IUSE: A Web-Based Tool for Engineering Design Pedagogy Research

Ms. Martina Margaret Moyne, University College Dublin

Martina Moyne is a PhD candidate in the School of Mechanical and Material Engineering, University College Dublin (UCD) and a Lecturer in Product Design in the Institute of Technology Carlow. 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 UCD 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 University

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 Walsh is the John L. Loeb Associate Professor of Engineering and Applied Sciences at the John A. Paulson Harvard School of Engineering and Applied Sciences and a Core Faculty Member at the Wyss Institute for Biologically Inspired Engineering. He is the is the founder of the Harvard Biodesign Lab, which brings together researchers from the engineering, industrial design, apparel, clinical and business communities to develop new disruptive robotic technologies for augmenting and restoring human performance. This research includes new approaches to the design, manufacture and control of wearable robotic devices and characterizing their performance through biomechanical and physiological studies so as to further the scientific understanding of how humans interact with such machines. He is passionate about educating future innovators and his research group also helped launch the Soft Robotics Toolkit that is an open source resource to promote and disseminate materials for soft robotics to educators and researchers. 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.

Dr. Donal Padraic Holland, University College Dublin

Dónal Holland is an Assistant Professor in Mechanical and Materials Engineering at University College Dublin (Ireland) and an Associate at the Harvard John A. Paulson School of Engineering and Applied Sciences.

IUSE: A Web-Based Tool for Engineering Design Pedagogy Research

Abstract

Project-based design classes are increasingly common in undergraduate engineering programs. Nevertheless, there is a paucity of guidelines to support the development, implementation and efficacy evaluation of such new courses. Engineering design projects frequently serve as experiential learning activities for students to appropriately apply a methodical design process to specific design contexts. However, it is challenging for instructors to ensure that students achieve the intended learning objectives within project-based design classes. It is also difficult for researchers to directly compare design processes followed by students within different learning environments. These challenges are partly due to difficulties in monitoring and tracking student activities in classes where each student may pursue a different design problem and solution, and where the majority of class activity may take place outside of scheduled contact hours. This poster presents preliminary results from a project aiming to gain an improved understanding of how engineering design is taught and learned in order to provide foundation for a new pedagogical framework to guide the development, evaluation and improvement of learning environments for project-based engineering courses.

The poster describes the Design Evaluation and Feedback Tool (DEFT), a custom-built web-based system that collects and reports data to support teaching, learning and research in project-based engineering design education, and a case study to demonstrate its capabilities as a method of collecting and analyzing data from student design teams. The system is intended to support educators in coaching and monitoring student designers, encourage students in reflective reporting on their experiential learning, and to serve as a data collection tool for education researchers.

This poster also presents the results of a case study of a proposed framework involving DEFT data to evaluate project-based design courses. The research consisted of interviews with the lead instructor of the classes (n=1), weekly observation of the student groups and the analysis of self-reported student design process data (n=12) to review the efficacy of the design class. The poster concludes by discussing class-specific modifications, plans to make the tool publicly available and to scale the use of DEFT in large numbers of engineering design courses.

1. Introduction

This poster presents preliminary results from a project aimed at providing a better understanding of 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.

Project-based design classes are increasingly common in undergraduate engineering programs, serving as experiential learning activities. They allow students to apply their theoretical knowledge to solve open-ended, ill-structured design problems [1, 2]. Design knowledge is largely procedural rather than declarative; students must learn to follow a methodical (top-down, breadth-first) process, while responding flexibly to the uncertainty inherent in design [3-5]. Thus, project-based design classes can serve both to reinforce engineering theory and to cover skills and knowledge not typically learned in traditional engineering science classes.

Achieving the required balance between the flexible and methodical aspects of design problem-solving is challenging in project-based learning environments. Engineering design educators need to provide personalized coaching and encourage student reflection. The implementation of such a flexible and coaching-orientated project-based design class is exacerbated by large class sizes and limited resources [6, 7]. The open-ended nature of design problems allows each student or group in the design class to pursue a different solution and they may conduct the majority of the class activity outside of the scheduled contact hours, which causes difficulty for instructors to monitor in large classes.

There are tools available for instructors that address some of their needs. Socrative, a web-based tool, allows instructors to monitor student understanding of class content through live, customizable multiple-choice questions [8]. An e-journal developed specifically for design classes can gather detailed qualitative design information for instructors [9]. CATME allows instructors to periodically assess student team dynamics in project-based classes [10]. A variety of instruments have been developed to collect data about student attitudes and confidence in engineering and science subjects [11, 12]. These tools can support instructors' coaching of students; however, these tools do not present a holistic data set of the student processes throughout the class for evaluation of the class's experiential learning methods.

The difficulty in monitoring and tracking student activities within design classes also provides barriers for researchers to directly compare the design processes followed by students within different learning environments. The nature of project-based design classes limits the usefulness of common research methods used previously in design studies such as protocol analysis (e.g. [13, 14]) and ethnography (e.g. [15, 16]).

Thus, a novel tool is required to both facilitate instructor monitoring of student processes and evaluation of project-based design classes, and collect design process-related data that will support researchers in gaining insight into how engineering design is taught and learned. This poster describes the Design Evaluation and Feedback Tool (DEFT), a custom-built web-based system that collects and reports data to support teaching, learning and research in project-based engineering design education, and a case study to demonstrate its capabilities as a method of collecting and analyzing data from student design teams.

2. The Development of DEFT

DEFT (https://www.deft-project.com) collects design process data through short, weekly questionnaires for students and instructors in engineering design classes, and generates weekly update reports for both groups of users. DEFT was developed through an iterative design and evaluation process, involving 321 students and 26 instructors in five different mechanical engineering design classes over five semesters at two universities in Ireland and the United States. All classes were project-based, with projects lasting between nine and fourteen weeks, and represented a variety of teaching and learning environments involving differing class sizes, drawing on varying engineering disciplines, and having class cohorts consisting of undergraduate and/or post-graduate students. The student response rate to the weekly questionnaires was high, with all students engaging with the tool (N = 321) during their projects and an average weekly student response rate of 92%. These compliance rates were achieved because the weekly DEFT entries were required coursework assignments in these classes.

The iterative design process consisted of an evaluation of the system each semester, using mixed methods. Observational data of student and instructor experiences with DEFT were collected. Interviews and post-class surveys with students and instructors provided data triangulation. The results of this research guided the development of each iteration of DEFT in time for the subsequent semester. Ethical approval for this research was granted by the Harvard University Committee on the Use of Human Subjects in Research and the University College Dublin Human Research Ethics Committee. The focus of the system development was to support educators in coaching and monitoring student designers, to serve as an aid for instructors in evaluating and improving such classes, and to provide a new data collection method for education researchers. The next section describes the DEFT system user interaction process.

3. Overview of DEFT system

User interactions with the DEFT system can be grouped into three phases: the start of a class, the week-to-week interactions, and the end of the class, as shown in Fig. 1. At the start of a module, the instructor creates a DEFT class for their students to engage with. The instructor provides contextual data on the class during the set-up, such as engineering disciplines, assessment methods, teaching methods etc.

The DEFT class is then ready for student engagement with the system. Students complete an entry survey to gain access to the class. This survey gathers self-reported information on students' experience of projects and teams, their attitudes towards design and their levels of confidence in design skills and processes. This survey has adapted questions found in education research literature [11, 12]. Once the students have completed their entry questionnaires, students and instructors complete weekly questionnaires for the duration of the design project.

Student weekly questionnaires collect student data on design processes and their peer evaluations, which is collated into a weekly progress report for instructors. These questions encourage students to reflectively report on their design process and on their allocation of time and effort to project-related activities. Following their weekly contact time with students, instructors complete weekly DEFT questionnaires, generating a report containing feedback on the quality of the work for students. A demonstration of the weekly questionnaires can be found at https://deft-project.com/demo.

At the end of the class, students complete an exit questionnaire containing many of the same questions as in the entry questionnaire. The resulting data can be used by instructors to

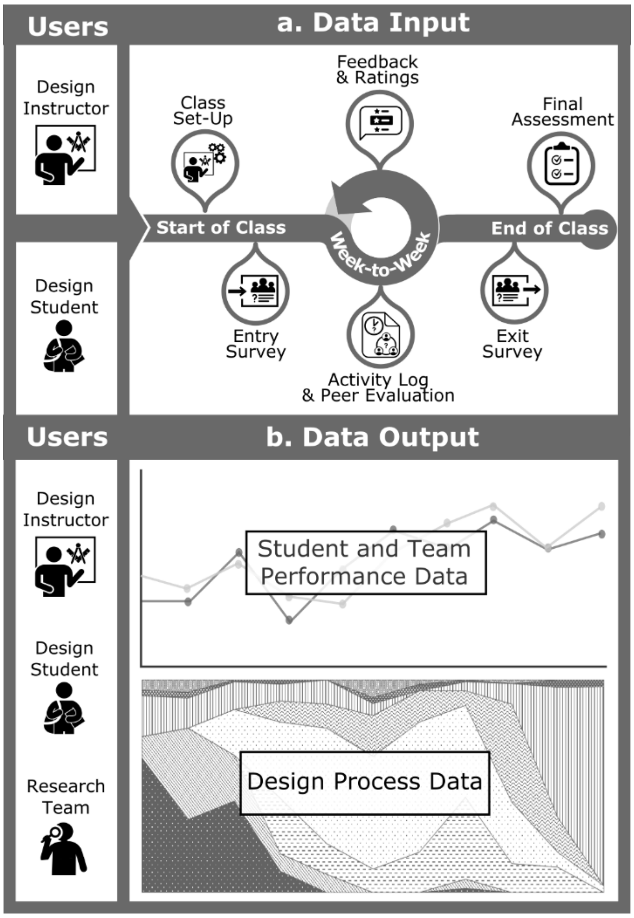

Figure 1 (a). The forms of data collected by DEFT from specific users at particular points along the phases of a design class. 1(b). The users and types of DEFT data output that they can engage with.

compare responses between the start and end of the class, and thereby evaluate the impact of the class on student knowledge, attitudes, and confidence. Instructors also complete an exit questionnaire, which asks them to evaluate the overall quality of the student design projects.

4. Evaluation and Usefulness of DEFT

The evaluation of DEFT was integral to the iterative design process. The feedback from the students and instructors was positive with the majority of users indicating their satisfaction with each iteration of the system. The major changes to DEFT through the iterations were restructuring of weekly questions to reduce the inflations of student peer ratings and instructor rating of groups; the restructuring of the activity log component of student weekly questionnaire; the modification of student and group weekly activity plots to present time spent on design activities as a percentage of the total weekly time spent, rather than the absolute time values (previously hours), to reduce inflation of activity hours; and the removal of individual student performance data from student weekly reports, showing team data only to encourage collaborative problem solving.

Students showed their appreciation for the activity-logging features and the increased frequency of written feedback. They also used the weekly reports for personal weekly reflection and to initiate team discussions. Instructors of large classes (>40 students) with typically less contact time with students found DEFT particularly useful for monitoring and tracking student progression and team dynamics. Data collected by DEFT also proved useful in helping instructors to resolve complaints for students who believed their project grade should be separated from that of their team, as they deemed their personal contribution more significant than that of their teammates. For instructors, DEFT allows the simple collection of information that allows them to self-evaluate their class and provides data-driven support for any proposed changes to their class. For researchers, the data collected by DEFT can be used to compare outcomes of a single class or compare between design classes at different universities. An example of a process plots for two student teams is given in figure 2. Despite the irregularity of engineering design projects, DEFT provides a framework for comparison across multiple projects and classes.

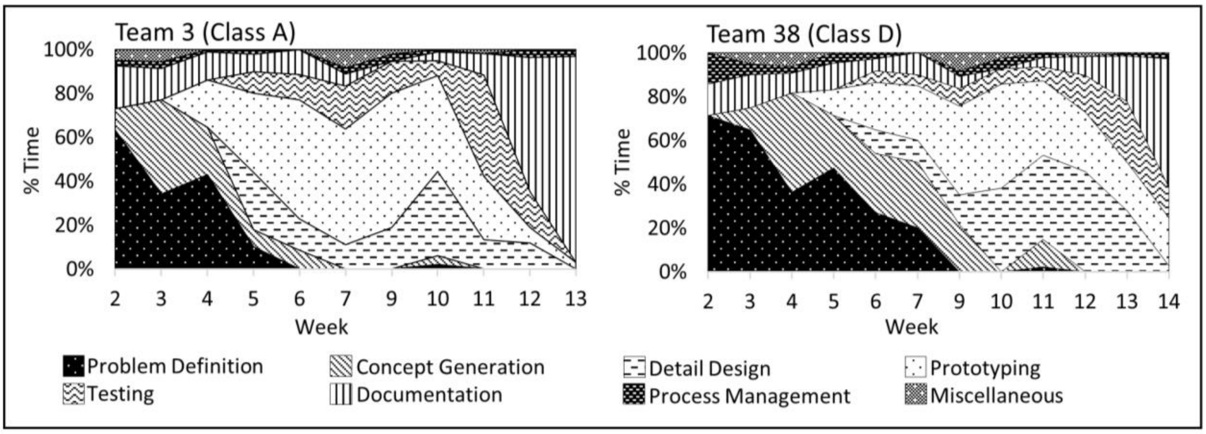

Figure 2 Example data collected through the DEFT system. These are design process plots for two student teams and allow comparisons between teams within a single class, or comparisons between classes.

5. Case study: course evaluation using DEFT

This poster also presents a summary of the results of a case study involving DEFT data from a postgraduate project-based design and innovation class. An analysis of self-reported student design process DEFT data with four teams of students (n=12) was compared with data gathered from an interview with the lead instructor of this class and the researcher's observation notes. The data was analyzed using a framework to evaluate the class efficacy and identify any improvements that could be made for subsequent classes. Assuming that experiential learning correlates with the time spent on design activities, the framework reviewed instructors' expectations of student time on design activities and the time students actually spent during a design project.

The research yielded insights into the relationships between learning objectives and student activity within the class. The primary findings consisted of discrepancies in the instructor's estimations of the percentage of time spent by students and the actual percentage of time that students spent on three key design activities (see figure 3 for detail). These were: 1) Researching, 2) Testing and gathering of feedback, and 3) Documentation. Students spent less time on researching and testing than the estimations of the instructor, however students spent substantially more time on documentation activities than expected.

From analyzing the activity logs, it was apparent that the student activities are driven by their assignments, which was the root cause of the high volume of documentation activities rather

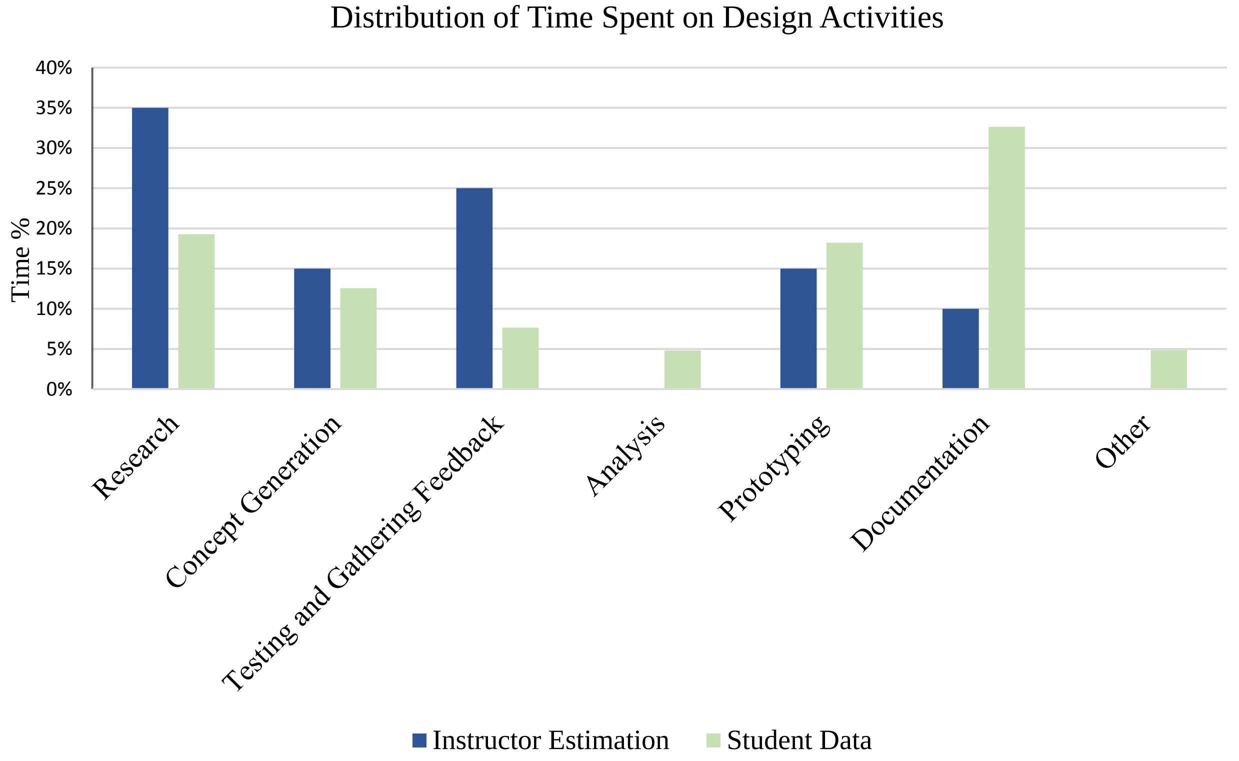

Figure 3. The comparison of the instructor's expectations of time distribution of students on design activities within the project, and the students' self-reported distribution of design activities data.

than research activities. As it is common for students to strategize and focus on deliverables rather than the experiencing of the design process [17], a review of the existing assignments with the instructor was conducted. Using the framework described, specific assignments were identified as detracting from the primary aims of the learning objectives at key points during the design process (detailed in table 1).

The interview also elicited the instructor's estimation of specific weeks that they assumed would cause challenges for the students when working in teams. When this is compared to weeks where students reported reduced satisfaction of their peers (indicative of issues within the team), the instructor's assumptions were mostly accurate, and were also confirmed by the researcher's observations. A primary reason for team dissatisfaction in the early stages of the design process was in the transitional phase from research into concept generation, where teams struggled with translating user needs research into a variety of ideas. Difficulties faced in later weeks were linked to the pressure of the pending deliverables.

The use of the DEFT data proves to be useful in the post-class evaluation and to drive and support any changes to the class. In this case study, the instructor will modify the quantity and structure of assignments to allow students to still focus on the attainment of deliverables, but have the deliverables focus more on design activities that are intrinsic to achieving the desired learning objectives (see table 1 for the proposed assignment changes).

Table 1. A comparison of existing design deliverables and the proposed deliverables for subsequent classes.

Group/Individual	Existing Assignments	% of grade	Proposed Assignments	% of grade
	Process Model Selection	7.5	(Removed)	-
Group	Research and Voice of Customer Report	20	Research and Voice of Customer Report	25
	Design Specifications (Functional Requirements)	7.5	(Removed)	-
	Concept Presentation	10	Concept Presentation	0
	Final Design Presentation	15	Final Design Presentation	15
	Final Design Report	15	Final Design Report (including on testing results)	25
			Prototyping	15
Individual	Reflective Essay No.1	7.5	Reflective Essay No.1	10
	Reflective Essay No. 2	7.5	Reflective Essay No. 2	10
	Design Debate	5	(Removed)	-

6. Conclusions and Future Work

The development of the DEFT system has been iterated and tested substantially with large quantities of students (n=321) and instructors (n=26). In the coming year, we plan to make the tool publicly available and to scale the use of DEFT in large numbers of engineering design courses. It is hoped that this tool will be of use to instructors and students in the future, with both tracking progression within a design class and evaluating their classes after completion and for researchers in collecting supporting data on design processes. In the subsequent year, the data collected through the DEFT system will be used to develop a pedagogical framework and a class efficacy evaluation framework for engineering design.

References

[1] 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.

[2] S. R. Daly, R. S. Adams and G. M. Bodner, "What Does it Mean to Design? A Qualitative Investigation of Design Professionals' Experiences," *J. Eng. Educ*., vol. 101, no. 2, pp. 187-219, Apr. 2012.

[3] J. Ball and T.C. Ormerod, “Structured opportunistic processing design: a critical discussion,”. *Int. J. Hum. Comput. Stud*., vol.43 no.1, pp.131—151, Jul. 1995.

[4] R. Guindon, “Designing the Design Process: Exploiting Opportunistic Thoughts,” *Hum. Comput. Interact*., vol. 5, no. 2, pp. 305—344, June 1990.

[5] G. Fricke, “Successful Individual Approaches in Engineering Design,” *Res. Eng. Des*., vol. 8, no.3:151—165, Sep. 1996.

[6] J. Cuseo, “The empirical case against large class size: adverse effects on the teaching, learning, and retention of first-year students,” *J. Fac. Dev*., 21(1), pp.5-21, Jan 2007.

[7] F. Maringe and N. Sing, "Teaching large classes in an increasingly internationalising higher education environment: pedagogical, quality and equity issues," *High Educ*, vol. 67, no.

6, pp. 761-782, Jun. 2014.

[8] D. Mendez, J. Slisko, "Software Socrative and smartphones as tools for implementation of basic processes of active physics learning in classroom: An initial feasibility study with prospective teachers," *Eur. J. Phys. Educ*., vol. 4, no. 2, 2013.

[9] A. Febrian, O. Lawanto, M. Cromwell, "Advancing Research on Engineering Design using e-Journal," in *ASEE/IEEE Frontiers in Educ. Conf.*, El Paso, Texas, USA, October 21-24, 2015.

[10] M. L. Loughry, M. W. Ohland and D. DeWayne Moore, "Development of a Theory-Based Assessment of Team Member Effectiveness," *Educ. Psychol. Meas*., vol. 67, no. 3, pp. 505-524, Jun. 2007.

[11] A. R. Carberry, H. Lee and M. W. Ohland, "Measuring Engineering Design Self-Efficacy," *J. Eng. Educ*., vol. 99, no.1, pp. 71-79, Jan. 2010.

[12] J. Barbera, W.K. Adams, C.E. Wieman, K.K. Perkins, and D.M. Bunce, "Modifying and validating the Colorado learning attitudes about science survey for use in chemistry," *J. Chem. Educ.*, vol. 85, no. 10, pp. 1435, Oct. 2008.

[13] T. M. Neill, J. S. Gero and J. Warren, "Understanding conceptual electronic design using protocol analysis," *Res. Eng. Des*., vol. 10, no. 3, pp. 129-140, Sep. 1998.

[14] P. Cash, B. Hicks and S. Culley, "Activity Theory as a means for multi-scale analysis of the engineering design process: A protocol study of design in practice," *Des. Stud*., vol. 38, pp. 1-32, May. 2015.

[15] L.L. Bucciarelli, "An ethnographic perspective on engineering design," *Des. Stud*., vol. 9, no,3, pp. 159-168, Jul. 1988.

[16] R.J. Anderson, "Representations and Requirements: The Value of Ethnography in System Design," *Hum. Comput. Interact*., vol. 9, no. 2, pp. 151-182, Jun. 1994

[17] M. Scardamalia, C. Bereiter, and M. Lamon, "The CSILE project: trying to bring the classroom into World 3," in *Classroom Lessons: Integrating cognitive theory and classroom practice*, K. McGilly, Ed, pages MIT Press, Cambridge, MA, 1994, pp. 201:228.