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Team-based learning in engineering design courses

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ABSTRACT: An important requirement of graduate engineers is their ability to manage and/or collaborate in complex, open-ended projects. This requires effective communication skills, as well as the ability to work independently and in a team environment. It is widely recognised that project and team-based learning, particularly within the framework of larger open-ended design and industry-based projects, provides undergraduate engineering students with the best opportunities to understand the complex multidisciplinary contexts that are typical for many professional tasks. In this article, the authors discuss their experiences gained from project-based learning within engineering design courses at the University of Auckland in Auckland, New Zealand. The issues covered include the identification of knowledge gained, the formulation of project objectives, and the opportunities and challenges associated with project management and teamwork. The results are drawn from students' initial exposure to project-based learning in the first year design course through to the final year design course. The main conclusions resulting from student feedback are also presented.

INTRODUCTION

In the article, the authors present an evaluation of outcomes from three design courses that are based on project and team-based learning taught to engineering students at different levels of a four-year degree programme in the Mechanical Engineering Department at the University of Auckland in Auckland, New Zealand. In terms of study years, the freshmen design course (first year) focuses primarily on a structured design experience, whereas courses for 3rd and 4th year students focus more on less structured open-ended design experiences. The main objective of the freshmen design course is to bring students' attention to the concepts and practice of engineering design with some limited hands-on experiments and projects. On the other hand, the main objective of the senior year design courses is to focus students' interest in the design of real-life products based on either guided or open-ended design experience using, where possible, industry-based projects. The ultimate objective of these courses is to provide students with the opportunity to work in realistic cooperative design environments in which they employ critical thinking, apply learned theoretical knowledge and gain skills for self-motivation and life-long learning through teamwork [1]. Although the teaching approach for these courses varies according to set requirements for the different levels of students, there is a common approach in all courses with respect to the project-based learning component. The underlying objective of this research study was to investigate, from different perspectives, the issues surrounding the expectations and learning outcomes from a project and team-based approach.

Traditionally, engineering design courses commonly combine lecture delivery with team project assignments, where small collaborative groups of students work on a specific problem. The benefits expected from the addition of project and team-based learning include greater interpersonal communication skills, knowledge sharing and information dissemination, along with a degree of self-learning of new material. The design courses studied here recognise the necessity for a modern engineering graduate to possess strong technical knowledge plus a wide array of personal, interpersonal and system building skills that allow them to function effectively in real engineering teams producing real products and systems [2]. The idea behind this research was to examine the effectiveness of the project and team-based learning approach and the assessment criteria used for the range of design courses; this had the following learning objectives:

- Develop innovative design concepts that would enhance the competitive advantage of a particular product using a systematic approach;
- Develop a good understanding of real-life consumer product design processes and the environment within which they need to operate;
- Become familiar with some modern design tools and techniques;
- Understand customer perceptions regarding designed products;
- Develop creativity skills;
- Learn the importance of sharing responsibility through teamwork with members having different norms, backgrounds and value systems.
- Develop good professional dissemination skills in terms of communicating ideas and concepts through presentations (eg reports, workbooks, posters, oral presentation and interviews).

According to cognitive science research regarding the nature of learning, students construct knowledge; they do not take it in as it is disseminated, but rather they build on knowledge they have gained previously [3]. They benefit from working together and may learn best from teaching each other. As a whole, students learn through making cognitive, social and experimental connections. In this context, project and team-

based learning plays an important role. In project-based learning, students work in teams to achieve optimal solutions for particular design problems that represent *real world* situations. They develop skills in collecting, evaluating, and synthesising information and resources in a professional manner, and then propose an optimal solution showing alternative approaches. As current employers have frequently expressed a desire to have graduate engineers (students) who can think critically, solve problems and work in teams, project and team-based learning is recognised as a better platform for engineering design courses. Project-based learning is a well-known method for imparting thinking competences and creating flexible learning environments, as well as directing students to foster learning and develop thinking skills [4][5]. Project and team-based learning methodologies place students in an active learning environment that puts them at the centre of the learning process. The knowledge gained through active learning is constructive knowledge achieved through active thinking and problem solving, both of which are important for modern graduate engineers. Project-based courses usually provide students with an opportunity to improve multi-disciplinary teamwork, communication skills, project management and problem solving abilities, as well as to immerse them in an environment that will enhance life-long learning [6]. A related pedagogical approach of project-based learning is Problem-Based Learning (PBL), which is well recognised within higher education. Although this approach is similar to project-based learning, it constrains students' activities more by asking them to solve specific problems, rather than relying on students to come up with their own problems in the course of completing a project. The acquisition and structuring of knowledge in PBL is thought to work through the following cognitive effects:

- Initial analysis of the problem and activation of prior knowledge through small-group discussion;
- Elaboration on prior knowledge and active processing of new information;
- Restructuring of the knowledge with the construction of a semantic network;
- Learning in context;
- Stimulation of curiosity related to the presentation of a relevant problem [7].

The project and team-based engineering design courses studied in this research utilise PBL, where open-ended mini projects are assigned to small groups of students. Students are provided with some specific objectives along with a typical design problem (real world product design and/or industry-based design problem). Individual teams, typically made up of 3 or 4 members, are formed by students from their respective class colleagues and are required to achieve a competitive and optimal design solution within the project time schedule (for example, within 40 hours). The project schedule is provided by the lecturer along with comprehensive guidelines. To ensure that each team member contributes fairly to the team effort, CDIO-based team contract guidelines are provided to the students. To avoid conflict among team members, each member must sign the agreed team contract developed during their initial team meeting and submit this to their assigned tutor before commencing work on the actual project. In addition, at the end of the project, students must submit a completed peer assessment form. The aim of *peer assessment* is to review how the members of the team evaluate their own and the other team members' contributions and performance throughout the project. This is sometimes taken into consideration when evaluating students' final grades. In addition, peer assessment is used to obtain feedback regarding how well students achieved the course objectives.

In this research, the authors study students' performance in teamwork while they explore real-world problems assigned in the project. In addition, students' perceptions of project-based learning are examined regarding the expected outcomes, which include a deeper knowledge of subject matter, increased motivation and improved problem-solving skills. Finally, the applicability of project-based design courses is verified with respect to their effect on developing an in-depth understanding of the knowledge acquired, performance assessment procedures used and student ownership of their own learning. Accordingly, the authors focus on the project and team-based experiences gained by students in three design courses with respect to learning objectives, implementation procedures, assessment criteria and expected outcomes.

RESEARCH DESIGN

This study is based on data from a large research study involving different classes in the Mechanical Engineering Department at the University of Auckland. The data was collected from three design-based engineering courses, one from 4th year, another from 3rd year and the third from 1st year of a four-year undergraduate engineering degree programme. During 2005, the responses from 50 students from the 4th year course, 30 students from the 3rd year course and around 500 students from the 1st year course were collected. From the total responses obtained from students, 48 4th year, 15 3rd year and a random sample of 30 1st year were used in the analysis. The engineering design courses studied in each year were all developed around a set of standards for lesson plan and assessment criteria. These standards specified learning objectives plus guidelines on how to achieve them. For the assessment criteria, quality indicators were clearly stated and scoring criteria were made available to students with regard to what was being judged, as well as the standards expected for acceptable performance.

The research was designed with the following specific set of objectives:

- Assess the achievement of the learning objectives through the use of project-based courses;
- Identify patterns of individual student's knowledge gained through teamwork;
- Assess the usefulness of team contracts in the learning process;
- Assess the applicability of the developed tools and methods used;
- Identify shortcomings in the team-based learning approach, if any, in the project-based engineering design courses.

Data was collected using a well-formatted questionnaire. Respondents (students) were asked to submit the completed questionnaire immediately after the submission of their final reports in the respective design courses. Key question areas included in the questionnaire are highlighted here. The first part of the questionnaire contained questions regarding peer assessment, which emphasised the distribution of workload among team members and the nature of these contributions, with respect to teamwork along with individual and team (performance) ratings. The second part of the questionnaire was related to teamwork itself. This part asked questions regarding student perceptions of the following:

- The achievement of learning outcomes with respect to the specified learning objectives;
- Responsibility taken by team members;
- Expression of opinions in team discussions;
- Methods of resolving disagreements within the team;
- Application of teamwork;
- Additional support required;
- Individual contributions made towards achieving the project goals;
- The knowledge gained through working in a team.

Open-ended comment sections on project and teamwork were also incorporated in the questionnaire. Comparative analysis between the expected performance suggested by students and the performance assessed by the instructor was also carried out.

In order to enhance students' *real life* experience, scenarios were developed in which they were presented with well formulated *client* letters explaining the design brief and business requirements expected from the ensuing product design. In the final year design course, the project was formulated and presented to the class by the Manufacturing Manager of the client company. CDIO-based guidelines for teamwork contracts, project scheduling, guidelines regarding presentation material and modes of presentation (structure and suggested format of design portfolio), and peer assessment forms were all provided to the students at the outset.

As each particular project-based learning environment is unique, individual assessment strategies were developed for each course. Among the several alternative assessment techniques used, evaluations by external experts and peer evaluations were applied. Since project-based learning usually involves a culminating experience, such as a formal presentation, a written report or a portfolio submission, the evaluation of these projects by outside experts seemed appropriate. Thus, in the performance evaluation processes used, course instructors, tutors and external company experts and design professionals were usually involved.

For a better understanding of the evaluation process by the team and its individual members, pre-prepared assessment criteria were delivered to students at the beginning of each project. These assessment criteria are based on the quality of the solution, design proposal, quality of the artefact, design process, group management and evidence of work effort (eg workbook).

In addition to written submissions like a design proposal, interviews with student teams were carried out in the 3rd and 4th year courses. Performance evaluation in the interview was based on professionalism and attitude, presentation quality and the ability to respond coherently to *client* questions. As an integral part of the assessment process for individual students, peer assessment was applied as a means of moderating individual student behaviour within the team setting, as evidence of contribution towards teamwork and an indication of skill level development across individuals within the team.

MAJOR FINDINGS

Qualitative and quantitative analyses were been performed for this study. Semi-structured interviews with students during the project, relative performance testing and assessment of presented material have also been considered for the analysis. In addition, the data collected by the questionnaire survey has been utilised for statistical and qualitative analysis purposes. From this, the self-assessed ratings of a student's performance with his/her team members' ratings were compared. To test the acceptability of an individual student's self-assessed score, the average rating was calculated for a particular individual provided by the team members against his/her expected rating and a correlation study was conducted. Students' perceptions of project-based learning, teamwork and the assessment by a panel of course evaluators (composed of lecturer, tutors and company experts) was also performed for the 4th year course to identify variations.

An analysis of the raw data collected from the questionnaire survey, observations and students presentations (eg technical reports) revealed some issues that repeatedly appeared. The first issue concerned the achievement of the learning objectives from the courses, which had been defined at the beginning of the project or course. The responses shed light on students' views on their achievement of the learning objectives expected from the course and it was interesting to compare their perceptions with the course organisers' intentions. The second issue that emerged from the study was the applicability of teamwork within project-based design courses. The third issue referred to the additional knowledge (apart from the specific design tasks) gained through the use of teamwork. The fourth issue related to the setting of project-based learning tasks within the context of realistic industrial environments.

The key question regarding learning objectives was *Did the learning outcomes you achieved from working in a team in this project match the learning objectives specified in the project handout*? To respond, students were given five options as shown in Figure 1. The responses are very positively in favour of the achievement of the learning objectives.

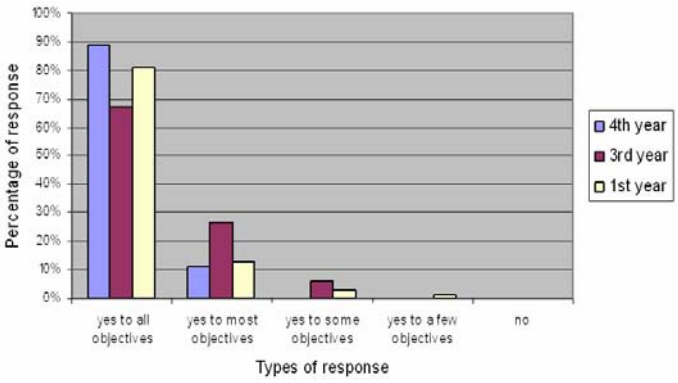

Figure 1: Responses to the achievement of learning objectives.

Before the study was conducted, the authors expected that the *team contract* might play an important role in indirectly enhancing an individual's contribution to teamwork. However, the main objective of the CDIO-based team contract is to ensure fair working policies for all members in a team. This issue was examined by collecting the data relating to the usefulness of the team contract as perceived by the students. This was analysed with respect to five usefulness categories as shown in Figure 2. The figure shows that, on average, 40% of students from each study year used the team contract to divide workload, while, on average, 39% of students used it to make decisions. A significant finding was that around 26% of students did not use the team contract at all.

As stated earlier, the project and team-based design courses were developed to ensure that students learnt from a *real*

industrial working scenario. Students' perceptions regarding the most important learning outcomes from the courses (apart from the technical objectives) were also investigated. These findings are presented in Figure 3.

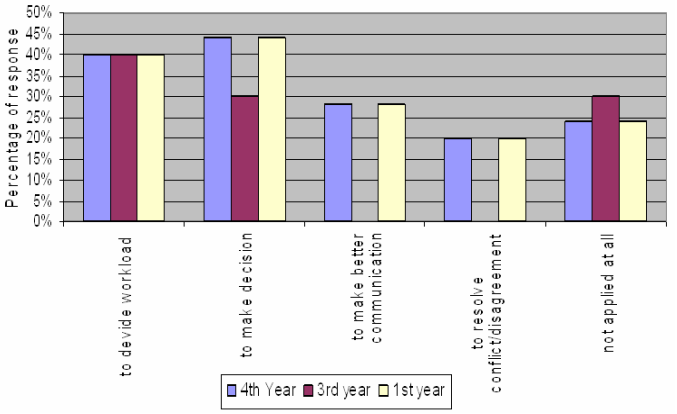

Figure 2: Usefulness of the team contract.

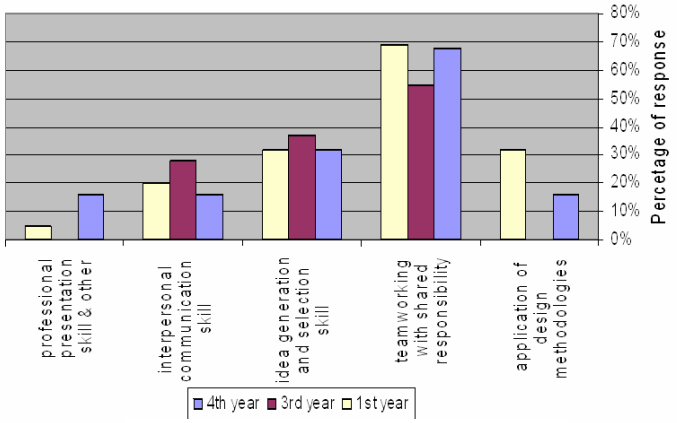

Figure 3: Most important knowledge gained through teamwork.

These findings indicate that students, through project and team-based learning, gain some important knowledge and skills that are demanded in real design environments.

Finally, an analysis was performed to verify the applicability of the use of peer assessment and the overall assessment criteria developed for these project-based courses. Regarding peer assessment, a t-test was conducted with the comparative scores provided by individual team members and their peers. It was found that the distributions for the contribution to teamwork, team performance and individual performance for both cases were significantly the same. This indicated that individual students were not claiming a greater contribution to teamwork and performance than that assessed by their respective team members. This would suggest that the current *peer assessment* is working well in terms of evaluating teamwork and individual performance.

However, another t-test was performed comparing individual performance, as assessed by peers, with that evaluated by the instructor. This indicated that the performance evaluated by the instructor was significantly lower than that suggested by the students. This means that either students have overrated their relative contribution or they have misunderstood the assessment criteria being used by the instructor. Clarification of this criteria may need to be more clearly conveyed to students in future.

CONCLUSIONS

These are based on student feedback obtained from project and team-based learning in three design courses from different years at the Mechanical Engineering Department at the University of Auckland. It was found that, in project-based learning, students perceived that they developed stronger thinking and problem-solving skills, effective communication skills and a greater sense of personal responsibility. Students reported a high level of satisfaction from their experiences in project-based learning. They appeared to have a substantially more positive attitude towards the instructional environment as was indicated in their responses to particular questions regarding the usefulness of peer assessment and their use of team contracts. With only a few exceptions, the majority of students agreed that they had achieved most of the learning objectives outlined for the courses. This resulted in students being able to set their strategies within the team, to achieve their objectives, divide the workload between team members to utilise potential expertise and skills from individuals, and accumulate the necessary knowledge and skills through teamwork, which was reflected in their final presentations. It was found that the collaborative groups fostered students' sense of collective ownership of the knowledge that was created throughout the project. The sharing of responsibility and contributions to specific tasks highlighted this issue.

The integration of project work within a structured design course curriculum, for freshman level (first year) students, enhanced their understanding and knowledge about real life design activities, which should enrich their current and future learning experiences. It has also been found that the assessment criteria used in such courses needs to be either demonstrated and communicated well, with some practical examples shown to students beforehand, or be modified to ensure that they match students' expectations. Overall, the project and team-based courses offered in the Mechanical Engineering Department seem to be running well and produce worthy engineering graduates capable of fulfilling the demands and meeting the challenges of modern professional engineering practice.

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