2021 ASEE ANNUAL CONFERENCE
Virtual Meeting | July 26–29, 2021 | Pacific Daylight Time
Paper ID #32336

Work in Progress: Transformational Change in a Masters-level Integrated Capstone Design Course that Partners Industry and Academia

Dr. Andrew L. Gillen, University College London

Andrew L. Gillen is a Lecturer in the Department of Civil, Environmental, and Geomatic Engineering at University College London. He has a Ph.D. in Engineering Education from Virginia Tech and B.S. in Civil Engineering from Northeastern University.

Dr. Michael L. Woodrow, University College London

University Lecturer with experience in both research and industry. Skilled in Fire Engineering, Integrated Design, Critical Thinking and Engineering Pedagogy. A professional with a Doctor of Philosophy (PhD) in Fire Engineering Education from The University of Edinburgh.

Prof. Jose Luis Torero, University College London

Professor José L. Torero works in the fields of safety, environmental remediation and sanitation where he specialises in complex environments such as developing nations, complex urban environments, novel architectures, critical infrastructure, aircraft and spacecraft. His work explores the interplay between professional education, project drivers and outcomes. He holds a BSc for the Pontificia Universidad Católica del Perú, and an MSc and PhD from the University of California, Berkeley. He received a Doctor Honoris Causa by Ghent University in 2016. He is a Chartered Engineer (UK), a Registered Professional Engineer in Queensland, a fellow of the Australian Academy of Technological Sciences and Engineering, the Royal Academy of Engineering (UK) and the Royal Society of Edinburgh (UK).

Transformational change in a masters-level integrated capstone design course that partners industry and academia (Work in Progress)

Introduction

Engineering design experiences are required by accrediting bodies around the world. For example, both ABET in the United States as well as JBM (Joint Board of Moderators) in the United Kingdom detail design learning requirements [1], [2]. Capstone or end-of-degree design courses are now prolific in engineering programs across disciplines as a means of meeting these standards, and there is a growing body of literature detailing practices in capstone design teaching (e.g. [3]), and models of industry partnership (e.g. [4]). Beyond accreditation requirements, teaching design through a problem-based approach contributes positively to student motivation [5]. Any design teaching in this way is challenging, but civil engineering, in particular, poses distinct challenges to developing *integrated* capstone design coursework. *Integrated* capstone design brings together the many subdisciplines (e.g. structural, environmental, geotechnical, etc) of civil engineering in the context of a project where the interactions of the sub-disciplines are complex and where extrinsic variables, associated to professional practice, many times drive decisions.

Our work takes place within a larger project to reform the integrated civil engineering capstone course. This course is offered as a final year experience for undergraduates, but masters-level students are also allowed to participate. The course is offered at a large, public research institution in the United Kingdom where professional certification can be attained via the accredited undergraduate or master's programs. The course was implemented more than a decade ago, and through these years it has been modified several times. In its current form, the capstone course has been largely outsourced to a major engineering firm that is renowned for its innovative approaches to civil engineering projects. Our project team seeks to implement yet another improvement effort. The goals of this project are threefold:

(1) Develop an understanding of how to balance industry involvement

(2) Generate mechanisms for sustainable adoption of changes (e.g. consensus building)

(3) Evaluate short- and long-term student outcomes for the course

In this work-in-progress paper, we will detail the context around the integrated capstone design (ICD) course and provide an overview of our intended adjustments to the course. This project involves both programmatic implementation and research elements. We will explain our research plans and current status as well as program evaluation efforts.

Course Description

This work takes place in the United Kingdom where Civil Engineering programs are accredited by the Joint Board of Moderators. In the United States, ABET provides a student outcome criterion that requires design [1]. JBM takes this a step further by identifying design as a major thread that should be central to curriculums [2]. Beyond capstone, the civil engineering department at the university under study already has design embedded throughout the Bachelor of Engineering (BEng) curriculum through regular design challenges. The BEng is a three-year program after which many students elect to stay for a fourth year to complete their Masters of Engineering (MEng). In the UK, the MEng is considered an undergraduate degree and is an encouraged path for professional certification. There are similarities between the MEng and the traditional Bachelor of Science model common in the United States.

From the months of September to March, students work together to tackle a major civil infrastructure project. Figure 1 depicts the ICD course schedule in general terms. Students' time is split between all-class sessions that take the form of lectures on both technical and nontechnical topics, optional workshops on specific aspects of their designs (e.g. long-span structures), design advice rotations with mentors from industry, and simulated client meetings. Students have group working time built into the schedule.

Figure 1. Weekly ICD Course Schedule

Semester 1										
Week	1	2	3	4	5	6	7	8	9	10
Day 1	All class	All class	Optional Wksp	Optional Wksp	All class	All class	Optional Wksp	All class	All class	Present Milestone
	All class	All class	Optional Wksp	Optional Wksp	All class	Group Freetime	All class	Optional Wksp	Group Freetime	
Day 2	All class	All class	Design Advice	All class	Client Meeting	Optional Wksp	Design Advice	Optional Wksp	Client Meeting	Group Freetime
	All class	All class	Design Advice	Group Freetime	Client Meeting	Optional Wksp	Design Advice	Optional Wksp	Client Meeting	Group Freetime
	Group Freetime	All class	Client Meeting	Group Freetime	Group Freetime	All class	Client Meeting	Group Freetime	Group Freetime	Group Freetime
	Group Freetime	Group Freetime	Client Meeting	Group Freetime	Group Freetime	All class	Client Meeting	Group Freetime	Group Freetime	Group Freetime
Semester 2										
Week	11	12	13	14	15	16	17	18	19	19
Day 1	All class	Design Advice	Group Freetime	Optional Wksp	Group Freetime	Design Advice	Optional Wksp	Group Freetime	Optional Wksp	Group Freetime
	Optional Wksp	Design Advice	Group Freetime	Optional Wksp	Group Freetime	Design Advice	Optional Wksp	Group Freetime	Optional Wksp	Group Freetime
Day 2	Optional Wksp	Optional Wksp	Optional Wksp	Group Freetime	Group Freetime	All class	Optional Wksp	Group Freetime	Group Freetime	Present Milestone
	Optional Wksp	Optional Wksp	Optional Wksp	All class	All class	All class	Optional Wksp	Group Freetime	Group Freetime	
	Client Meeting	Optional Wksp	Client Meeting	Optional Wksp	Client Meeting	Group Freetime	Optional Wksp	Client Meeting	Group Freetime	
	Client Meeting	Optional Wksp	Client Meeting	Optional Wksp	Client Meeting	Group Freetime	Optional Wksp	Client Meeting	Group Freetime	

The integrated nature of this course means that students take responsibility over sub-disciplines (e.g. geotechnical, structural) of civil engineering and work towards group goals that combine these independent components (e.g. designing sustainable social housing). Example projects from previous years include social housing developments, sports arenas, highspeed railways, and public parks. Mentors from industry serve as clients and provide regular workshops as well individual and group support for these projects. Since its inception, the course has encouraged students to frame their work and decision making within the context of professional practice.

Proposed Changes to Instructional Approach

Responsibility for the ICD course has changed hands several times in recent years, and the department has currently contracted with local industry to deliver most of the workshops, design project briefs, serve as mentors, and help with grading. It is important to note that this is done by design where the motivation behind the outsourcing remains the intent to maintain a professional practice framework. Nevertheless, the combination of outsourcing a large part of the course design and implementation to external partners and the shifting ownership over this capstone may have, unintentionally, resulted in a deviation from the intended path. This problem of maintaining continuous improvement in a culture of turnover has motivated other evaluative efforts in the literature [6]. In this particular case it raises the question of what is the appropriate balance of industry involvement that will guarantee both a professional practise framework and an adequate learning environment. Based on this interpretation and rooting ourselves in an evidence-based approach, our team seeks to change the instructional techniques by emphasizing student self-direction, focusing on problem formulation as opposed to jumping to quick solutions, and balancing industrial influence. While these issues are presented separately, we recognize that they are intertwined. When appropriate we will point to the relationships between these three aspects of the problem.

Emphasizing self-directed learning. Arguably, the course in its current form is structured to promote student independence as learners. Most of the work is done independently or in groups and students must seek out resources and apply previous knowledge from theory-based coursework to practical design. However, self-direction requires more than just the opportunity to be independent. It requires metacognitive skills including self-evaluation [7]. Furthermore, the interactions with mentors have to be such that they enable the development of these skills. A potential conflict arises in that teamwork in industry assumes those skills have already been developed and therefore there is a natural tendency to guide in a directive manner. We plan to implement strategies towards promoting these skills in the new iteration of the course. Moreover, we seek to reframe the actual project as a vehicle for individual learning and not an end in itself.

Focusing on problem formulation. The current course requires students to generate a set of reports in the first semester and present preliminary ideas during the first few weeks. Nearly every group quickly establishes concept solutions. The structure of the project briefs details the major aspects of the problem (e.g. students must consider integration into current transportation networks), but in doing so, prescribes the possible approaches the students may take. The accelerated development of concept solutions and nature of the project briefs seems to lead students to adopt directed solutions without giving due attention to the complexity of the problem space. This is an area where the direct extrapolation of common industry practices seems to limit the capacity that the project has as an enabler for the development of a mindset of deep critical thinking. In this improvement project, we plan to use the first semester to emphasize problem formulation, co-creating the brief with students. The literature suggests that questioning is an inherent aspect of this problem formulation stage, and that thinking like a designer means engaging in a distinct manner of inquiry [8]. The Design Council’s Double Diamond framework structures a period of problem formulation before developing solutions and iterations between this and the design development stages [9]. Although we are not adopting every aspect of this framework, the notion of explicitly setting aside time for this manner of thinking guides our approach. In this next iteration of the course, we hope to challenge the methods ingrained in our students through their traditional coursework.

Balancing academic and industrial influence. Lastly, the balance of industrial influence presents an immediate and significant challenge for the department. There are split opinions on the importance of industry participation in this capstone course. At the same time, anecdotally, many academics recluse themselves from participation in the course on the grounds they are uncomfortable with advising on an experience meant to feel authentic to industrial practice. Design courses are often aimed at providing this authentic experience, and there are many arguments for the benefits of industry involvement for both faculty and students [10]. However, we argue that it is an assumption that industry involvement always leads to positive outcomes, and there is a need to more critically evaluate the balance of industry involvement. Moreover, if the main goal is to replicate an industry experience, students would be better served with an internship program rather than a capstone. We aim to emphasize bringing in the right people into the correct environment to enable the co-creation of the desired learning experiences.

Research and Evaluation

Understanding an organizational shift. As the course has transitioned through different coordinators and iterations through the years, academic involvement has changed. Although there remains disagreement among faculty in the department about the purpose of the course and the balance of industry involvement, our first research objective is to build an understanding of why the broader academic involvement in the ICD course waned in recent years. Considering how organizations change, we will explore stakeholder perceptions of the course's purpose and how they see their role (or lack thereof). Stakeholders in a complex collaboration such as the ICD course can be defined as those affected by or that have an effect on the collaborative problem (i.e. delivering a high quality learning experience) [11]. In this investigation, these are defined as students, academics, and industry partners.

To answer this initial question (i.e. why has academic involvement changed), we plan to take a primarily qualitative approach involving semi-structured interviews with a purposefully sampled [12] collection of stakeholders. Individuals with intimate knowledge of the history of the course and department will aid in selection of participants in addition to other methods such as an initial stage of surveying.

Evaluating student outcomes. A central motivation for implementing these changes is to shift the emphasis from product to process, from overly scoped projects to intentionally designed student learning experiences, and from grade-oriented to self-improvement oriented. To this end, the proposed learning goals are similar to past iterations, but we reframed outcomes towards process over product and reduced redundancies to add clarity for both instructor and learner on what the central outcomes of the course should be. See Table 1 for a list of the proposed learning outcomes.

Table 1. Proposed Learning Outcomes

Learning Theme	**Specific Student Outcome**
Design Expertise	• Deeply formulate a civil engineering infrastructure problem including identifying stakeholder needs and problem constraints beyond the superficial. • Exercise design skills on a civil engineering problem to provide creative, original, and feasible solutions.
Reflective Practice	• Engage critically with their own designs to evaluate quality and develop resilience to iterative changes in design. • Effectively communicate a design to a variety of audiences using visual, written, and oral presentation techniques. • Operate effectively in a team environment showing respect for alternative perspective and building productive relationships.
Independence	• Apply prior knowledge and understanding from education, personal and professional experience to solve a design problem on a civil engineering project. • Identify and acquire new knowledge and understanding required for design, and subsequently apply it to a civil engineering project.

Evidence for these outcomes will include student data as part of regular formative and summative course assessment. We will also explore future questions related to student outcomes that may involve interviewing or observations as sources of evidence.

Current Status and Future Work

We have recently processed ethics approval and are limited in the results we can report at this time. Although the focus of this initial stage is on the organizational shift, future work will encompass additional research questions to help us meet our goals and contribute to the body of knowledge around capstone design. This may include collection of observation data or tapping into existing institutional metrics for measuring student perceptions. Anecdotal evidence suggests general student dissatisfaction with the current model. Moving forward, we are particularly interested in how the language used to describe the different external partners contributes to how stakeholders position their influence (e.g. the word consultant implies a different power dynamic than advisor).

In presenting this work-in-progress, we hope to identify challenges and blind spots in our approach. By taking on this project, we want to effect lasting change on the department and rekindle a sense of ownership among the faculty. The results of this work will not only impact our local decision-making, but also have implications for the broader literature on capstone, particularly by adding insight into masters-level capstone work and integrated civil design experiences. Moreover, discovering why the broader academic involvement in the ICD course waned in recent years is the first step in developing a better understanding of how to design for sustainable change in complex educational collaborations, something of relevancy across engineering education disciplines.

References

[1] ABET, ‘Criteria for Accrediting Engineering Programs, 2018 – 2019’. [Online]. Available: https://www.abet.org/accreditation/accreditation-criteria/criteria-for-accrediting-engineering-programs-2018-2019/. [Accessed: 27-Jan-2020].

[2] Institution of Civil Engineers, ‘Joint Board of Moderators 2017 Guidelines for Developing Degree Programmes’. [Online]. Available: https://www.jbm.org.uk/Files/JBMSite/fe/fec419ee-8adf-4451-9d10-afae9751b467.pdf.

[3] J. J. Pembridge and M. C. Paretti, ‘Characterizing capstone design teaching: A functional taxonomy’, *J. Eng. Educ.*, vol. 108, no. 2, Jun. 2019, doi: 10.1002/jee.20259.

[4] Y.-S. Shin, K.-W. Lee, J.-S. Ahn, and J.-W. Jung, ‘Development of internship & capstone design integrated program for university-industry collaboration’, *Procedia - Soc. Behav. Sci.*, vol. 102, pp. 386–391, Nov. 2013, doi: 10.1016/j.sbspro.2013.10.753.

[5] B. Jones, C. Epler, P. Mokri, L. Bryant, and M. Paretti, ‘The Effects of a Collaborative Problem-based Learning Experience on Students’ Motivation in Engineering Capstone Courses’, *Interdiscip. J. Probl.-Based Learn.*, vol. 7, no. 2, May 2013, doi: 10.7771/1541-5015.1344.

[6] P. B. Crilly and R. J. Hartnett, ‘Student Outcome Assessment and Course Continuity for Programs With Moderate Faculty Turnover’, presented at the 2015 ASEE Annual Conference & Exposition, 2015, pp. 26.1420.1-26.1420.7.

[7] S. A. Ambrose, M. W. Bridges, M. DiPietro, M. C. Lovett, and M. K. Norman, *How learning works: Seven research-based principles for smart teaching*. John Wiley & Sons, 2010.

[8] C. L. Dym, A. M. Agogino, O. Eris, D. D. Frey, and L. J. Leifer, ‘Engineering Design Thinking, Teaching, and Learning’, *J. Eng. Educ.*, vol. 94, no. 1, pp. 103–120, Jan. 2005, doi: 10.1002/j.2168-9830.2005.tb00832.x.

[9] ‘What is the framework for innovation? Design Council’s evolved Double Diamond’, *Design Council*, 17-Mar-2015. [Online]. Available: https://www.designcouncil.org.uk/news-opinion/what-framework-innovation-design-councils-evolved-double-diamond. [Accessed: 27-Jan-2020].

[10] J. Goldberg, V. Cariapa, G. Corliss, and K. Kaiser, ‘Benefits of Industry Involvement in Multidisciplinary Capstone Design Courses’, *Int. J. Eng. Educ.*, vol. 30, no. 1, 2014.

[11] B. Gray and J. M. Purdy, *Collaborating for our future: multistakeholder partnerships for solving complex problems*, First edition. Oxford ; New York, NY: Oxford University Press, 2018.

[12] J. W. Creswell, *Research design: qualitative, quantitative, and mixed methods approaches*, 4th ed. Thousand Oaks: SAGE Publications, 2014.