Critical Conversations: How Collaborative Learning Activities Can Prepare Students for Structural Engineering Practice

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***Abstract**: Junior structural engineers rarely work alone. Their design calculations are usually peer reviewed, and they may be involved in reviewing other engineers' designs. They are also likely to have to articulate their design decisions to their supervisor or the project team, if not the client. At the University of Technology, Sydney the authors redesigned the asssessment tasks in the subject Concrete Design to be collaborative learning-oriented tasks that provide an opportunity for students to develop and practice the skills they will need to interact with other professionals in the workplace and continue learning during their career. We theorised that allowing students to collaborate during quizzes and a project would make these activities more learning-oriented, in that students would actively learn from each other while completing their assessment. Data from various sources were collected to examine the impact of this collaborative assessment on student learning. These sources included instructor observation, analysis of student responses to a reflection activity, student surveys and student results. Students reported that not only were these activities enjoyable but they also significantly improved their learning.*

Introduction

Junior structural engineers rarely work alone. Their design calculations are usually peer reviewed, and they may be involved in reviewing other engineers' designs. They are also likely to have to articulate their design decisions to their supervisor or the project team, if not the client. However the curriculum in a typical engineering program is so crowded that there is insufficient time to cover everything students need to know to immediately function as a structural engineer in the workplace on graduation. Hence, graduate engineers will need to undertake ongoing informal learning in their workplace (Trevelyan 2007). To develop these skills students require opportunities to experience, practise, reflect and improve their ability to work in a collaborative environment, and in doing so take more responsibility for their own learning.

Many students resist taking responsibility for their own learning rather expecting this to be the responsibility of their lecturers. In addition, when students engage in design subjects for the first time this resistance is often reinforced by their prior education experience. Typically before undertaking their initial design subject students have completed mainly 'engineering science' subjects, for example Statics, Mechanics of Solids & Structural Analysis. These subjects are usually characterised by closed formed problems, which are solved by the demonstrated method and have numerical answers that can be expressed to many significant figures. Furthermore, everyone's answer is the same unless they got it 'wrong'. This is different to engineering practice where problems are rarely closed form, there are often several methods of approach which can lead to different solutions that all meet the design requirements, ie everyone's solution will not look the same. In design situations engineers use their calculations to support their decisions, but these decisions also typically rely on using professional judgement. The authors initially found it difficult to get students to participate in collaborative learning activities and in particular those that involved them using their own judgement or critical analysis. To address this issue the course Concrete Design was redesigned to include collaborative peer learning orientated assessment tasks.

Background

Professionals, in addition to being technically competent, require the skills of collaboration, communication and the ability to work in teams (Lang et al 1999, Scott & Yates 2002, Mills & Treagust 2003). However, there are reported competency gaps between the skills required by employers including communication, critical thinking, leadership, teamwork skills and life-long learning capabilities, and those developed by students during their undergraduate courses (Hargreaves 1997, Meier et al 2000, Jones 2003, Bryan et al 2005, Markes 2006, & Chung et al 2008). Scott and Yates (2002) note that successful engineering graduates rated their ability to contribute positively to team-based projects as the most important of 49 possible reasons for their success. Workplace learning and professional practice is often collaborative (Littlejohn, Margaryan & Milligan (2009). It follows that students' preparation for entering this environment should include opportunities to practise collaborative learning with their peers. Collaborative learning also provides opportunities to develop interpersonal and critical evaluation skills in addition to professional judgement. The ability to critically evaluate and clearly articulate your point of view are requisite skills for successful participation in collaborative professional practice. Despite this students often receive little training and infrequent opportunities to develop such skills during their academic studies.

Collaborative learning is also attractive from the perspective of the social constructivist model of learning (Jawitz and Case, 2009). The social constructivist view is that learning takes place when students construct their knowledge through individual engagement and social interactions with others (Wu, Beiber and Hiltz, 2008, Purzer, 2009). It is the students doing the learning rather than the teacher doing the teaching that determines whether learning takes place, and so this is a student-centred philosophy. Hagstrom (2006) argues that "…contexts for new knowledge construction include a blending of people … and provides the occasion for the construction of new knowledge….If educators simply tell students what they need to know, they encourage reliance on memorization of facts. For students to make cognitive changes, the learning experience must begin with each student becoming aware of his or her own present understanding" (Hagstrom, 2006, p28). Dana (2007) reports that compared to traditional competitive or individualistic learning environments, benefits of small group or team based learning include higher student achievement, greater use of higher level reasoning and critical thinking skills, more positive attitudes toward the subject matter and satisfaction with the class, and better interpersonal relationships among students and between students and instructor

While projects, assignments and laboratories are regularly considered as opportunities to incorporate collaborative learning activities it is less common to undertake collaborative examinations and quizzes. Stark (2006) describes the use of team exams in management education. He first conducts an individual exam and then gives the same exam to teams to complete. He observed that "...students engage each other in serious discussion of the material to the same end – that of understanding the material better than they did before." Stark further reports students' learning benefits from having to explain concepts to their peers and that "Team exams make postexam feedback more of a student-directed and student-centred activity". Stark (2006) uses several types of collaborative exams including the immediate feedback assessment technique described below.

Immediate feedback assessment technique (IF-AT) cards (figure 1) developed by Epstein (http://www.epsteineducation.com/home) allow students to immediately identify if they have answered multiple-choice questions correctly. If an answer is incorrect, groups consider the remaining options, and try again. This process continues until the correct answer is achieved. In controlled trials the IF-AT method was shown to promote more retention of learned material, that it was the immediate nature of the feedback that improved learning (Epstein et al 2002, Dihoff et al. 2004, Brosvic et al 2005, Brosvic & Epstein 2007), that student satisfaction with this test method was higher than previously used methods (Epstein & Brosvic 2002, Persky & Pollack 2008), that it is equivalent to more traditional test approaches in terms of scope and level of material tested (Persky & Pollack 2008), and that it promotes higher levels of independent learning (Brosvic et al 2005; Persky &

Pollack 2008). Furthermore Persky & Pollack (2008) report that use of the IF-AT "allows a student to assess his or her own mastery of the material, indicates to the student areas of potential misconception, and allows the student to think about and rework problems. Each of these elements potentially increases deep learning."(p.5) The answer-until-correct process facilitated by the IF-AT cards is leveraged by Michaelsen (Michaelsen, Knight & Fink (2004)) to extend the benefits of immediate feedback to the collaborative environment of team based learning.

In this paper we report combining a collaborative group project that includes self and peer assessment, and first individual then collaborative quizzes (using immediate feedback assessment techniques (IFAT)) to produce collaborative peer learning opportunities to assist students to develop the skills required for collaboration in professional practice.

Assessment tasks in the subject Concrete Design

Concrete Design is undertaken by all civil, civil and environmental, and construction engineering students at UTS. The subject's primary aims are to develop students' understanding of the behaviour of reinforced concrete structural elements such as beams, slabs and columns, and to develop competence in using and interpreting the Australian Standard for Structural Design Actions (AS/NZ 1170) and for Concrete Structures (AS3600). The subject introduces students to the fundamentals of the structural design process and the philosophy of limit state design.

Assessment tasks in the subject were designed to include a collaborative project with three temporally separated submissions, in-class topic quizzes and a formal end of semester examination. While the project and quizzes were redesigned to promote collaborative learning, the format of the final exam remained the same as those used in previous semesters. The contribution of each assessment to a student's final grade was assignment mark (project + 2 smaller assignments) 30%, quiz marks 20% and final examination 50%.

Design Project

As with Mills and Treagust (2003), the design project was developed to "...provide students with an authentic learning task that reflected the complexity of the professional structural engineering environment, and provided them the opportunity to develop their understanding through social interaction with their peers and the lecturer, as well as personal reflection."(Mills and Treagust 2003 p.214)

In the design project, students work in randomly allocated groups of 3 or 4 to design beam, slab and column elements for one storey of a low-rise reinforced concrete building. The design project consists of three staged assessment tasks where students submit their design calculations, decisions and drawings: 1. Loading and Beam Design, 2. Floor System Design, and 3. Column Design. Traditional lectures and are used to examine the theory behind the design and analysis required to address each part of the project.

The project was specifically designed to be too much work for one or two students to complete alone, so that students were forced to work collaboratively to complete the assessment tasks. The project also required students to make design recommendations ie to use their engineering judgement. Students were asked to complete two designs for the floor system, the first as a two-way slab and the second as a flat slab; each group then had to recommend one of these floor systems for their project, and justify their recommendation. Decisions made about one element of a design inevitably affect other elements in the system. This was reinforced when the students were required to design the columns for their building using both floor systems. Students could see how the design requirements for the columns varied depending on the floor system used. Having to explain and justify their design provided an opportunity of students to both practice and demonstrate the skills required to explain their work to a supervisor or client in the workplace.

To promote the development of both discipline-specific and generic professional skills, as well as academic honesty, a process of self and peer assessment was used in assessing the design project. The results of these assessments are used to provide constructive feedback to students as well as to determine individual assignment marks by appropriate adjustment of group marks. After submitting each stage of the project students use the online tool SPARK^{PLUS} to submit their self and peer assessments. SPARK^{PLUS} (SPARK^{PLUS}) uses the self and peer ratings to generate an individual's performance factor. The various rating factors, graphics and peer feedback comments are shared within each group in feedback sessions where students are required to discuss the absolute and relative values of the rating factors (which may indicate problems to be resolved within the group) and to decide on what measures individuals within the group, and the group collectively, should take to improve their next submission or group work experience. While working through that submission students are also asked to identify and discuss what they have learnt from each other. The process of critically evaluating their own and their team members' work and behaviour is explicitly linked to the assessment tasks by using criteria in SPARK^{PLUS} that address the subject learning outcomes. The use of SPARK^{PLUS} for self and peer assessment of individual contributions to a group submission in reinforced concrete design has been previously reported in Gardner and Willey (2008).

In-class topic quizzes

Using in-class multiple-choice quizzes is nothing new, especially in large class. What is more innovative is to have students, immediately after completing their individual quiz, gathering into their project groups to redo the quiz together using the Immediate Feedback Assessment Technique (IF-AT) cards (Figure 1). These cards require the students to scratch off a covering over the response they think is correct (hence they are referred to in class as 'scratch cards'). If they have selected the correct response there will be a star or other geometric shape revealed, as shown in Figure 1. If the group selects the correct response at their first try they are allocated full marks for that question. If the group selects an incorrect response ie they reveal a blank space, they can continue to select another answer until the correct answer is obtained enabling them to receive partial credit. A student's final quiz mark is calculated as 80% of what they scored individually and 20% of what they scored collaboratively. Holding the quizzes at the end of each topic is similar to the use reported by Stark (2006) as opposed to the team based learning process reported by Michaelsen (Michaelsen, Fink & Knight, 2004) where IF-AT quizzes were used to assess students understanding of pre-work.

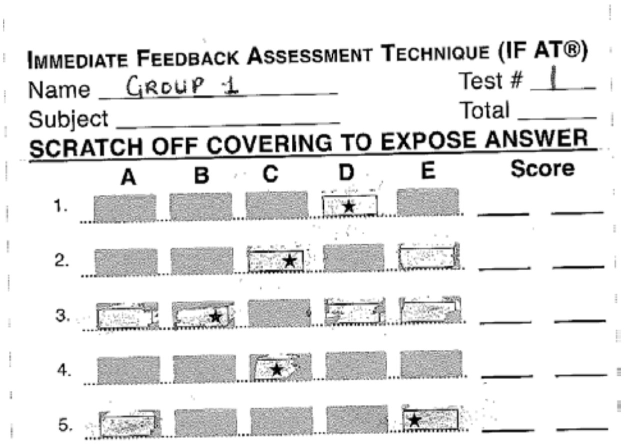

Figure 1: IF-AT card used by Group 1 during a collaborative quiz – showing a star under the correct answer and multiple attempts to find the correct answer for Questions 2, 3 & 5.

Method

After the last quiz, all students were invited to complete a survey instrument investigating their experience of the collaborative quizzes used throughout the semester. The survey questions were a mixture of six point Likert scale (strongly disagree, disagree, slightly disagree, slightly agree, agree, strongly agree) and open-ended responses. The survey questions were grouped into three broad categories: the effect of the quizzes on student engagement, the effect of immediate feedback and the effect on student understanding of the subject material. The survey was paper-based and students completed it in class. The survey results were collated by a third party with results only being provided to the author involved in the subject after the posting of final grades. Students were informed of this approach to encourage them to provide honest responses without fear that anything they said could in any way influence their subject results.

In addition, during the first peer feedback session, groups were asked to participate in a reflective exercise where each group was asked to recall what they had decided/agreed to do to improve their group processes for their second submission. The responses were collected and collated to investigate the aspects of group work most frequently identified by students as needing attention.

Results, Evaluation and Discussion of collaborative learning activities

Post Quiz Student Survey

Of the cohort of 101, 67 students (66%) agreed to complete the survey. Table 1 shows the student responses to these survey statements grouped into the three categories: the effect of the quizzes on student engagement, the effect of immediate feedback, and the effect on student understanding of the subject material. To simplify preliminary analysis the strongly agree, agree and slightly agree responses were added to give the 'Total agree' value. Similarly, the strongly disagree, disagree and slightly disagree responses added to give the 'Total disagree' value.

Survey Statements	Total agree %	Total disagree %
Student Engagement statements		
The use of the IF-AT cards (the scratch cards) made the group quizzes fun.	73%	27%
The use of the group quizzes & IF-AT cards (the scratch cards) increased my overall 'engagement' with the material in this subject.	67%	33%
Knowing that I would be expected to contribute to the group component of the quizzes increased my motivation to learn the relevant material.	72%	28%
Statements relating to clarifying or confirming understanding		
Even when we were confident that we had chosen the correct answer, & got the question correct the first time, the immediate feedback provided by the IF-AT cards (the scratch cards) was useful as it confirmed our understanding of the relevant material.	85%	15%
When we had some doubt about our chosen answer, but we still got the question correct the first time, the immediate feedback provided by the IF-AT cards (the scratch cards) contributed to our learning as it clarified our understanding of the relevant material.	78%	22%
When our chosen answer was incorrect, the immediate feedback provided by the IF-AT cards (the scratch cards) caused us to reflect and re-evaluate our thinking in choosing another answer.	76%	24%
Even when it took more than one attempt, I still liked the immediate feedback provided by the IF-AT cards (the scratch cards) as it enabled us to demonstrate that we had some understanding of the question.	73%	27%
The immediate feedback provided by the IF-AT cards (the scratch cards) enabled me to identify gaps in my knowledge of the subject material, this will direct my study for the final exam.	63%	37%
Statements relating to the collaboration process		
Having to collaborate to decide on answers during the quizzes has improved my understanding of the subject material.	72%	28%
Having to collaborate to decide on answers during the quizzes has improved my ability to think through and resolve problems.	72%	28%
Having to discuss the answers to the quiz with my group members helped me to understand material that I hadn't previously fully understood by myself.	79%	21%
During the semester our group moved from discussing "who" was right to "what" was right when discussing the quiz questions.	64%	36%

Table 1: Aggregated responses to student survey questions

The results (reported in Table 1) show that overall students were extremely positive in their opinion that the collaborative learning activities made a significant contribution to their learning. Students reported high engagement with the class and that the immediate feedback provided by the IF-AT cards (the scratch cards) was useful as it confirmed their understanding of the relevant material (85%) or clarified their understanding (78%). Furthermore, more than 70% of the students agreed that the discussions they had with their peers improved their understanding of the subject material (72%), improved their ability to think through and resolve problems (72%), and helped them to understand material that they hadn't previously fully understood by themselves (79%).

Groups were randomly selected at the start of the course resulting in most groups consisting of students with different levels of ability. We theorised that this would provide high achieving students the opportunity to identify their learning gaps through teaching others and poorer performing students the opportunity to increase their understanding through listening to the explanations provided by their peers. Figure 2 shows that for the majority of students (66%) learning was equally divided between listening and explaining.

A total of nine students in the subject received a final grade of Credit or higher (ie a final mark ≥ 65%). Of these nine students, one student chose not to participate in the survey, two said their learning usually occurred when they were explaining to other group members, while the remaining six said that their learning was about equally divided between listening and explaining. Hence, contrary to our theory most high performing students were not dominating group conversations and mainly teaching others but were also learning from the contributions of their peers.

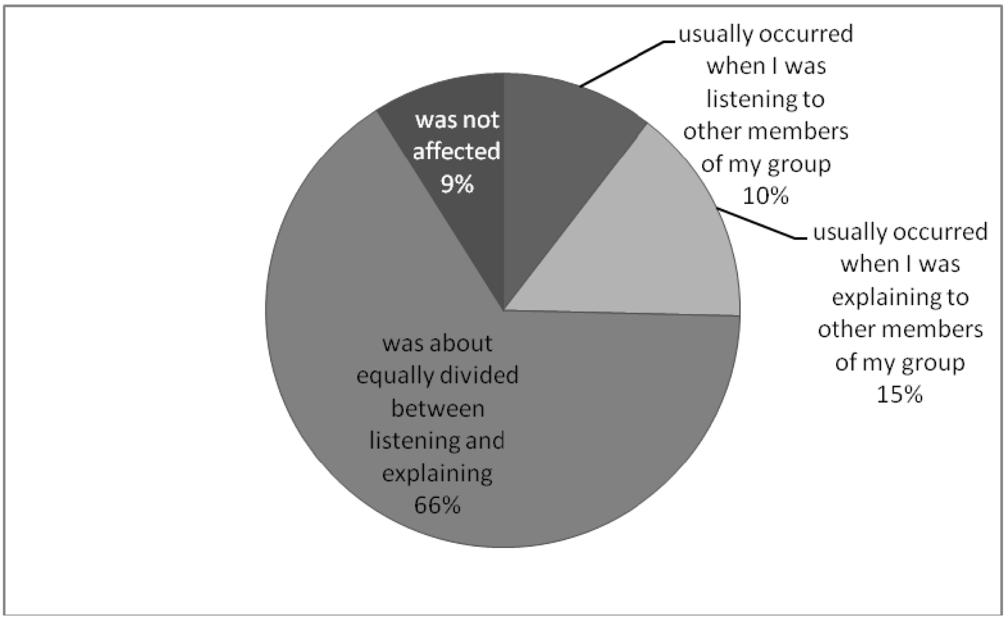

Figure 2: Results from post-quiz survey to the statement: "In discussing the quiz questions with my group members, my learning:"

Analysis of group reflections

As previously discussed in the first peer feedback session, groups were asked to write what they had decided/agreed to do to improve their group processes for their second submission. While this reflection exercise was intended to help students both manage and improve their group processes we analysed the information from all 26 groups to investigate the most common aspects of group work that teams identified as needing attention.

The results of this analysis, reported in Table 2, show that the most frequently reported aspects of group function that groups agreed to improve related to better planning (mentioned 22 times), improved communication amongst team members (mentioned 15 times), improved collaboration (mentioned 8 times) and time management (mentioned 6 times). Furthermore, the most commonly reported reason for improving planning was to allow sufficient time to check or review work before submission ie for quality control.

While students are explicitly taught the importance of addressing such issues (at UTS for example in first year Engineering Communications, second year Design Fundamentals and third year Engineering Project Management) the results suggest that many students in initially planning their group work focus on the project outcomes at the expense of good group practices including planning, communication and time management. This is probably in part because professional skills such as these are regularly not explicitly assessed when grading a project. Despite this, the reflective exercise shows the potential of project work to not only provide students with an opportunity to develop these skills but after reflection make their importance self-evident. However the authors' observations of this activity suggest that without the reflective exercise this realisation would not have occurred. The authors therefore recommend the use of a reflective feedforward process combined with either formative or summative assessment to motivate students to consider good team practices when planning their projects. Furthermore, the expected quality of these team practices should increase as students progress through their degree.

Furthermore, interestingly some groups reported they agreed to "contribute to all areas, instead of separating the project into separate tasks" while others chose to "delegate tasks to members to ensure a fair distribution of work". While these two strategies may both result in a quality project, the authors encourage all students to participate in group discussions to engage with, discuss and understand all parts of the project to facilitate the conversations that produce the benefits of peer learning. The instructor also observed that groups tended to use one or the other of these two strategies in completing the previously mentioned group quizzes. In future work we intend to further investigate the impact of these different strategies to inform improvements in our learning oriented assessment design.

Table 2: What students agreed to do to improve their next submission

Theme	No. of times mentioned	Examples of student comments related to theme
More planning	22	"Devise a game plan/ plan of attack for the next assignments, rather than just jumping in ie. A more organised approach" "Set actual deadlines at least a week before due date" "Finish earlier to allow time to check over calculations and work." "Have regular group meetings to discuss the assignment problems so that every team member is on schedule" "Complete assignment earlier to allow time for review." "Organise and plan the assignment earlier so that everything can be properly checked and revised."
Better communication	15	"Provide updates rather than just updates during meetings". "Actually tell constructive critique rather than just taking the work and fixing it up." "Meet more often as a group to discuss and review what is happening with the project" "Communicate, communicate, communicate...." "Improve communication by email, phone, etc." "Group meeting – talk out problems."
Collaborate more	8	"Contribute to all areas instead of separating project into separate tasks" "work together"
Time management	6	"Exercise more time management skills" "Attend meetings" "Be on time for meetings" "Spend more time on assignment" "Not sleeping at UTS the night before it was due (ie time management)"
More even allocation of tasks	4	"Delegate tasks to members to ensure a fair distribution of work." "More even distribution of work." "distribute load equally"

Conclusions

In the subject Concrete Design a group project with integrated self and peer assessment processes was combined with collaborative assessment activities (including quizzes) to develop students' skills to design various reinforced concrete elements. The process requires students to not only apply their engineering knowledge and use judgement in making design decisions, but to articulate and explain their design. The process of critically evaluating their own and their team members' work and behaviour is explicitly linked to the assessment tasks by using criteria that address the subject learning outcomes. The combination of group peer feedback sessions and a reflective exercise played a significant role in engaging students with developing both their technical and more generic professional skills such as planning, communication, and time management. The authors recommend the use of a reflective feedforward process combined with either formative or summative assessment to motivate students to consider good team practices when planning their projects with the expected quality of these team practices increasing as students progress through their degree.

We found that in regard to the quizzes, students reported high engagement with the class, that the conversations they had with their group peers helped them identify and subsequently address gaps in their knowledge relating to the course material, that the IF-AT cards helped them confirm or clarify understanding, caused them to reflect and increased their motivation to learn. Encouragingly, the majority of students agreed that the collaborative quizzes helped them to understand material that they hadn't previously fully understood on their own.

While improvements could be made to the assessment design we found the collaborative activities assisted students to develop the skills required to engage in the informal collaborative learning characterised by professional practice while simultaneously enhancing their ability to undertake lifelong learning.

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