# Multiple assessment strategies for capstone civil engineering class design project

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***Abstract****: The Civil Engineering Design Project at the University of South Australia is a final year, final semester project undertaken by all civil engineering students. The capstone course is focussed around a group learning experience, as the whole class works as a self-managed design consultancy for the duration of the project. The project incorporates tender, feasibility study and concept design as well as detailed design stages with students also required to present their project publicly at Engineers Australia at the conclusion. Developing clear and equitable assessment practices in such a major group project is a challenge that has been met through the use of multiple assessment strategies for individuals, work groups and the class as a whole. A triangulation type process is used between various assessment methods to arrive at final grades for each student. This paper describes both the project and assessment practices used in it.*

## Introduction

Capstone projects are almost universal components of engineering degree programs in Australia as well as other countries. The civil engineering program at the University of South Australia differs from many other institutions in that each final year student undertakes two capstone projects. One of these is a research project undertaken in pairs and extending over the full year, forming 25% of their total course load in the year. The second project, which is the subject of this paper, is the capstone Civil Engineering Design Project (CEDP), undertaken by the entire class, forming 50% of the load in the final semester. Hence the two projects form 50% of their final year, with the remaining load consisting of courses in environmental engineering and electives in their choice of specialisation area.

One of the major challenges posed when teaching a project taken by the class as a whole is that of awarding individual grades to students. Clearly the inputs and learning outcomes of individual students will be different and could be graded differently. However, this must be weighed against the fact that in professional practice, the results of a company or project team are assessed as a whole by both external stakeholders and company management, and will inevitably be somewhat subjective. Hence, a realistic grading system for a project undertaken as a class must contain elements of both class assessment as well as individual assessment, subjective and objective assessment. Finding an acceptable balance between these components can be a difficult problem. The solution used at the University of South Australia has been developed over several years, but is still open to discussion and change.

## Large group capstone design projects

A major survey of Capstone Engineering courses in North America was conducted by Todd et al in 1995, in which they received responses from 176 of the 221 engineering schools surveyed. Only about 4% of the respondents stated that they did not offer a Capstone engineering course, although the authors indicated that follow-up telephone calls to departments that did not respond to the survey showed that many of these did not offer capstone courses. Todd et al noted that the nature of capstone courses tended to vary across the discipline areas with mechanical, electrical and computer engineering courses frequently requiring “design, fabrication and testing of a product”, chemical engineering courses focussing “mainly on experimental research” and civil engineering emphasising only the design (Todd et al, 1995, p. 166). As explained in a subsequent article (Dutson, Todd, Magleby and Sorenson, 1997), this is because construction of civil engineering projects is "usually impossible since large structures and systems are involved" (p. 19). The 1995 results indicated that 32% of the capstone courses involved students working as individuals on a project, 83% involved students working in departmental teams and 21% as interdisciplinary teams (results exceed 100% as several respondents selected more than one option, presumably indicating that more than one capstone course is available, such as at the University Of South Australia, or that students have different options). However, less than 7% of respondents indicated that more than 7 students worked on the same project, with many using the same project for teams of 4-6 students who worked on a competitive basis (Todd et al, 1995, p. 170). These results indicate that the use of whole class projects was not common.

In a more recent US survey of capstone design courses and assessment (McKenzie et al, 2004) with 119 responses from 274 engineering school, it was noticeable that there had been a significant shift away from individual projects. Only 10% of respondents indicated that students worked on individual projects, 88% indicated that students were organized into teams (of which 47% were multidisciplinary) and 2% reported that their capstone project organization was in a state of transition. However, whole class projects were not reported.

Jawitz, Shay and Moore (2002) reported on a survey of capstone projects in five different programs at the University of Cape Town in South Africa. Four of the programs reported that students undertook two separate projects in final year, one focussing on research and the other on design. The research projects were either individual or done in pairs and the design projects were done in groups, but not as a whole class.

A whole class design project at the West Virginia University with a very similar structure to that at the University Of South Australia was discussed by Shaeiwitz (2001). He noted that 25-30 students appeared to be "a critical number of students. When class sizes exceed this number, we have found that the group is too large for one chief engineer to manage. For this situation we have two different projects, two groups, two chief engineers, two clients." (Shaeiwitz, 2001, p. 481) At the University of South Australia, design project class sizes have ranged between 20 to 45 students over the last 10 years, but have generally had enrolments in the low to mid 30's. To date we have found that any number can be managed provided the project scope is adjusted accordingly, additional academic staff are involved and that with larger groups the students adopt more senior managers, such as a Project Manager, Deputy Project Manager and Quality Manager, for example.

## Assessment practices in large-scale group project work

Whilst capstone projects are clearly widely utilised and in the majority of cases now involve student teams, the assessment practices reported for the projects still tend to contain significant individual components and be focussed primarily on a written or product outcome. As summarised by Jawitz et al (2002) "Where group work was included, assessment appeared to focus on the product rather than on the process and a variety of mechanisms were evident for allocating marks to individuals based on the group work product. Nowhere did we find evidence that any of the programmes attempted to assess student ability to work in groups…" This was also reflected in the survey results of Todd et al (1995).

While McKenzie et al's 2004 survey still indicated that oral presentations and final written reports were the assessment means adopted by over 90% of projects, an increasing number also used intermediate written reports and 68% now reported using peer and/or self assessments. In addition a small number (less than 15%) reported using a range of other assessment methods including student surveys, student portfolios, focus groups or interviews, self-reflection journals or papers, logbooks and others. With regard to grade assignment, 71% of respondents reported that grades in the capstone design courses were "individually assigned based on integrated individual performance" while 9% reported that the final grades "were the same for all team members based on integrated team performance" and 19% reported that "their grading practice was a combination of these approaches" (McKenzie et al, 2004).

It has been noted that “The very nature of design courses often leads to subjective evaluations” and that “The individual effort of a student on a project team is often difficult to identify and reward” (Dutson et al 1997, p. 19). This can be a dilemma for academic staff responsible for capstone courses; particularly in the light of what can be a conflict between requirements of the university for very objective assessment criteria and the reality that assessment of design and product outcomes in professional practice frequently is subjective in nature. The assessment of a project should be focussed on the full range of skills being developed during the project, namely the professional skills such as teamwork, communication, life-long learning, understanding of social, environmental and economic contexts and so on as well as technical skills. The development of these professional skills is now a component of the accreditation criteria for engineering programs in the majority of countries, as well as part of many universities graduate qualities or outcomes requirements. Whilst it is probably impossible (and unrealistic) to eliminate all subjectivity from assessment of design projects, there are now several examples in the engineering education literature of assessment tools and techniques that can be used for assessing professional skills, some of which have been discussed by Shuman, Besterfield-Sacre and McGourty (2005). They have emphasised the use of “multi-source feedback”, peer evaluation methods and project rubrics. The assessment methods used in the CEDP at the University Of South Australia are an example of multi-source feedback.

## The Civil Engineering Design Project at the University of South Australia

### Project duration, content and time commitment required

The Civil Engineering Design Project (CEDP) at the University of South Australia runs for one semester as a double course. It aims to enable graduates to cope with the main exigencies encountered by practitioners in negotiation, planning, undertaking and reporting civil engineering developments or schemes. The project is supervised by both senior academic staff with industry experience, as well as industry based engineers who have been involved with the project in practice, or have specific expertise in the project area.

The projects chosen are generally real projects in the early stages of planning or development or sometimes early stages of construction. A project brief is developed by collaboration between academic staff and the relevant industry group and permission is obtained from the relevant industry stakeholders to use various resources such as site surveys, geotechnical reports, environmental assessments and so on that the students might need. Examples of recent past projects and industry supporters include – The Mawson Transport Hub and The Bakewell Bridge replacement both supported by Transport SA and The Adelaide Airport Redevelopment supported by Maunsell Pty Ltd. The key concerns in selection of the project are that it is sufficiently broad so that it can incorporate all specialisation areas of civil engineering and provide sufficient volume of work for the class size each year (but not be too extensive so that it is overwhelming), and also that the project be sufficiently ill-defined that it allows students to explore various options rather than there being one obvious solution.

A total of 8 hours per week, in 2 x 4 hour sessions, is allocated as class time to the project over a period of 14 weeks (this extends into the swot vac phase of the semester). All students are required to be in attendance during those core hours and any team, class or client meetings must be scheduled during those hours unless otherwise agreed, so that part-time students are not disadvantaged. Guest lectures and other presentations are also scheduled during core times. In addition to the core hours, it is expected that students will spend a similar amount of time involved in work towards the project outside of scheduled class time. Hence it is expected that students will spend 16 hours per week working on the project averaged over its duration.

### Project stages, documentation and management

The CEDP consists of three phases as follows:

- Expression of Interest
- Feasibility study and Conceptual Design
- Detailed Design

The Expression of Interest (or Tender) phase is undertaken during the first two weeks of semester. For this first phase, the class is divided into groups of approximately 6 members and each group is required to submit a tender document to undertake the Feasibility Study and Conceptual Design phase of the project. The tender document is expected to contain at least the following:

- Company capability statement (management structure, past experience, financial backing)
- Company Quality statement
- Conceptual sketches of layouts and proposals
- List of major components of the Feasibility Study and their sub-components
- List of issues identified as problems, together with possible methods of resolution
- A schedule of work that the company (i.e. the whole class in Stage 2) will undertake to complete the Feasibility Study and Concept Design with estimated person-days and targets; and
- A quotation for the completion of the Feasibility Study & Concept Design and all of its associated documents (e.g. Environmental Impact Statement, Design Brief etc). .

At the end of the two weeks the student teams present their tender document and make an oral presentation to the clients (the academic staff and the industry representative) and the winning tender is selected. For the remaining two stages of the project, the class forms a single company (with the company name adopted being that of the winning tender group) and is responsible for determining the organisational structure of that company including any work teams assigned to undertake identified components of the development or scheme. The class elects leaders for each phase, including a Project Manager, Quality Manager and Team Leaders, but may also decide to adopt alternative management structures. The class management group and company structure changes at the end of the Feasibility Study phase. As many students as possible are encouraged to take on a leadership role during the project, and a student who takes on a class management role in one phase (such as Project Manager) is not allowed to take on a leadership role in the subsequent phase. Similarly, students can only be a team leader in one phase. Regular meetings are held with the academic staff and industry clients to review progress and guide the class in the project, with short talks, guest lecturers and additional documents provided at appropriate stages and as requested by the class.

The aim of the Feasibility Study phase (which extends over 6 weeks) is to determine the optimum scheme from a technical, economic, environmental, construction, social and so on view. A Feasibility Study Report and Environmental Impact Assessment are the minimum expected outputs of this phase. The chosen scheme is then developed to the stage of producing a Detailed Design Brief at the end of the Concept Development process. The Detailed Design is then undertaken over the following 6 weeks and is documented through a final set of Detailed Design Drawings and Calculations, a Specification and Bill of Quantities. Throughout the project, the class is also required to develop, document and implement an appropriate Quality Management System. As part of this process, minutes of meetings are required to be kept and all meetings are expected to be chaired by the student leaders and conducted in a professional manner. Timesheets are also kept to enable monitoring of the project's progress against both time schedules and submitted bid price.

At the conclusion of each phase the Project Manager is required to submit a report that both documents the performance of the company with respect to timelines, budget and project outcomes but also incorporates a reflection by the class and team managers on the performance of the class as a whole and the teams within it with respect to achieving learning objectives such as teamwork, communication and technical outputs. This report also includes recommendations for improvement in future stages and for the project course as a whole in future years. Every student is required to keep a work diary for the duration of the project, that documents both the tasks they have undertaken, problems they have encountered and how they solved them and their reflections on any aspect of the project and their participation in it.

## Learning spaces

One of the key improvements that has been made in the Design Project during the last 8 years has been the provision of a dedicated learning space for the students. Students enrolled in the design project and/or research project courses have the sole use of a Project-based learning space which consists of a large, flexible teaching space (movable small group tables and chairs), where guest lectures, class meetings and student presentations are held and where students can work together informally in small groups or as a class. Opening from this room is a meeting room where team meetings can be held and a small technical library for the project is stored. Another wing of the project room contains 10 computer terminals and a printer as well as additional points for student laptops. The computer terminals are restricted by logon protocols to the sole use of students enrolled in the project courses. All parts of the project space have large pin boards and white boards to enable students to share necessary information required for the project such as site maps, aerial photographs, project work schedules and so on. The importance of dedicated project space and "living" space for the students involved in the project can not be underestimated. Whilst the process of refurbishing and dedicating this space was originally met with reluctance by the university and took considerable persuading as well as a major contribution of funds from the school to achieve, its success has now been recognised and the university is moving to develop other such spaces in other schools and campuses.

# Assessment practices used in the project

## Learning outcomes

The learning outcomes specified for the course are that on completion of the course, students should be able to:

- consult with a client to establish a brief which aims to achieve broadly-stated final objectives in the field of civil engineering;
- apply judgement to situations where the requirements of development and the need to conserve the environment come into conflict;
- draw up a set of enabling objectives which if followed will achieve an agreed objective;
- identify and obtain, where possible, all data, surveys, reports, standards and codes of practice needed to achieve an agreed objective;
- report outcomes of investigations in a professional manner acceptable to a client.
- understand the management of project teams and budgets

Each student is required to make at least one oral presentation during the duration of the project. Each student is also required to produce at least 1 CAD drawing as part of the Detail Design stage.

## Assessment details

A detailed assessment breakdown is supplied to all students in the Course information handout at the beginning of the course. This states the abilities that will be assessed and the proportion of assessment in each stage that will be assessed as an individual, a team and a class. The list of abilities to be assessed is an expansion of the learning outcomes detailed previously and includes both technical and professional skills as follows:

### Technical abilities assessed:

- Ability to break a broadly-stated engineering goal into a series of logical steps which, if followed through, result in a satisfactory design.
- Ability to recognise the data needed for each step of a major investigation/design task.
- Ability to execute each step of a major project with accuracy and speed.
- Ability to organise and plan a work programme to meet designated deadlines.
- Ability to recognise impractical solutions and, where possible, modify specifications, boundary conditions, design assumptions, etc., to achieve more realistic results.

### Communication and "team" skills assessed

- Ability to communicate concepts and original ideas to fellow team members.
- Ability to report and explain technical findings, both written (including numerical and graphical presentation) and spoken, clearly and concisely.
- Ability to participate and co-operate as a willing and responsible team member.

The assessment of technical, communication and team skills is carried out by the academic staff members responsible for the project, but is also influenced by peer evaluations.

### Peer assessments

Each student is asked to assess their fellow team members' performance against the following criteria:
- Participation in group discussions
- Completing tasks on time and satisfactorily
- Effort and enthusiasm
- Overall contribution to final reports

They are also able to make written comments about each student. The average of each student's assessment from the team is then used for the individual component of the assessment (subject to possible moderation as described below). Students do not assess themselves in the peer assessment but are asked to describe their own contribution to their team's work. Peer assessments are conducted for each team rather than the whole class, so each student will be assessing up to 6 other students at most. These teams may be technically based (e.g. the structural team in a detailed design stage), or more general such as the tender teams in the first stage. In the Feasibility Study and Detailed Design stages, team leaders are involved in two peer assessments – one of the team that they have led and the other of the management group as a team (i.e. the Project Manager, Quality Manager, any other class management positions and the team leaders as a management group). The class managers are involved in peer assessment of the management team and also provide an additional report discussed below.

### Allocation of marks within each stage

The allocation of marks for each stage of the project is detailed in Table 1.

**Table 1: Allocation of marks in each stage of the project**

| | |
|---|---|
| **Expression of Interest Stage** | |
| Team mark (70%) consisting of: | |
| – Teamwork, communication and effort | 30% |
| – Technical content of the work | 20% |
| – Document presentation and professionalism | 20% |
| Peer Assessment | 30% |
| TOTAL for this stage | 100% x 15 marks |
| **Feasibility Study and Detailed Design Stages (each the same)** | |
| Class mark (30%) consisting of: | |
| – Teamwork, communication and effort | 10% |
| – Presentation – consistency and professionalism of documentation | 10% |
| – Quality management implementation and commitment | 10% |
| Team mark (40%) consisting of: | |
| – Teamwork, communication and effort | 15% |
| – Technical content of the work | 20% |
| – Presentation – consistency and professionalism of documentation | 5% |
| Peer Assessment | 25% |
| Work Diary | 5% |
| TOTAL for each of these stages | 100% x 40 marks |
| **Oral presentation** (individual mark) | 5% |
| TOTAL | 100 marks |

## Evidence and process used for assessment

Multiple sources are used to provide evidence to determine final assessments in each stage of the project. These include:

- The written reports at each stage of the project, which include tender submissions in the first stage, a Feasibility Study Report, Quality Manual, Environmental Impact Assessment and Detailed Design Brief in the Feasibility stage, and the Detailed Design calculations/report and drawings, Specification, Bill of Quantities, Environmental Management Plan and updated Quality Manual in the Detailed Design stage.
- Oral presentations made to the client at the end of each project stage
- Lecturers' observations during class sessions, meetings and presentations (recorded in their course journal)
- Discussions (formal and informal) held with individual students throughout the project
- Interviews with project and team leaders as required
- The Project Manager's written reports at the end of the Feasibility and Detailed Design stages, which incorporates Team Leader reports as well
- Work diaries of individual students
- Timesheet and attendance records

Assessment is carried out at the end of each stage of the project and feedback is provided to the students each time. The feedback includes written feedback sheets for each team's component of the work as well as the class as a whole, with the feedback sheets divided into the same categories as given in Table 1. Individual students are invited to meet with the course coordinator to find out their individual mark and get feedback from the peer assessments and the lecturer's observations. In general the majority of students will ask for their mark, but only about half the class seeks more detailed feedback in a meeting. If a student has scored poorly on their peer assessment, then the lecturer will require a meeting with them to discuss the issues raised by their peers and what they need to do to improve this in the following stage. This generally ensures that no student performs poorly in more than one stage of the project. There is no doubt that it is a time-consuming and intensive exercise for the academic staff involved each time. However, the time commitment at those times is partially offset by the fact that there are other periods within the project where the students are basically getting on with the job without the need for much involvement from the academic staff apart from being available for consultation during the specified course hours.

At each stage of the assessment the written reports form the basis of the technical content and document presentation components of the work. The standard against which the documents are assessed is that which would be reasonably expected of graduate engineers in practice, and hence relies on the industry experience of the academic staff involved as well as some feedback from the industry clients during their attendance at oral presentations and meetings. The remainder of the evidence sources are used to assess the "teamwork, communication and effort" components of the assessment and for moderation of marks across teams and the class. Triangulation between the multiple sources of evidence is used to arrive at the final assessment for each student, which is one of the recent recommendations for further research noted by the steering committee of the National Engineering Education Research Colloquies in the United States (2006)

## The Alpha factor

One issue that arises when a high proportion of the assessment is based on class and team marks is that the distribution of the grades is inevitably "clumped" rather than anything like a normal curve. For some academic staff this may present a challenge to what they believe should be the case. However, it should be noted that the middle of the "clump" certainly changes from year to year. When the project goes really well, the students worked well together, produced an innovative and effective design solution on time and on budget then that centre clump may be at a Distinction level. In other years where students argued, didn't contribute, didn't care because they already had jobs lined up and managing the project was like drawing teeth (this was 2006!) the centre clump was at the P1/Credit boundary. The problem in either case is not with the majority of the students, who basically should get the average mark, but with the student(s) who does very little, or the student(s) who contribute significantly more than the average. To accommodate these issues we developed the "alpha factor".

The "Alpha factor" is a number between 0.9 and 1.05 that the lecturers may apply as a power factor to an individual's final mark at each stage and/or the end of the project. This is an incentive component for those who choose to take on leadership roles in the project (subject to satisfactory performance, of course!). It is also used for those who have made significant contributions to the project in other ways, such as doing significant work on a technical aspect of the project, which assisted other members of the class. It is akin to a Performance Bonus situation in the workplace. It can also be used to penalise those students who have not contributed. In the majority of cases, the factor will be 1 (i.e. no adjustments made), and in most other cases it is in the range of 0.98 to 1.02. However, in one or two cases over the years it has been 0.9. In general it would be applied to less than 20% of the students in the class and a value less than 1 is generally not required in more than one stage for an individual student due to the interview and feedback processes mentioned previously.

## Project evaluation

The CEDP is evaluated annually through the use of the standard University of South Australia course and lecturer evaluation instruments and at various stages has been more intensively evaluated through focus groups and other means. In addition the feedback provided in the Project Manager's reports is another avenue of evaluation and continuous improvement available each time the course is run. The percentage of students who have agreed or strongly agreed with the statement "Overall I was satisfied with the quality of this course" has ranged from 90.5% to 100% over the years 2002 to 2006. Text responses to questions regarding what students have found most useful for their own learning overwhelmingly focus on the "real life" aspects of the project and the professional skills development such as teamwork, communication, leadership development and so on. For example "*This course offered not only real-life project experience, but was structured so that the emphasis was on individuals within the team working together*." Scores for the evaluation questions "I have received feedback that is constructive and helpful" and "The assessment tasks were related to the qualities of a University of South Australia graduate" are consistently in the top or next to top quartiles.

## Conclusion

In McKenzie et al's 2004 survey of capstone courses and assessment they found that 51% of respondents' perceptions were that students felt the assessment in their project was fair and they seldom heard complaints, 30% thought students felt that assessments were very fair. No respondents felt that all bias or distortion had been eliminated in their assessments, so the "take-home" message is that assessment methods can always be improved, and that this discussion may provide some additional ideas that could be implemented within your own capstone projects. Whole class design projects present many challenges to the academic staff member with respect to organisation, management, assessment and time commitment, but they are also one of the most rewarding teaching and learning experiences that can be undertaken as an engineering academic.

### References

Dutson, A.J., Todd, R.H., Magleby, S.P. & Sorensen, C.D. (1997). A review of literature on teaching engineering design through project-oriented capstone courses. *Journal of Engineering Education, 86*(1), 17-28.

Jawitz, J., Shay, S., & Moore, R. (2002). Management and assessment of final year projects in engineering, *International Journal of Engineering Education, 18(4),* 472-478.

McKenzie, L.J., Trevisan, M.S., Davis, D.C. & Beyerlein, S.W. (2004). Capstone design courses and assessment: A national study, *Proceedings of the 2004 American Society of Engineering Education Annual Conference & Exposition.*

Shaeiwitz, J. A. (2001). Teaching design by integration through the curriculum and assessing the curriculum using design projects, *International Journal of Engineering Education, 17(4 & 5),* 479-482.

Shuman, L.J., Besterfield-Sacre, M. & McGourty, J. (2005). The ABET "Professional skills" – Can they be taught? Can they be assessed? *Journal of Engineering Education, 94*(1), 41-55.

Steering committee of the National Engineering Education Research Colloquies (2006). The research agenda for the new discipline of engineering education, *Journal of Engineering Education, 95(4),* 259-261.

Todd, R.H., Magleby, S.P., Sorensen, C.D., Swan, B.R., & Anthony, D.K. (1995). A survey of capstone engineering courses in North America. *Journal of Engineering Education, 84*(2), 165-174.