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Real-World Process Design for Mechanical Engineering Students: A Case Study of PBL in DIT

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ABSTRACT

Engineering education deals primarily with calculating quantitative performance of engineering objects, such as machines, circuits or dams, and with designing variations of these objects. However when engineering graduates enter the workforce they must be able to do a great deal more than solve the technical problems taught in engineering school [1]. More specifically they will need to deal with a great range of problems some of which are not technical engineering problems at all. Examples of such problems include working as part of a larger group, project management, negotiation, component sourcing and an awareness of the multi-disciplinary nature of engineering.

Such real-world engineering problems force graduate engineers to draw on their professional and personal resourcefulness, adapt to on-the-job pressure, cope with people problems and broaden their knowledge base. Increased competition and high labour costs put pressure on engineering graduates to contribute to companies as soon as they enter the workplace and reduces the time available to graduates to develop these skills on-the-job.

To help students develop real-world engineering skills as part of their engineering education the Mechanical Engineering Department in Dublin Institute of Technology (DIT) three years ago introduced Problem Based Learning (PBL). This paper describes a PBL module for Third Year Mechanical Engineering students at DIT designed to help students refine their soft skills in addition to a deeper understanding of their technical skills. This approach, developed by Kelleher, gives students the opportunity to develop a range of experiences which will prepare them to contribute to their employer on entry to the company.

INTRODUCTION

Graduate engineers of the future must be capable of (1) working and learning as part of a team, (2) communicating their ideas and requirements effectively through presentations, and (3) negotiating to find the optimum solution to the problem they are working on [1]. Companies want graduate engineers who can perform from day one. To meet this expectation student engineers should be given the opportunity to develop such skills during their professional preparation. In most DIT engineering programs students typically work on clearly-defined projects as individuals or in groups of three or four in the early years of their formal engineering education. Such projects allow students to work as part of a small team. Students can develop and refine their soft skills but do not get an opportunity to evaluate their knowledge or understanding in the context of larger groups.

To promote deep learning, where students get experience of working as part of a larger group, the Third Year Mechanical Design Projects in DIT are arranged in the form of PBL exercises. The course was developed by Kelleher and has operated in the form described herein for the last 3 years. PBL presents students with a real-world problem and students explore various solutions in a self-learning capacity before proposing an appropriate solution. This approach to learning, where a problem is posed to drive the learning, was introduced by the McMaster Medical School in the 1960s. Because the medical students typically worked in groups of 5 or 6 students the approach is often called small group PBL. The model described in this case study involves larger groups of between 25 and 30 students and is often referred to as large group PBL.

PBL has now become a widespread teaching method in many professional fields, particularly in disciplines where students must learn to apply knowledge not just acquire it [2]. PBL is grounded in a constructivist theory of learning and is based on the premise that learners come to know something new, not by passively hearing it, but by actively engaging with it and connecting it to what they already know. The philosophy of PBL is to build and support a learning process established around engineering problem solving. In this case students learn by conducting a relatively complex mechanical engineering design project under the supervision of lecturers who act as coaches and facilitators.

SECTION 2: THE PBL COURSE STRUCTURE

Third Year Mechanical Engineering students in DIT are split into class groups of between 25 and 30. To really engage the students and to make the project as relevant as possible for each group, students select a project under the supervision of the lecturers involved. A brainstorming session, where the students propose several different projects, is used to generate a list of potential projects. All of these are considered in turn by the full class and the lecturers before the students vote for one. The chosen project, which should relate to the mass production of a consumer product, must involve different mechanical engineering areas which the students have already encountered. This enables students to apply and gain a deep understanding of how various mechanical engineering topics integrate. However the problem must highlight for students the need to learn new knowledge before they can solve the problem. For the purpose of the project the lecturers act in the role of clients. The projects selected by the two student groups in 2007/08 were to define, design, specify and source the components needed for production equipment to (1) assemble a ball-point pen and (2) to package bulk jam into 454g pots.

The objective of the design project is to give students the opportunity to manage and deliver a real-world project under simulated industrial conditions. To make the experience more realistic students must overcome challenges of working and liaising as part of a larger group. In so doing students are exposed to a range of challenges experienced by engineers in industry settings. With guidance from the facilitators students are expected to take full responsibility for managing the project and deliver an appropriate solution.

Students have 12 formal sessions of 3 hours duration each over a six-week period and are expected to use these sessions to review and plan their work to ensure that they can meet the relevant project milestones. An overview of the milestones in addition to a generalized list of tasks, and the allowed duration of each task, is shown in Figure 1. Formal deliverables for the course are (1) a preliminary report, (2) a final report and (3) a final presentation in front of a board of assessors. Every student is expected to present the elements of the design which they developed and be able to answer questions about any aspect of the project. This encourages a sense of shared ownership and responsibility for the project in addition to ensuring that all students engage in and benefit from the learning process.

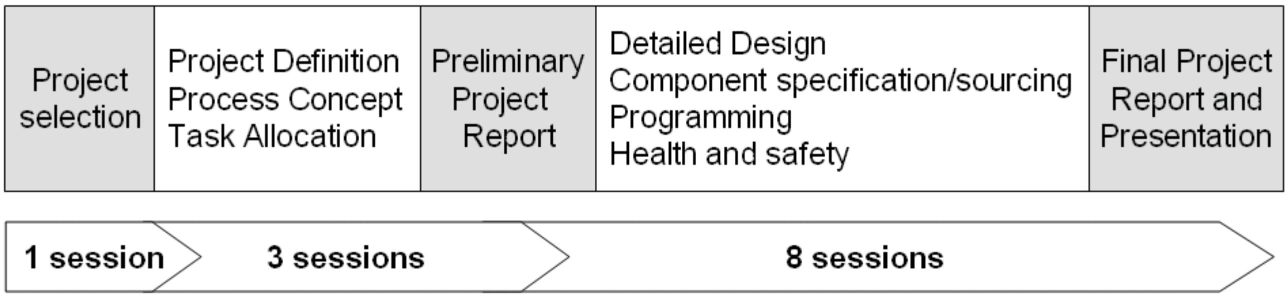

Figure 1: Project milestones, generalised list of tasks and the number of sessions between milestones.

During the initial sessions students are encouraged to define project objectives. The definition stage involves students developing a design brief to focus their design. This typically involves detailing the dimensions and materials of all components, the required production rate, the viscosity of any liquids involved, legislation to be complied with and any other requirements in terms of packaging, etc. Students then develop an initial, high-level concept for the production machine which is typically in the form of a preliminary process flow. Students are expected to focus on key process steps and develop a machine concept around that. Students are encouraged to use sketches and simple calculations to evaluate their designs. This enables students to quickly analyse the practicality of their design, and practice in performing preliminary calculations.

With the process concept selected all students are divided into sub-groups. Each sub-group is responsible for a specific stage of the project. The number of sub-groups created is based on the number of stages required to satisfy the process concept. The project definition, process concept and task allocation forms the preliminary project report. This obliges students to commit to doing specific tasks within a specific timeframe and forms part of the formal project assessment.

Table 1 lists typical job titles and primary responsibilities for each sub-group. The number of students assigned to each task is proportional to the predicted workload. The detailed design function is the largest group of students. These students are expected to create CAD models of the assembly machine based on dimensions justified by calculations. To encourage students to use standard components where possible the sourcing group is expected to find available components which satisfy these requirements. The dimensions for components selected are fed back to the design group to be incorporated into the CAD model. Experience of such an iterative process gives students confidence and is important in educating engineers about the importance of multidisciplinary teams.

A single student is assigned the task of researching the applicable legislation to ensure that the final machine will comply with it. This typically includes ensuring that the correct materials are specified where specific requirements exist and that safety guards, switches and waterproof components, etc are incorporated into the machine design. This highlights the importance of CE marking on machines to be manufactured or operated within Europe. The machine programming function is normally handled by a single student. Pseudo-code is developed to encourage the students to consider machine timing, or sequencing, as part of the overall design process.

Title	Approximate number of students	Primary responsibilities
Project manager	1	Responsibility for co-ordination of work and report editor
Detailed designers	20	To fully detail the design for each stage of the process. Design groups are created to work on each stage.
Machine programmer	1	To develop code to operate/sequence the machine.
Legislation	1	Ensure that relevant legislation, particularly health and safety is being complied with.
Component sourcing	3	To find suppliers of components specified (and encourage use of standard components where feasible).

Table 1: Typical job titles and primary responsibilities for each team member.

SECTION 3: ASSESSMENT

As already described the formal deliverables for the course are (1) a preliminary report, (2) a final report and (3) a final presentation in front of a board of assessors. The reports must clearly indicate the responsibilities of each individual involved. Assessment and relevant feedback is important for the students. The assessment of group PBL projects is a challenge, particularly where the contribution of each student must be graded. Co-operative learning, where students work together to learn, as opposed to competing with each other for marks is the ideal and some challenges have been reported in helping students understand the importance of co-operation [3]. A group-mark for the entire project team might be a disadvantage to the stronger or more committed students and might also be abused by weaker students who might assume a passive role in the project. To alleviate this problem the authors implement a combined team and individual assessment. Based on a review of the interim and final reports in addition to the formal presentation the same grade is awarded to all students in each group by the board of assessors. This board of assessors includes the Head of Department and the lecturers involved. The deliverables are assessed to evaluate how the students have managed to meet the specified module learning outcomes. The task allocation list together with observations made during the formal project sessions are then used to adjust the mark for each student based on their individual contribution to the successful outcome of the project. The marks may be adjusted either upwards or downwards, based on this assessment.

SECTION 4: DISCUSSION

Some sub-groups were nervous about accepting students who they felt would not attend the tutorial sessions. In the case of one group, students who missed the initial classes were assigned to a non-essential task of final packaging. This action was taken due to the students' concern that they would

get a reduced mark if they had a non-committed member in their team. This sidelining had the effect that the students involved developed an exemplary attendance record for the remainder of the project and made a substantial contribution to the overall success of the project.
Some students were reluctant to make decisions since they are afraid of being “incorrect”. This probably comes from an expectation that there is a right or a wrong answer for everything. The design problems posed have many solutions and, being an iterative process, the students are encouraged to refine their concept and justify the chosen solution. To encourage the students to think the process is emphasized above the product. It is important that students learn to justify their decisions since it is an important ability for engineers to develop.

Students find it very hard to plan and integrate their activities as part of a larger group. A number of sub-groups, particularly the CAD, machine programming and component sourcing groups, complained that they did not receive the information they needed to complete their task in a timely fashion. When this delay was communicated to the full group it highlighted the importance of time and project management for the success of the entire project.

From the experience of running this project over a number of years in the Department of Mechanical Engineering, it is clear that the student project manager chosen to run the project has a significant influence on the overall success of the project. Based on previous experience of the class group and observations of likely candidates during initial brainstorming sessions lecturers may have opinions regarding the most suitable candidate and the expectations on what (s)he must do are clearly outlined to the class group. However the students select their own project manager and must live with the consequences. The project manager also serves as the editor for the final report. It is a challenging and demanding role since (s)he must continuously push and cajole their “colleagues”, who in reality are classmates, to meet the relevant deadlines. It has been proposed by a number of students that the effectiveness of the project manager could be increased by allowing them to assign a certain proportion of the marks. Such self-assessment has been reported as an element of other PBL studies [3]. However the adoption of such an approach has not been seriously considered to date since it is felt that it may result in conflict within the class group.

SECTION 5: CONCLUDING REMARKS

The authors believe large-group PBL in DIT offers many potential benefits to students, lecturers and ultimately industry. In addition to the engineering skills learned, applied and refined by the students during the project other potential benefits are summarized in the Table 2. Students benefit from the opportunity to develop project management, presentation and negotiation skills, in addition to an increased awareness of component sourcing and the multi-disciplinary nature of mechanical engineering and are better prepared for embarking on their final year projects. Lecturers benefit from working with more motivated students who can actually apply theory in a practical way. Potential benefits for industry are easier assimilation of students into the workplace since the students have increased experience of working as part of a larger team. The project increases students’ confidence resulting in more resourceful, motivated students who can be easily assimilated into workplace teams. Students have expressed their enjoyment of the course despite the amount of work involved and commented that they felt the course prepared them well for final year projects, particularly in terms of project management and presentation skills.

The projects are time consuming for both students and lecturers. Any issues that arise in the simulated industrial environment must be addressed by the course facilitators.

As highlighted by Harris and Briscoe-Andrews program evaluation is important to understand if the course is effective in achieving desired learning outcomes [4]. Evaluating is difficult since (1) the lead-time for students to enter the workplace delays a formal response from industry, (2) students' lack of experience of alternative learning methods may affect student objectivity in conducting a student evaluation and (3) the absence of a control group may affect the interpretation of any results obtained. No formal evaluation specific to this module has been conducted to date. However as course participants have now graduated and are working in industry a formal evaluation is planned to evaluate the benefits and drawbacks for all stakeholders.

Potential benefits of large-group Problem-Based-Learning		
For Students	**For Lecturers and DIT**	**For Industry**
Acquire and develop project management, presentation and negotiation skills	Motivates students to take more interest in mechanical engineering	Easier assimilation of students into the workplace
Better-prepared for final year project	Provides a more authentic assessment tool	Experience of working in a team environment
Suits learners who like continuous assessment (rather than single end-of-year exam)	Allows students to apply theory in a practical way	Resourceful, self-motivated students
Increased awareness of the role of sourcing components/outsourcing in mechanical engineering		
Greater sense of satisfaction and comprehension of the multi-disciplinary nature of mechanical engineering		

Table 2: Potential benefits of large-group Problem Based Learning.

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