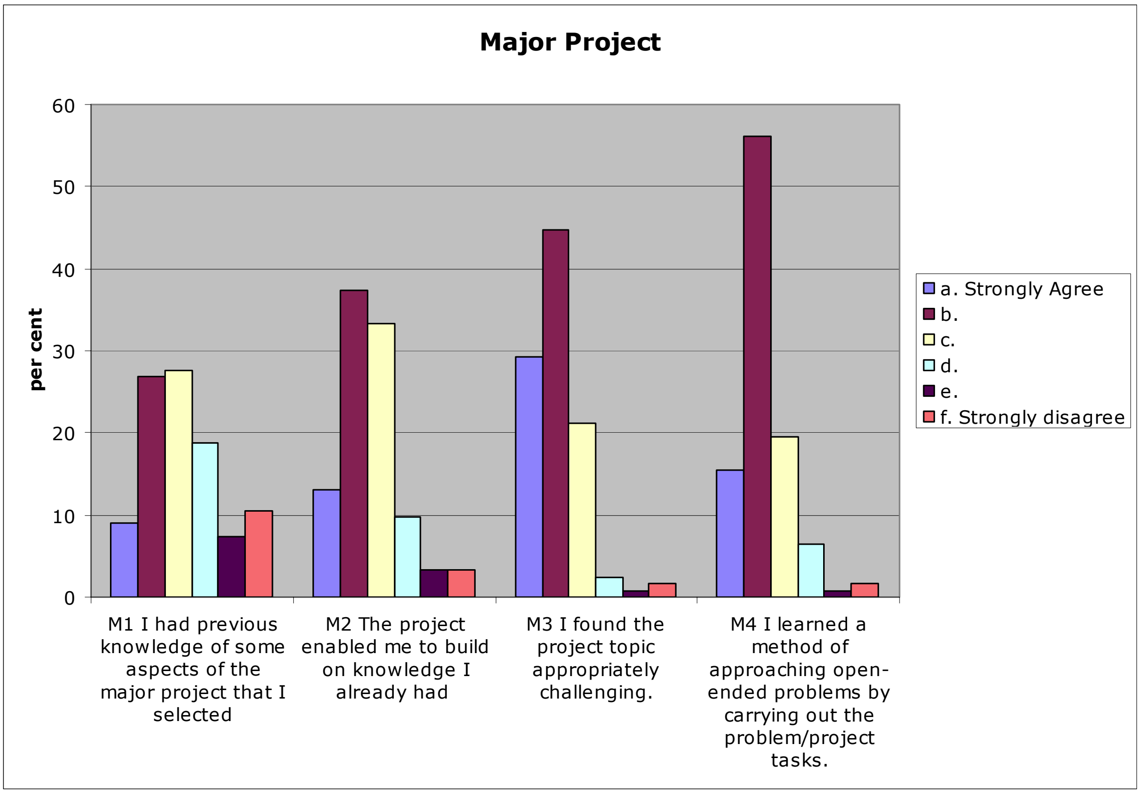

Figure 1: Cognitive aspects of project-based learning

The results show mixed response to question M1 on having prior knowledge. This is understandable due to the unusual nature of the project task – to design an air-powered vehicle. Students however clearly felt that they built on prior knowledge (M2). The level of challenge was also seen as appropriate, suggesting that students did not see the course as a soft option. Students clearly felt that the method of solving open-ended problems was attained.

Application of online support

Students were assessed on the notebook activities and the reflective portfolio. There was no direct instruction or assessment on the tasks that group members were expected to carry out in team meetings. This led to some concern about whether students would use and follow guides to these processes. Questions S2–S5 in Figure 2 indicate that the students saw the purpose of and made use of the scaffolding provided by these guides. The use of the group facilitation guide (S3) shows the highest level of 'strongly agree' responses in the survey. This is encouraging as use of this guide was an optional extra rather than a requirement.

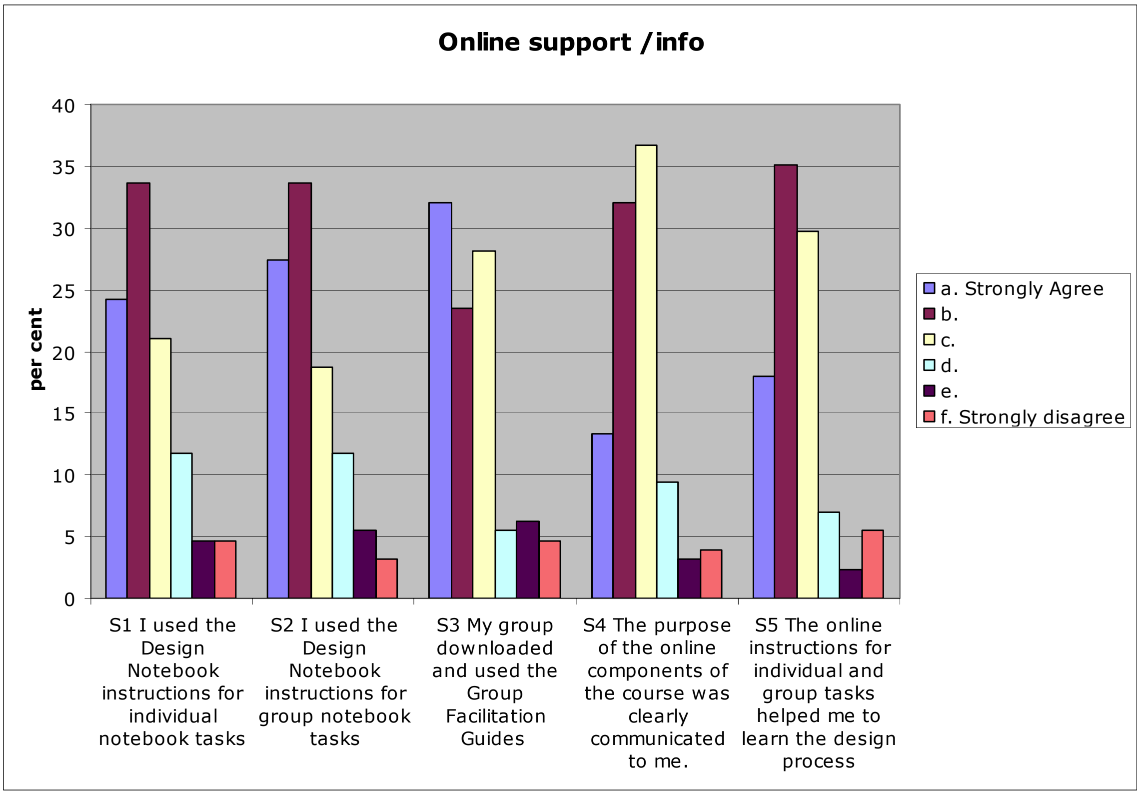

Figure 2: Application of online support

Group work related to the major project

Questions T1–T4 on working in groups (Figure 3) show strong agreement on key aspects of group work, and the value of group work in the course. The data show strong agreement on working closely with other students, and learning from other students, during the group process. Both of these are critical to the intended learning processes for the course, as they contribute to the development of the students' understanding of the design process as well as the development of communication and teamwork skills. T4 shows that students generally found working in a group to be a valuable learning experience. This is also critical as students will be engaged in group work again, on design courses later in their degree programs. It also suggests that the facilitation process for group work have been generally successful.

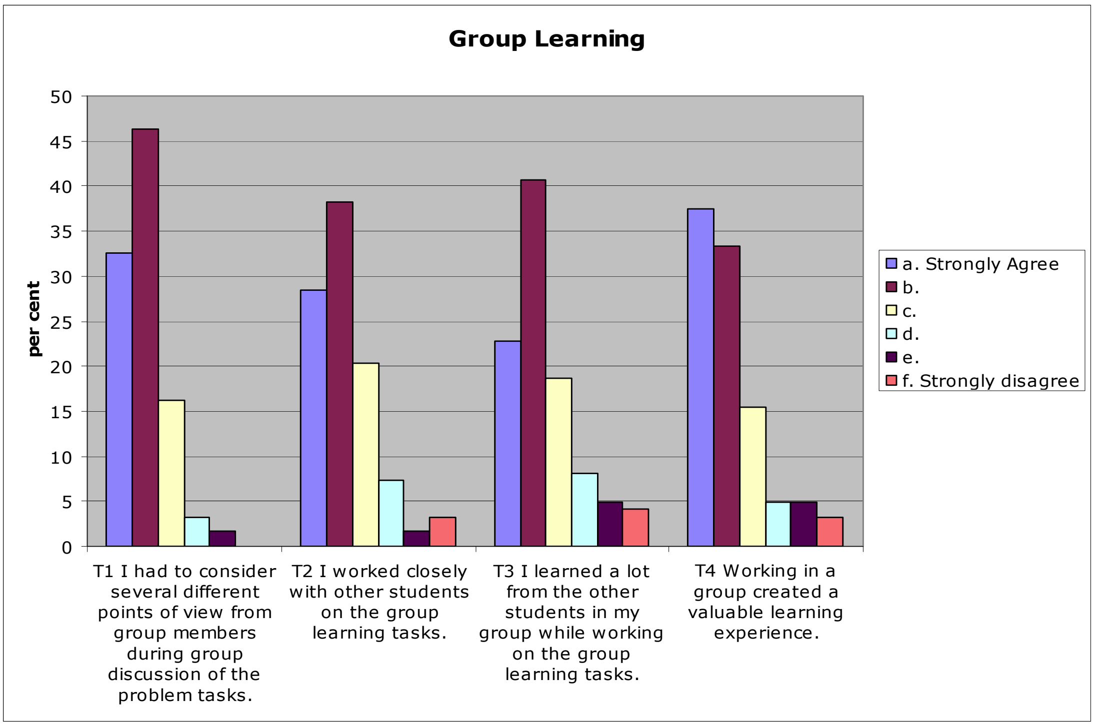

Figure 3: Group work related to the major project

Reflective tasks and peer review

Questions L1–L5 in Figure 4 focus on written reflection and peer review. Communication skills and the ability to communicate in writing were identified as an important outcome for the course – a contribution to the development of graduate attributes. The reflective portfolio tasks had this aim in addition to a reflection on learning at the end of each phase. These questions also focus on the effectiveness of the CPR process. Feedback is more equivocal in this area than in the aspects above. While the majority of students agreed, significant levels of disagreement to L1 shows that many students were not convinced of the value of the reflective portfolios for learning the design process. Responses to L2 show a similar level of disagreement on the value of peer assessment. There was strong agreement with L4, showing that the students do not expect to be developing written communication, which may explain some of the disagreement in L1 and L2. Responses to L5 show a high-level agreement, showing that students did feel they improved their written communication skills as a result.

The responses to L7 and L8 are important. L7 shows that students generally feel they developed a deep understanding of the design process, and L8 shows a perception that the skills learned will be of value to them in other engineering courses. This also suggests that students do not see the course as a soft option. Disagreement with these statements is the lowest of all the questions in this group. It is still, however, nearly 10%, indicating a range of students who have not seen the full value of the process. More communication on the importance and value of the learning processes in the course may reduce this percentage further in future offerings of the course.

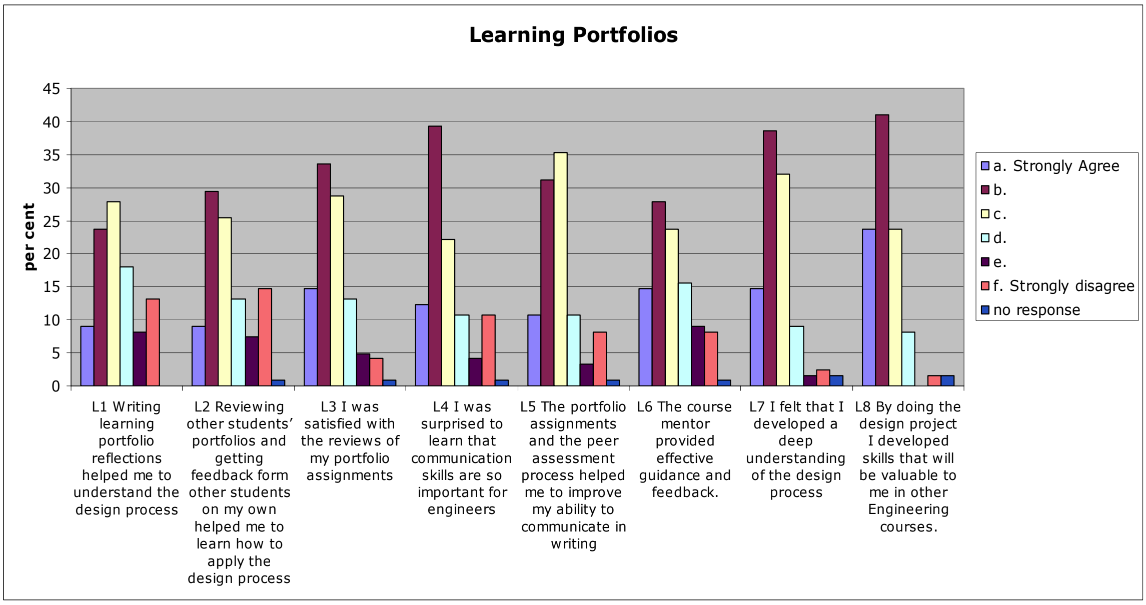

Figure 4: Reflective tasks and peer review

Conclusions

The course appears to have successfully met most of its aims – a good result for the first time offering of a major innovation. The key learning activities associated with phases of the design process led to completion of design projects as intended. Students rose to the challenge of assessment tasks such as group design reports, reflective portfolios and design notebooks, as well as the design project. The evaluation data reported above suggest student satisfaction with the process and what they learned. While the data also suggest some areas for improvement, the main aims relating to implementing a project-based learning approach that includes group work and individual reflection and peer review were achieved in a way that most students engaged with and enjoyed.

Online support played a key role in integrating the course, and facilitating project based learning for a group of 240 students in the School of Mechanical and Manufacturing Engineering project. Student feedback indicated that they made use of the online resources for facilitating the design process and group work, and that they found the group project to be a satisfying learning experience. The group facilitation guides, developed on the basis of research by Hmelo-Silver (2004) appeared to have been a valuable development for this course, and will be the subject of further study. Online student peer assessment and review using CPR and iPeer also played a role in enabling the learning processes and giving the students feedback on their own work and contribution. The students gave positive feedback on most aspects of what they learned, and the way they learned, showing a response to the course and the skills they developed that refutes the "soft option" perception of design courses in engineering reported by Dym et al. (2005). Dym et al. also report that design courses can make excessive demands on staff time. The online processes used in this course ensured that learning activities were completed for every phase of the process without placing heavy demands on staff time after the initial set up.

The range of online processes used in this course could be applied in other project or problem-based courses, as they are designed and developed to encourage self-directed learning and to make staff workloads sustainable. Individual activity and group facilitation guides for phases of the PBL or design process, combined with small-group online discussions, enable self-direction of individual learning and group processes, reducing but not eliminating the need for facilitation by academic staff. These were seen by staff and students to be a valuable support for student learning. Written reflections on learning from phases of the project were assessed by an online student peer review, which provided additional reflection and rapid feedback and assessment. Reflection on group processes and assessment of individual contributions was provided by iPeer. There are other online peer review systems available with different characteristics. Both of the systems used in this project, CPR and iPeer, are freely available for staff who wish to use them. All of these processes help to focus self-directed student learning in a PBL environment without adding time demands on academic staff after the initial setup. These processes can be used to support and enable project and problem-based learning in a range of disciplines.

More development work needs to be done on management of student expectations, so that students have a better understanding of the importance of written reflection and peer review in this course. A valuable area for further research and development is to investigate the processes that students use in more detail, so the key learning outcomes from project based learning can be further identified and strengthened in later offerings of this course.

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