GRADUATE STUDY OF DESIGN PEDAGOGY

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Abstract

A graduate course in the pedagogy of engineering design has been developed, implemented, and refined over the past three years. This was done to address a three-fold need: undergraduate design courses can benefit from the involvement of teaching assistants who are well-prepared to contribute effectively to the day-to-day learning process, graduate students are seen to be capable of contributing significantly to design pedagogy, and these graduate students can also become much better prepared to take on leadership roles in the area of undergraduate teaching.

It has long been assumed that the mere fact of exposure to many years of being taught provides sufficient preparation for graduate students to take on the teaching mantle. The shift away from conventional modes of teaching to inquiry-based learning, however, requires that teaching personnel take on quite different roles and use a distinctly different set of skills and tools than those with which they are familiar. Modeling the pedagogical approach of the graduate course on the inquiry-based learning modality of the undergraduate design courses is observed to be an effective method for cultivating many of the important skills and attitudes required to facilitate learning in the undergraduate design programme.

Keywords: Design pedagogy, inquiry-based learning, graduate training

1. Introduction

There are, of course, very many issues associated with engineering design programmes as evidenced by a burgeoning body of literature on the subject. This paper addresses two particular aspects of the changes that are being observed in this area: the increasingly challenging situation faced by instructors of large classes when combined with the need to realize the benefits of inquiry-based learning.

Whereas the objective of design learning is to learn not only methods that are useful to advance the design process but also to learn how to manage the process itself, it is evident that inquiry-based learning is an appropriate modality for students to achieve the required competencies. The role of the instructional staff in this situation is to create an environment within which the learning can effectively take place. The experience of the authors is that a significant objective of design teaching is increasingly to achieve these outcomes for larger and larger numbers of students with ever-dwindling teaching resources. The pedagogical environment within which the authors find themselves demands that each student design team receives frequent, knowledgeable individualized guidance and support to an extent far beyond the few minutes per week that the limited number of instructors can budget for each team.

As is often the case, low-paid graduate teaching assistants (TA's) are the first line of support for both the beleaguered instructor and the undergraduate students. The typical engineering graduate student, however, by nature tends to be a relatively inexperienced specialist rather than the experienced generalist that is more likely to describe an engineering designer. The first specific objective of the graduate course, then, was to create an environment within which inexperienced TA's very quickly develop the capability to contribute effectively to the design learning process.

As a point of reference, Torvi [1] completed a survey of Graduate Teaching Assistant instruction at a number of institutions in 1994. This revealed relatively little high-level involvement in teaching and also rather limited formal preparation and support for this. Notwithstanding the comments regarding publications on design curricula, there is still seen to be relatively little literature that specifically addresses the preparation of teachers of engineering design. For example, Black and Bradford [2] address the planning and operation of an undergraduate design course without discussing instructor preparation. Only recently is there seen to be growing evidence of published work in this area (e.g. [3], [4]). Particular note should also be made of the Graduate Courses in the Engineering Education (GCEE) programme development undertaken under the auspices of the UNESCO International Committee on Engineering Education (UICEE) [5]. A variety of course descriptions and links are available at this site; an example is the UICEE Grad Course GCEE-07 "Educational Technology and Computers in Engineering Education" offered through the Ryerson Centre for Engineering Education [6].

The approach taken in the course described here is perceived to differ from those alluded to above in at least one important respect: rather than being preparatory in nature, this course is entirely geared to providing the support needed by teaching assistants for the undergraduate design course on a 'just-in-time' basis. The reality for the authors is that the likelihood of extensive preparation being available to TA's in advance of their taking up teaching duties is very remote. Similarly, very few graduate students have extensive design experience. It is essential, then, that approaches be developed which allow teaching assistants to very quickly learn what they need to function effectively for the undergraduate student design teams.

One change that is required is a significant departure from the traditional nature of the undergraduate student/instructor relationship. Inquiry-based learning requires design teams to develop and maintain 'ownership' of the product realization process. As such it is essential that members of the design instructor team shift away from being viewed by students as the 'source of all answers' and into a mentoring role. Being a mentor in this situation can involve raising questions, offering suggestions, pointing to potential methods and resources – none of which require actually knowing what 'the answer' is. Thus it is seen that this role can potentially be taken on by relatively inexperienced TA's. In this paper we outline how this can be achieved alongside the development of many other capabilities that are required to teach an engineering design course such as evaluating the suitability of potential projects, critiquing student work, resolving team issues, grading, and the conduct of a variety of design-related activities.

This paper takes the following form: the Background section first outlines the origins and the development of the recently implemented capstone undergraduate design courses in the Manufacturing and Mechanical Engineering programmes at the University of Calgary; it then outlines the parallel developments in design-oriented graduate teaching in the department. The Course Description section describes the evolution of both the content and the learning modality embodied in the graduate course. In the section on Course Outcomes, a range of observed outcomes are presented.

2. Background

Design teaching in the final year of undergraduate Mechanical and Manufacturing programmes at the University of Calgary underwent a rather profound change in 1997-1998. A single semester course within which a relatively narrow range of design activities comprised the basis for the course was replaced with a two-semester course that was intended to encompass a considerably broader range of aspects of the product realization process. The pivotal shift was from an instructor-led process with all students working on the same project to an inquiry-based approach with each team of students working on – and taking complete responsibility for – a separate project. This change was motivated in part by changes in requirements for engineering programme accreditation in Canada and also by a university-wide initiative to incorporate a number of core features in every undergraduate programme [7]. In particular, the design courses were to embody interdisciplinarity, experiential learning, research, and provision for broad and extended faculty/student interaction to satisfy the university curriculum requirements and two-semester, team-based real-world design projects to satisfy accreditation changes. This represents effectively a culture shift of the type described by Venable [8].

In order to incorporate these features, the new capstone courses were designed around the following:

- 3-5 member student design teams (where appropriate involving a mix of mechanical and manufacturing engineering students); all teams work on different projects;
- projects proposed by a variety of clients and chosen on the basis of scope, feasibility and technical suitability;
- requirements and specifications to be developed by the design team;
- each project to have a client or customer a suitable supervisor (typically not one of the design instructors);
- each student applies to work on a particular project (or projects);
- project work shall incorporate at least some aspect of design realization and verification;
- evaluation to be tied primarily to the design review process

It was quickly realized that offering the course content by relying primarily upon lecturing would not achieve the desired outcomes. Instead the course was built using a variety of structured, semi-structured, and quite unstructured activities – a mixture often taking place within a particular period – each aimed at the cultivation of some key aspect of the design process such as formulating requirements, determining priorities, function decomposition, etc. (Slightly less than half of the timetabled time is devoted to structured activities.) The guiding principles were, however, quite simple:

- design work is to be aimed at satisfying client, customer needs as well as recognizing legal, infrastructure, budget etc. constraints;
- design teams are responsible for negotiating scope and requirements and establishing and providing appropriate deliverables;

- course components should be scheduled to take place at times when there is likely to be a need by most or all project teams;
- course components should allow students to attempt to achieve an outcome prior to there being extensive instruction; instruction which follows should then be attuned to providing (constructive, where possible) feedback on student work;
- whenever possible, domain experts (rather than the instructors) should be brought in to deliver course material.

It was also realized that offering the course in this fashion needed additional pedagogical tools. A Course Handbook was developed to provide students with comprehensive information on policies, procedures, and departmental resources. An Instructor Manual came to serve as a repository of teaching materials (importantly incorporating a critique of the strengths and weaknesses of each component). These have been described by Johnston *et* al [9]. Another very important component which was developed is termed the 'Toolbox' [10]; this was designed and implemented by Brusse-Gendre [11]. Its use has been described by Brusse-Gendre *et al* [12].

A particularly useful outcome that emerged from extensive use of the Instructor Manual was a fairly stable sequence of course events and phases. Even though specific activities evolved from year to year, it became evident that it was appropriate to identify a framework of key phases and deliverables that was workable for the vast majority of projects and which was compatible with the idea of design teams taking responsibility for most aspects of their project work. This observation pointed to the potential compatibility with a concurrently-offered pedagogy course.

These two design courses (one each for the mechanical and manufacturing programmes) must now accommodate the full departmental quota (up to 140) final year students. There are two instructors and there have been from four to six teaching assistants available. Fortuitously, during the early years the instructors had access to teaching assistants who did have design experience. It was apparent even at that stage, however, that it was essential to have weekly meetings to plan, co-ordinate, and evaluate course progress as well as to deal with issues arising from a wide variety of situations. As the years progressed and the availability of experienced teaching assistants dwindled, it became evident that there was a clear and pressing need for a process capable of supporting novice teaching assistants. In the next section we describe the evolution of this process.

3. Graduate course evolution and description

At the time when the new capstone design courses were introduced, the department offered a one semester graduate course in design methodology. This was in part a survey course which looked at a wide variety of methodological issues and literature and in part a design laboratory where actual design projects were used as a 'test bench' for design theory. There was no attempt to link this course with the delivery of the undergraduate courses. As the need for capable teaching assistants rose, it became evident that this design methodology course was not capable of providing teaching assistants with the appropriate preparation concurrently with the undergraduate courses. The need for concurrency thus became the first of the guiding principles for the pedagogy course. (For those graduate students who take the pedagogy course without being assigned as a teaching assistant to the undergraduate course it is nonetheless a requirement that they work with at least one design team.)

Because most new teaching assistants are unfamiliar with the inquiry-based learning mode employed in the undergraduate design courses, it was decided that this would be a prominent feature of the graduate course. However, because it would create too much uncertainty if this were the only learning mode, it was evident that the extent of this type of activity should be restricted to non-core aspects of the course.

Coaching the TA's to establish the appropriate relationship with their design team or teams is, however, of paramount importance and must take place before they even meet the undergraduates. This is most easily initiated by requiring the TA's to automatically answer *"I don't know"* to all design-oriented questions in the first instance – even if they may be aware of a satisfactory or excellent answer; the easiest way for the design teams to abandon responsibility for their design learning and progress is to have an instructor supply answers. At the same time, it needs to be recognized that there is potentially a wide range of student responses to this situation – ranging from "What do we do next?" to "Get out of our way; we know all about designing!" The TA's need to be able to recognize the needs of each team and be able to respond appropriately so more refined responses need to follow. In the first instance the team may need a menu of options from which to choose. In the second, the team needs to be challenged with "What if …?" scenarios.

To help establish this pattern it is necessary to equip the TA with a (relatively small, in the first instance) number of potential responses to frequently asked questions and situations such as those described above. At the beginning of the course it is possible to identify a number of these and to provide the TA with responses such as:

- "Who is affected by this? Get their input.";
- "Where would you look for this information?" and
- "Which of the tools in the Toolbox might work in this situation?"
- "What potential consequences do you expect from this decision and how can you deal with them?"

This mode of teaching is well elucidated by Samuel and Lewis [13].

The predominant teaching mode for the graduate course that quickly evolved took the form of a weekly symposium. Agenda items may be proposed by either the course instructors or the TA's. The instructors need the benefit of experience to predict what questions and situations are likely to arise in the succeeding week and can provide the TA's with the most useful resources with which they should become familiar. Being able to point to specific Tools or sections of the Student Handbook, or laboratory facilities can be highly beneficial provided these are offered in response to specific queries or needs since the receptiveness to guidance appears to be strongly correlated to the urgency of the perceived need. This process is seen to provide the TA's with an opportunity to learn new material as well as to review and refresh their own familiarity with design methods.

At the same time, the TA's are in an excellent position to perceive difficulties (and successes) that the students are having; the symposium environment provides an excellent forum within which they can offer analysis of situations, compare potential courses of action and propose novel solutions for a wider variety of situations than their previous experience has embraced.

As the courses (and projects) progress, each new phase brings forth new challenges and learning opportunities thus the TA's expand their areas of competence. When it comes time to evaluate student work, another modality of the course is exploited. In the first instance, the

TA's are expected to evaluate the conduct and effectiveness of the design team meetings. Use of standardized grading forms provides the TA with an initial framework; the establishment of norms is done by a combination of having the instructors co-evaluate teams in the first instance as well as dealing with the specific issues in the weekly symposia. This same approach is used for design reviews that constitute the most significant grade components. One or two design reviews are designated which all TA's should attend and each, then, has an opportunity to defend their evaluations.

The following schedule provides an indication of the content of the first term of the undergraduate courses – and hence by implication much of the content of the graduate pedagogy course.

Table 1. Topics, Activities, and Tools used in Term 1 of the Capstone Design Courses

Week	Topics	Activities	Tools
1	Introduction, Resumes/Application letters, Project conduct	Lectures / critiques, Mini-competition project	Engineering Records, Effective Meetings
2	Teamwork, Functionality, Design for X	Competition, Initiate mtgs. with sponsors and supervisors	About Teams, Course Handbook
3	Intellectual Property, Specifications, Human Factors	Guest lectures, DFX exercise, Human Factors exercise, I/P agreements due	Eliciting Input, Kano Model Analysis, Requirements Management
4	Lifecycle Design, Design Reviews	Project work	Design Reviews
5, 6		All teams conduct Requirements Reviews	
7	Project Management and Planning, Creativity	Guest presentations, Project Planning exercise	Configuration Management, Sources of Ideas and Information
8	Feasibility Analysis, Evaluation	Case study, Project Plan due	Evaluation Matrices
9	Failure Modes and Effects Analysis	Case study	FMEA
10, 11		All teams conduct Conceptual Design Reviews	
12	Design Review *post mortem*	Team Contract Due	Design Verification

The other component of the graduate pedagogy course emerges once the undergraduate course is well underway. This comprises a pedagogical project that is intended to generate an addition to the courseware. A broad range of projects have been undertaken and range from additions to the Toolbox, new or modified evaluation procedures, novel in-class activities, or critiques of existing learning methods or resources. A few examples are listed in the 'Course Outcomes' section.

Evaluation of the performance in the graduate pedagogy course is based upon a mix of the above components. As a starting point, it is expected that satisfactory performance in the course (represented by a 'B' grade) will normally be achieved by demonstrating competent mentoring of undergraduate design teams. This is assessed by direct observation of the mentoring process with the potential addition of feedback from the design teams. The 'added value' represented by the courseware projects is normally viewed as adding to the course grade to an extent reflecting the quality and extent of this project work.

4. Graduate course outcomes

A wide variety of outcomes have been observed. Some of these take the form of 'hard data' comprising written work generated by graduate students; yet others can only be assessed through observing the interactions between graduate and undergraduate students. These can be classified as follows:

- ability to support undergraduate course objectives (e.g. inquiry-based learning, experiential learning, research);
- ability to deal effectively and constructively with problems (e.g. with team relationships, problem clients, inadequate resources) – using these as opportunities to teach valuable lessons;
- knowledge and of the potential role of a wide variety of both design process and learning tools and mastery of a variety of techniques;

It has been observed that by the end of the course there is relatively little that distinguishes novice TA's from more the more experienced in these respects. What is observed is that the more experienced TA's tend to have rather more confidence in actively addressing a greater variety of shortcomings; confidence and consistency in the evaluation of design teams also tends – not surprisingly – to improve with experience.

It has been gratifying to see the rapidity with which inexperienced TA's become highly engaged in the process. Once they understand that their role does not require them to be expert in all things they (correctly) perceive that they can bring a wealth of different life experience (whether it is their research, volunteering with service or technical organizations, or involvement in student government) to bear. That they are typically closer to the current undergraduate learning process than more senior instructors (whose undergrad experiences often reflect very different times and circumstances) brings a valuable point of view to the instructional team. That they are treated as respected members of this team having important contributions to make is also seen to be a highly maturational and beneficial outcome of this structure.

This is reinforced by the opportunity to contribute materially to the wealth of knowledge and experience embodied in the constantly growing/evolving courseware.

Some sample titles of written contributions include :

- Engineering Design Education and Communication including Interdisciplinary Design Communication
- A Proposal for Courseware to Address the Problems Created by the Addition of a Requirements Review
- Observational Learning in the Design Process – The 'Defender' Project (a multi-media based decomposition of a video programme case study)
- "Getting Started" - a new tool designed to accelerate and facilitate the introductory phase of project development.

A particularly noteworthy and memorable contribution (that should have been videotaped for posterity) could have been titled "How Not to Conduct a Design Review"; three TA's took over a tutorial session and staged an impromptu Conceptual Design Review that captured (in hilarious fashion) many of the worst features observed in previous years' design reviews and in the process demonstrated advanced histrionic capabilities.

5. Current developments and further outcomes

New first year design and communications courses were introduced in 2002 into the engineering common curriculum at the University of Calgary. The mandate of these courses was to embrace many of the same features identified in the curriculum renewal process. Consequently, many of the components of both the capstone design courses and the pedagogy course described here have proven useful in the design and implementation of these new courses. More than six hundred first year students work with more than a dozen-member instructional team. Team members come from not only several engineering departments (design) but also Fine Art (graphical communication and visual literacy) and Communications (written and oral communication).

Several of the teaching assistants were drawn from the ranks of those who had worked with the capstone mechanical and manufacturing design courses. In addition, some of the courseware developed earlier such as some of the Student Handbook and the Toolbox was assessed to be useful for the freshman courses thus exploiting re-usability and cultivating a consistent 'design culture'.

Not insignificantly, a one-week preparatory session for new members of the instructional team was designed and led in part by an early graduate of the pedagogy course – providing evidence of the creativity and leadership potential which this programme has sought to cultivate.

6. Conclusions

It has been demonstrated that it is possible to prepare new teaching assistants to contribute effectively and quickly to undergraduate design courses. This is attributed in part to the use of inquiry-based learning in the undergraduate courses and in part to the modality of the graduate course. The process described here has to date graduated approximately a score of graduate students who have demonstrated their ability to cultivate undergraduate design capabilities.

It is deemed important for these purposes that mastery of the processes associated with creating an effective environment for learning design are of comparable importance to the actual course content. The course described here is designed to address the former dimension. It is perceived, then, as a potentially valuable adjunct to existing types of graduate course that are more focused on advanced design methods and design course content.

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