Towards a Pedagogical Framework for Project-Based Engineering Design Courses

Ms. Martina Moyne, University College Dublin

Martina Moyne is a PhD candidate in the School of Mechanical and Material Engineering, University College Dublin (UCD). She received her BDes in Industrial Design and MSc in Medical Device Design in the National College of Art and Design (NCAD) and ME in Management in UCD. She is a part time lecturer in NCAD and prior to pursuing her PhD, she worked for six years in Nypro Healthcare as a Senior Product Engineer. Her research interests are in design engineering pedagogy, medical device design and human factors engineering.

Mr. Maxwell Herman, Harvard John A. Paulson School of Engineering and Applied Science

Maxwell Herman is a researcher working in the John A. Paulson school of Engineering and Applied Sciences at Harvard University. He received his BS and MS from Carnegie Mellon University in 2013. He is currently working as an software engineer designing and building online education tools for use in the classroom.

Prof. Conor Walsh P.E., Harvard University

Conor is Associate Professor of Mechanical and Biomedical Engineering at the Harvard School of Engineering and Applied Sciences and a Core Faculty Member at the Wyss Institute for Biologically Inspired Engineering at Harvard. He is the founder of the Harvard Biodesign Lab, which brings together researchers from the engineering, industrial design, medical and business communities to develop smart medical devices and translate them to industrial partners in collaboration with the Wyss Institute's Advanced Technology Team. Conor's research projects focus on wearable robotics to assist the disabled and able-bodied, as well as on tools for minimally invasive diagnosis and treatment of disease. His educational interest is in the area of medical device innovation where he mentors student design teams on projects with clinicians in Boston and in emerging regions such as India. Conor received his B.A.I and B.A. degrees in Mechanical and Manufacturing engineering from Trinity College in Dublin, Ireland, in 2003 and M.S. and Ph.D. degrees in Mechanical Engineering from the Massachusetts Institute of Technology in 2006 and 2010. Conor is Assistant Professor of Mechanical and Biomedical Engineering at the Harvard School of Engineering and Applied Sciences. He is also the founder of the Harvard Biodesign Lab, which brings together researchers from the engineering, industrial design, medical and business communities to develop smart medical devices and translate them to industrial partners in collaboration with the Wyss Institute's Advanced Technology Team. Conor received his B.A.I and B.A. degrees in Mechanical and Manufacturing engineering from Trinity College in Dublin, Ireland, in 2003 and M.S. and Ph.D. degrees in Mechanical Engineering from the Massachusetts Institute of Technology in 2006 and 2010. He has been the recipient of over a dozen invention, entrepreneurship, and student mentoring awards including the MIT $100K business plan competition, Whitaker Health Sciences Fund Fellowship, and the MIT Graduate Student Mentor of the Year.

Dr. Donal Padraic Holland, University College Dublin

Dónal Holland is an Assistant Professor in the School of Mechanical and Materials Engineering at University College Dublin, and an Associate at the Harvard School of Engineering and Applied Sciences. His research interests include engineering design education, methodologies for mechanical design, and the development of soft and wearable robotic technologies. He leads the development of the Soft Robotics Toolkit (http://softroboticstoolkit.com/).

Executive Summary: Towards a Pedagogical Framework for Project-Based Engineering Design Courses

Introduction

This poster presents preliminary results from a project aimed at better understanding how engineering design is taught and learned. The overall aim of the project is to develop a pedagogical framework to guide the development, evaluation, and improvement of learning environments for project-based engineering design courses. Design is a fundamental activity in engineering and involves tackling open-ended, ill-defined problems. Design knowledge is largely procedural rather than declarative; students must learn to follow a methodical (top-down, breadth-first) process, while learning to adapt this problem-solving strategy in response to the uncertainty inherent in design [1–3]. The appropriate balance between the flexible and methodical aspects of design problem solving is highly context-dependent; it varies depending on the type of project being undertaken, the students involved in the project, the resources available, and so on. This introduces challenges to project-based design education, in particular the need for coaching and feedback tailored to the particular context of each student project. To provide such feedback, instructors need to monitor the progress of each student, which is a challenge in large classes.

A related problem in design research is the difficulty in collecting data about the design process. Beginning with the "Design Methods Movement" in the 1960s, researchers have attempted to describe the methodologies and processes followed by designers in a variety of fields. Such studies typically fall somewhere along a spectrum between two research approaches: lab-based studies in which participants undertake contrived design tasks while "thinking aloud" (e.g [2], [4]); and ethnographic studies on which researchers observe real design teams over the duration of a project (e.g. [5]). While these research approaches have yielded insights on design psychology, and thereby have the potential to impact design education, both approaches are subject to limitations. The lab-based studies tend to focus exclusively on the ideation stage of a simplified design process, stripped of its context and of the social interactions essential to design. The ethnographic studies address this problem by collecting rich data from the field, but it is difficult to compare across multiple studies and teams because, in ethnographic research, the researcher is the instrument [6].

Thus, there is a need for research and teaching instruments that would allow the collection of rich data from large numbers of people engaged in engineering design activities. Such tools would enable improved design education by providing instructors with the information they need to effectively coach students, and would support research in design by enabling the collection and comparison of data from large numbers of teams and individuals engaged in real design activities.

The Design Evaluation and Feedback Tool (DEFT)

Over the past year we have been developing and testing a web-based data collection and feedback tool for use in project-based engineering design classes. The Design Evaluation and Feedback Tool (DEFT, http://deft-project.com/) system contains regular short questionnaires to be completed by students and instructors; the responses to these questionnaires are used to produce weekly reports for both types of user. The initial prototype of the system consisted of a combination of online and paper-based surveys, and this prototype was tested with 13 students in a medical device design class at Harvard. Each week, students were asked to

complete an online questionnaire. The student responses were used to create a paper report and feedback form for instructors, which was completed each week following design review meetings with the student teams. In turn the instructor forms were used to create a feedback report for the students. Data processing and report generating was done completely by hand. Based on the outcomes of this pilot test, a completely web-based version of the system has been developed; components of this system have been used by 320 students in five undergraduate engineering design classes. The online system completely automates the data processing and report generation, allowing the system to scale to larger numbers of users with minimal added effort.

The core of the DEFT system is a weekly questionnaire which asks students to describe their class-related activities during the preceding week, to rate and comment on the performance of their peers, and to answer some questions intended to elicit reflection on their own approach to the design process. Figure 1 shows an excerpt from the "beta version" of the student weekly questionnaire. The resulting data is used to construct an overview of the design process followed by each student; this overview can then be used as research data; as a reflective tool for students; and as a class evaluation tool by instructors.

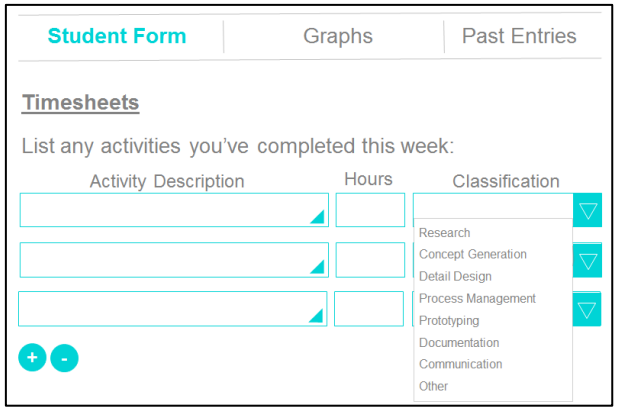

Figure 1 Excerpt from weekly student questionnaire

Weekly instructor questionnaires are used to collect feedback for the students and to provide contextual research data. Instructors are asked to rate the quality of the students' work over the previous week, and to provide verbal responses describing the tasks that the students have performed well, the tasks that require more work, and steps the students should take over the coming week. The instructor questionnaires contain data from the responses to the student questionnaires so that they are customized to each student project, thereby allowing for the context-dependent nature of design. Figure 2 shows an excerpt from the instructor weekly questionnaire.

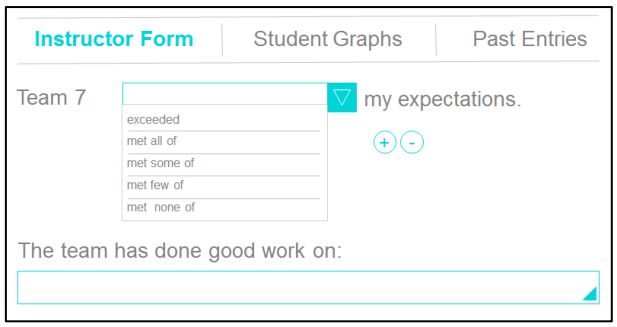

Figure 2 Excerpt from weekly instructor questionnaire

The data collected from both sets of questionnaires are used to create weekly reports for both students and instructors. The reports describe the activities and perceived work quality of both teams and individual students, as well as verbal comments describing the progress of the design projects. To protect their privacy, each student can only see the ratings of their own team as a whole, and their own individual performance. Instructors can see all data for any of their students, thereby allowing them to identify students or teams who may be struggling and require further advice or coaching. Figure 3 shows example reports generated by the system.

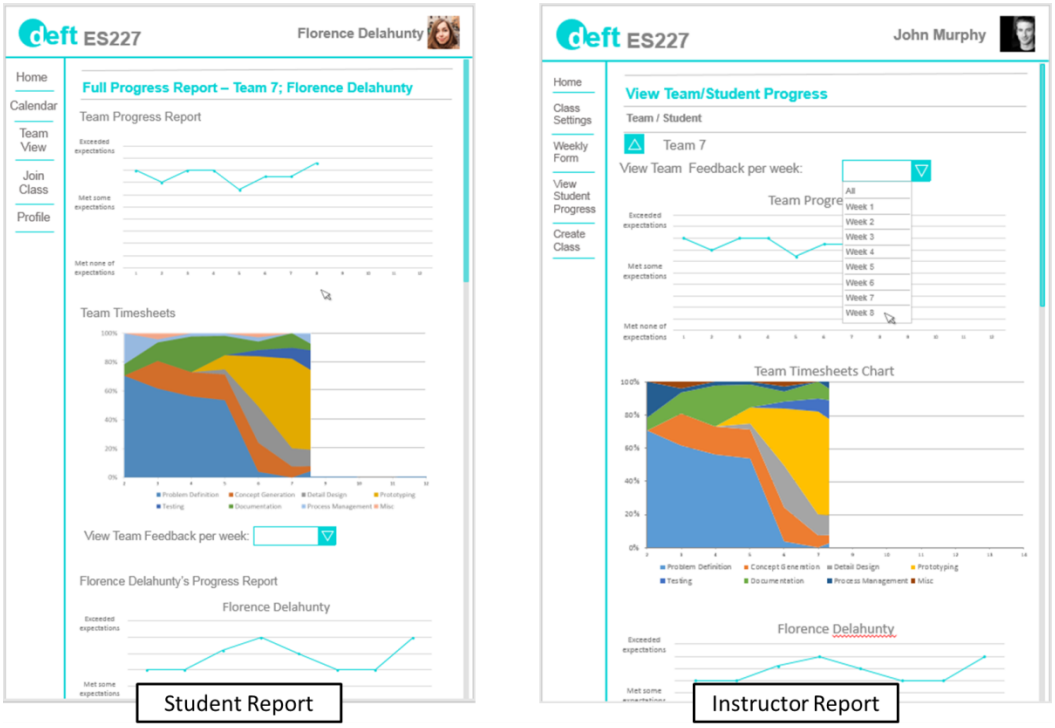

Figure 3 Weekly reports automatically produced by the DEFT system.

In addition to these weekly questionnaires, the system also collects data at the beginning and end of every class. This provides contextual data to allow comparison between different students and learning environments, while also providing useful information to instructors. Entry and exit surveys collect information about students' backgrounds, their attitudes and self-efficacy regarding engineering design, and their reflections on what they have learned during the class. Instructor class setup surveys provide information about the learning environment and objectives of a class, and a final assessment form collects a summative evaluation of each student's work in the class.

The aim of the DEFT system is to provide a useful teaching and learning tool, while also enabling the collection of research data describing the design processes followed by large numbers of students, and enabling the comparison of design processes across different learning environments. However, a description of a students' design process is not of much use in itself, so the system also collects rich data about the context in which a given process is situated. Figure 4 shows a conceptual overview of the data collected by the system.

Evaluating the DEFT System

In order to successfully collect research data in a wide variety of design classroom, it is necessary that the DEFT system be seen as a useful and unobtrusive tool for students and instructors. Thus, the evaluation of the system to data has focused on user needs research. Interviews have been conducted with design educators in order to collect data on the learning environment of their classes and to define requirements for a system that would assist their teaching. In the eight classes that have used the DEFT system, interviews and additional surveys have been conducted with both students and instructors to collect feedback on the system, and this feedback has been used to refine the design of the system. Likert scale questions have been added to the weekly questionnaires to collect further information on users' experience with the DEFT system. Participant observation data has also been collected in one class that was using the DEFT system; we plan to continue collecting such data in an effort to validate the data collected using the web-based questionnaires.

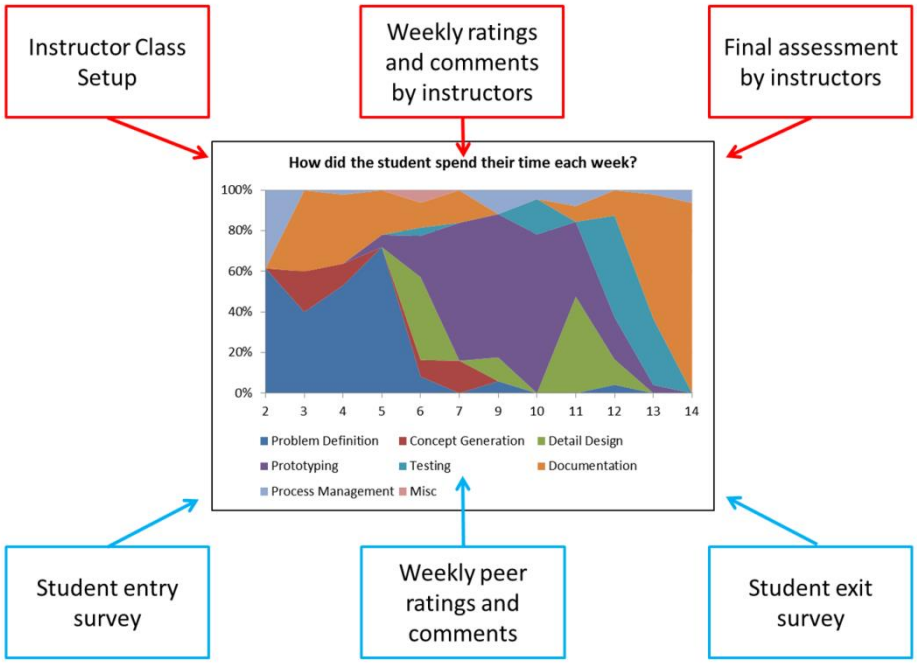

Figure 4 Conceptual overview of data collected by DEFT system. The description of each participant's design process is central; the other text boxes represent the contextual data collected by the system.

Future Work

We have developed two iterations of the DEFT system, and have run pilot tests with 320 students in total. In the coming year, we plan to test the third version of the system with at least 200 students at two universities. This will yield a substantial quantity of research data in itself,

and we will continue to conduct interviews and participant observation research as a form of data triangulation. In subsequent years, the DEFT system will be made freely available for use by other educators and researchers. The data collected through the DEFT system will then be used to develop a pedagogical framework for engineering design.

References

[1] Ball, J. and Ormerod, T. C. Structured opportunistic processing design: a critical discussion. *International Journal of Human-Computer Studies*, 43(1):131—151, 1995.

[2] Guindon, R. Designing the Design Process: Exploiting Opportunistic Thoughts. *Human-Computer Interaction*, 5(2):305—344, June 1990.

[3] Fricke, G. Successful Individual Approaches in Engineering Design. *Research in Engineering Design*, 8(3):151—165, 1996.

[4] Atman, C. J., Adams, R. S., Cardella, M., Turns, J., Mosborg, S., and Saleem, J. Engineering Design Processes: A Comparison of Students and Expert Practitioners. *Journal of Engineering Education*, 96(4):359-379, Oct. 2007.

[5] Bucciarelli, L. L. *Designing Engineers*. MIT Press, Cambridge, MA, 1994.

[6] Guba, E. G. and Lincoln, Y. S. The evaluator as instrument. In *Effective evaluation*, pages 128-152. Jossey-Bass Publishers, San Francisco, 1981.