# The Development and Evaluation of DEFT, a Web-Based Tool for Engineering Design Education

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**Abstract**—This article describes the development of 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. The DEFT system collects data through short weekly questionnaires for students and instructors in engineering design classes, and uses these data to produce weekly reports for both types of user. The system is intended to engage students in reflective reporting on their experiential learning, to support educators in coaching student designers, and to serve as a data collection tool for education researchers. DEFT was developed through an iterative design and evaluation process, involving 185 students and 18 instructors at two universities. The system was evaluated using a combination of participation observation, user interviews, and anonymous questionnaires, and the results guided subsequent improvements to the system. This article describes the development and evaluation process, provides an overview of the resulting system, and ends by discussing the potential for DEFT to be used in evaluating and improving project-based design classes.

**Index Terms**—Engineering design education, data collection tools, project-based learning

## 1 Introduction

Project-based design classes are increasingly common in undergraduate engineering programs. Engineering design projects can serve as experiential learning activities, providing opportunities for students to apply their theoretical knowledge in solving practical problems [1]. In contrast to the closed-ended problems with unique solutions that students typically solve in engineering science classes, design problems are open-ended, ill-defined, and involve inherent uncertainty [2], [3]. 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 [4], [5], [6]. 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.

However, developing and delivering effective project-based design classes is not straightforward. The appropriate balance between the flexible and methodical aspects of design problem solving is highly context-dependent, and students require expert coaching to learn to navigate this process. The open-ended nature of design problems means that each student in a particular class may pursue a different solution, requiring a different problem-solving process and a different set of technical knowledge. Thus, each student (or student team) may require personalized guidance and feedback from instructors. In addition, instructors must engage students in reflecting on their learning experiences to develop a deeper understanding of design processes [7], [8], [9]. Reflection is most effective when completed frequently and after appropriate milestones [7], [8], [9], [10]. However, students often find themselves working under severe time constraints to produce graded deliverables; these time constraints can serve as obstacles to frequent and meaningful reflection [11].

The challenges that engineering design educators face in providing personalized coaching and encouraging student reflection are exacerbated by large class sizes and limited resources [12], [13]. In part, these challenges are due to difficulties in monitoring student progress and learning. Thus, providing instructors with data about their students' design processes may aid in tackling these challenges. However, collecting data about design processes is difficult in general. Since the 1960s, the field of design studies has focused on describing and interpreting design processes [14]. The most common research methods used in design studies are protocol analysis [15], [16], [17] and ethnography [18], [19], [21]. Protocol analysis studies involve recording participants "thinking aloud" while solving design problems; the recorded audio transcripts are then analyzed to identify the problem-solving process employed. Ethnographic studies involve researchers collecting qualitative data on designers over a prolonged period, and typically result in rich data describing a small number of subjects. While both methods have yielded insights on the psychological processes involved in design, they are extremely time-consuming and require methodological expertise and are therefore not appropriate data collection approaches for use by instructors in the typical engineering design class.

There is therefore a need for data collection tools that support teaching and learning in project-based design classes by engaging students in reflective activities and providing instructors with timely information about their students' progress and learning. There are some tools that address aspects of these needs. Web-based tools such as Socrative allow instructors to monitor student understanding of class content through live, customizable multiple-choice questions [22]. These systems can be used in conjunction with concept inventories intended to assess students' conceptual understanding of engineering design topics [23], [24], [25]. Peer evaluation systems such as CATME allow instructors to periodically assess student team dynamics in project-based classes [26], [27], while timesheets and e-journals can be used to record students' design activities [28], [29]. A variety of instruments have been developed to collect data about student attitudes and confidence in engineering and science subjects [30], [31]. These data collection tools can play a role in supporting instructors' coaching of students, and engaging students in reflective reporting on their problem-solving processes. However, to the best of the authors' knowledge, there are no available tools that allow instructors to collect detailed and quantitative information about their students' ongoing work practices, in an unobtrusive way, throughout the duration of a design project. This lack of such tools is an impediment to teaching and learning in design classes.

This article presents a new web-based data collection tool for use in project-based engineering design classes. DEFT (the Design Evaluation and Feedback Tool, https://www.deft-project.com) is a web-based system that facilitates frequent student reflective reporting and instructor feedback through short, weekly questionnaires; the system uses questionnaire responses to generate weekly reports for both types of user that includes written and visual

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TABLE 1
Design Iteration and Evaluation History of DEFT

| | Version 1 | Version 2 | Version 3 | Version 4 |
|---|---|---|---|---|
| **Implementation** | Combination of paper-based and online questionnaires | Custom-built web-based system | Custom-built web-based system | Custom-built web-based system |
| **Semester** | Spring 2015 | Spring 2016 | Fall 2016 | Spring 2017 |
| **Location** | USA (Class A) | USA (Classes A and B) | Ireland (Classes C and D) | USA (Class A) |
| **Number of Classes** | 1 | 2 | 2 | 1 |
| **Number of Students** | 14 | 21 | 136 | 14 |
| **Number of Instructors** | 4 | 6 | 9 | 4 |
| **Evaluation methods** | Instructor interviews; participant observation | Instructor and student interviews; participant observation | Instructor interviews; anonymous student questionnaires; participant observation | Instructor and student interviews; participant observation |
| **Major changes to subsequent DEFT version** | Integration of system into custom-built online platform; automation of some data processing and reporting | Instructor and peer rating re-phrased in terms of expectations; student activity logs structured around generic phases of the design process; user interface re-designed | New algorithm for individual student performance ratings developed and tested | Development of more fine-grained instructor feedback methods; student activity logs structured around concrete tasks rather than abstract design process phases |

representations of students' design processes and team dynamics. The system is intended to support teaching and learning in project-based classes, 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 following section describes the process that was used to develop and evaluate DEFT. The subsequent section describes the current DEFT system, the results of the evaluation process, and some potential uses of the system by instructors and researchers.

## 2 Methods and Materials

To date, 185 students and 18 instructors (including teaching assistants) have used the DEFT system in four different mechanical engineering design classes over four semesters at two large universities in the US and Ireland. All classes were project-based, lasted a single semester, and involved teams of students working with stakeholders to identify problems and develop solutions. In each class, weekly review meetings allowed students to update instructors on their progress and to receive verbal feedback and guidance. The classes were selected to represent a variety of teaching and learning contexts, so that the use of the system could be evaluated on different scales and with different types of students. Classes A and B were relatively small engineering design classes involving multidisciplinary teams of students at a private university with class sizes ranging from 10 to 14 students. Classes C and D were larger classes involving teams of mechanical and biomedical engineering students at a public university with class sizes ranging from 38 to 98 students. Classes B and C involved only undergraduate students, while Classes A and D involved both undergraduate and graduate students. In Class A, multiple cohorts of students across multiple semesters used different versions of the DEFT system, enabling direct comparisons to be drawn between each version. Student compliance with DEFT was excellent, with all students $(n = 185)$ engaging with the tool during their project, with an average weekly student response rate of 94 percent across all classes. This high compliance was possible because instructors treated the weekly DEFT student entries as required student assignments.

Each semester, an evaluation of the system was conducted through a mixed-methods study design. The lead author acted as a participant observer in all classes and recorded the experiences of students and instructors using the system. At the end of each semester, interviews or questionnaires were used to elicit feedback from users of the system, and to gain further insight on the observations recorded during the semester. Interviews were conducted with instructors from all classes, and with 92 percent of students from Class A. Student interviews were conducted after grades had been released, to ensure that students' responses were not influenced by concerns about grades. Since classes C and D contained much larger student cohorts, it was not feasible to conduct interviews with students in these classes. Instead, anonymous web-based surveys, separate from DEFT, were used to gather feedback on student experiences with DEFT; 33 percent of students in Class C and 58 percent of students in Class D provided responses to these feedback surveys. This research was approved by the Harvard University Committee (IRB16-0370 and IRB17-0612) on the Use of Human Subjects in Research and the University College Dublin Human Research Ethics Committee (LS-E-16-165-Moyne-Holland).

The lessons drawn from each evaluation were used to redesign the system in time for use in the subsequent semester. The DEFT system began as a set of paper-based and online questionnaires, with data processed manually each week to prepare reports for students and instructors.

Through an iterative design and testing process, a web-based version with automated data processing and reporting was subsequently developed. Table 1 provides an overview of the iterative process followed and the major changes to the system between each iteration. Each iteration was tested over one full semester; the system remained consistent throughout each test.

## 3 Results and Discussions

### 3.1 DEFT System Overview

The iterative development process described above has resulted in a custom-built web-based system intended to support teaching and learning in project-based engineering design classes. The system was built using the MEAN stack (MongoDB, Express.js, AngularJS, and Node.js), allowing both the server and client-side code to be written almost entirely in a single language, JavaScript. The back end of DEFT consists of a webserver running in the Node.js environment utilizing Express.js to handle HTTP requests and serve bare bones webpage templates to the user when they visit the website. The templates sent to the user do not contain any data, therefore in addition to the templates, the user is sent AngularJS controllers that dynamically populate and update the page by fetching data from the webserver. A MongoDB instance provides a NoSQL document-oriented database to hold all user data and a RESTful API is used to get data from and store data to the database. The system uses other Node.js libraries to perform useful

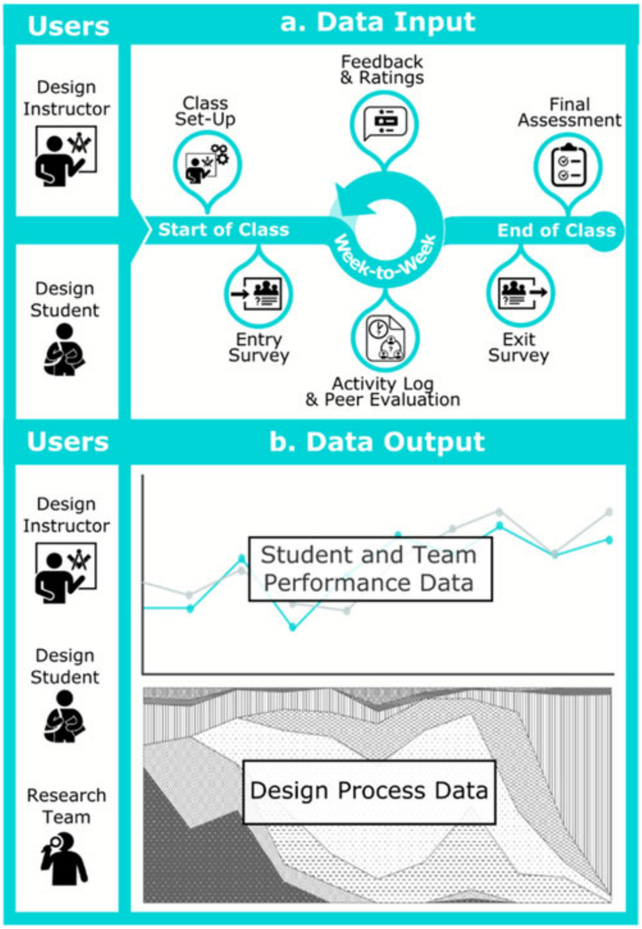


Fig. 1. (a) The types of data collected by DEFT from particular users at specific points along the phases of a design class. (b) The users and types of DEFT data output that they can engage with.

functions, including d3.js to achieve real-time plotting of data-driven SVG graphs in the browser.

As shown in Fig. 1, user interactions with the DEFT system can be grouped into three phases: the start of a class, the weekly interactions during the class, and the end of the class. At the beginning of a class, the instructor creates a DEFT instance by completing a short set-up questionnaire. This questionnaire allows the instructor to choose appropriate settings for the system, and gathers contextual information about the design class, including engineering discipline, student level, and learning objectives. Students in the class can then sign up to the system by completing an entry questionnaire, which collects background information about the students including their self-reported level of experience in project- and team-based classes, their attitudes towards design, and their level of confidence in undertaking engineering design projects. This student questionnaire contains items adapted from the education research literature [28], [29]; instructors also have the option to add custom questions to this entry questionnaire.

Each week during the project-based design class, DEFT collects data on the design process followed by each student in the class, and on the quality of the work produced by students. These data are used to produce reports for instructors and students, supporting monitoring of student progress and feedback from instructors. Fig. 2 depicts the weekly flow of information between instructors and students using DEFT. Each week, after completing work on their project, students respond to a short questionnaire. This weekly questionnaire asks students to describe the project-related activities undertaken that week, and to estimate the amount of time spent on each activity. These questions encourage students to reflectively report on their design process and on their allocation of

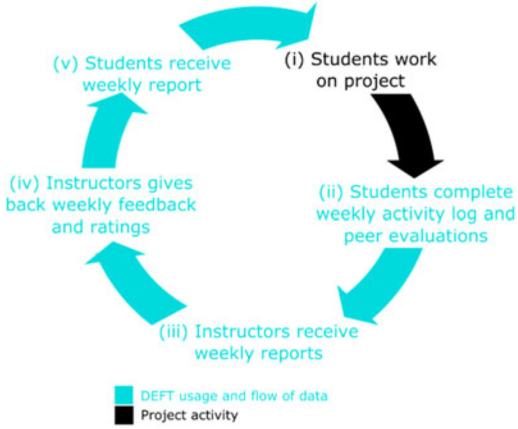


Fig. 2. Flow of information during a typical week with DEFT.

time and effort to project-related activities. Students also provide data about their level of satisfaction with their own work, and feedback on the work of their teammates.

After students complete their weekly DEFT form, the system generates a report on each team for instructors. The report contains students' accounts of their design activities design activities, bar charts of the team's time distribution of design activities from the previous week, a plot displaying the team's design process throughout the project, a plot displaying peer ratings throughout the project, and a plot displaying the instructor ratings of the student team's progress to date in the class. These reports enable instructors to identify potential problems in the work of each team, and to provide appropriate feedback and guidance. As the class progresses, the data collected continues to grow, and trends in performance, group time management, and team dynamics became apparent. Following each weekly review meeting with students, instructors complete a short questionnaire in which they provide advice for tasks to be undertaken during the following week and rate the team's overall progress and quality of work, the team's application of advice given by instructors in previous weeks, the team's initiative, and the team's preparation for their weekly meeting. An example of the student and instructor weekly questionnaires can be found at http://www.deft-project.com/demo.

The instructors' responses are combined with the data from the weekly student questionnaire to generate a weekly report for each student. This report contains information about how their group's work is perceived by their instructors, a visualization of their allocation of time to project activities, and advice for the coming week. The feedback augments the verbal guidance that students receive during their weekly review meetings with instructors. The report is intended to support students in reflective reporting on their work in the class and identifying potential problems, thereby supporting experiential learning.

At the end of the class, students complete an exit questionnaire containing many of the same questions as in the entry questionnaire. As before, instructors have the option to customize the questionnaire to best suit their particular class. The resulting data can be used to compare responses between the start and end of the class, and thereby to 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. Table 2 provides an overview of the data collected by DEFT at the start and end of each class.

### 3.2 DEFT System Evaluation and Refinement

This section describes some of the main results from the iterative design and evaluation process used to develop DEFT, and provides a rationale for some of the design decisions taken for the system. Overall, the feedback from students and instructors has been

TABLE 2
Contextual Data Collected During the "Start of Class" and "End of Class" Phases from Both Instructors and Students

| | Start of class | End of class |
|---|---|---|
| **Instructor** | • Class discipline, level and context<br>• Learning objectives | • Team grades |
| **Student** | • Design self-efficacy<br>• Attitudes towards design<br>• Previous experience with design and teams | • Design self-efficacy<br>• Attitudes towards design<br>• General class experience |

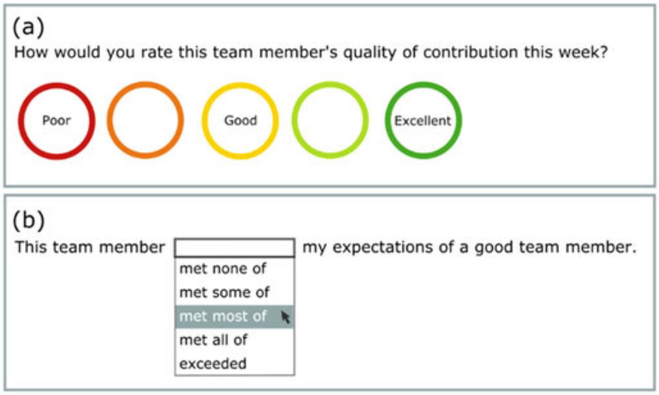


Fig. 3. (a) Excerpt from version 2 of the weekly student questionnaire. (b) Excerpt from version 3 of the weekly student questionnaire.

positive, with the majority of users indicating overall satisfaction with each version of the system. Students indicated appreciation for the activity-logging features of DEFT, as well as the increased frequency of feedback compared to other classes which did not use DEFT. Student interviews indicated that they used DEFT weekly reports as an aid for individual reflection and for team meetings, allowing them to focus their team discussions on guidance and feedback from their instructors. In the larger classes (Classes C and D), where instructors had less contact time with individual students, users found the DEFT reports particularly useful. The lead instructors from Classes C and D indicated that DEFT allowed them to monitor student team dynamics via the students' peer review data and intervene where necessary, to an extent not previously possible in these classes.

The system also proved useful during disputes over grading. In one of the larger classes, the instructor received complaints from students who believed their project grade should be separated from that of their teams and evaluated on their individual contribution, which the students deemed more significant than their teammates. The instructor used the DEFT activity logging and peer evaluation data to identify the project deliverables that caused problems with team dynamics, and to gauge the contribution of each team member to those deliverables. This enabled the instructor to have more productive discussions with students about their grades, and to re-evaluate or defend grades accurately.

To illustrate the process of design and evaluation used in developing DEFT, the remainder of this section describes changes to the system between Class A in 2016 (DEFT version 2) and 2017 (DEFT version 4), and compares the data collected through and about these versions. These versions were chosen for comparison as Class A is the only class to date in which different versions of DEFT have been used; as other aspects of the learning environment were largely unchanged between both years, this is the most reliable method available to test the effect of alternate DEFT designs. Table 3 summarizes the main results of changes to the system between 2016 and 2017. As a result of refinements to the system, overall student satisfaction with DEFT increased from 60 percent $(\mathrm{n} = 10)$ to 91.6 percent $(\mathrm{n} = 12)$.

The main challenge encountered throughout the development process has been the design of questions that elicit accurate data from users. For example, in both the student and instructor weekly questionnaires, users are asked to rate the performance of students on a 5-point scale. In version 2 of DEFT, this question used a color-coded scale ranging from "Poor" to "Excellent" (Fig. 3a). Interviews with users indicated that the phrasing and layout of the question encouraged grade inflation, as any rating less than "Good" was perceived as overly negative. To address this problem, user feedback was gathered on alternative question phrasings and layouts and a new design for the question was selected. The new question eliminates the color coding and uses a "fill-in-the-blanks" format, in which users indicate how a particular student's work matches their expectations of a good team member or student (Fig. 3b).

The effect of the new question was evaluated by comparing data from Class A in 2016 (when the old question was used) and 2017 (when the new question was used). Using an independent-samples t-test, a significant decrease was observed in the mean instructor rating of student teams from 2016 $(\mu = 3.055,\ \mathrm{SD} = 0.928)$ to 2017 $(\mu = 2.84,\ \mathrm{SD} = 0.723)$; $\mathrm{t}(237) = 2.05,\ \mathrm{p} = 0.041$, indicating that the new question may have reduced the pressure to inflate grades. A similar comparison of the data for the student peer rating in 2016 $(\mu = 3.83,\ \mathrm{SD} = 0.756)$ and 2017 $(\mu = 3.76,\ \mathrm{SD} = 0.943)$ found a non-significant decrease in the mean rating, $\mathrm{t}(955) = 1.32,\ \mathrm{p} = 0.188$, indicating that students still tended to rate their peers highly. However, the larger standard deviation in the 2017 peer rating data may indicate that the new question encouraged students to use a wider range of peer ratings.

The weekly reports provided to students in versions 2 and 3 contained information about how their work was perceived by their teammates and instructors. A potential risk in providing this information is that it could increase the pressure to inflate peer ratings. Given the consistently high peer ratings discussed above, a second potential risk is that students could have an inflated perception of the quality of their own work. Finally, by focusing on individual performance in a team-based environment, this data was observed to have a detrimental effect on team cohesion. To address these problems and encourage collaborative problem solving, the latest version of the student report does not contain any data about individual performance. Instead, students are presented with team data only.

The activity-logging component of the student weekly questionnaire also went through multiple iterations during the development of DEFT. Interviews revealed that in the 2016 offering of

TABLE 3
Change in Student Perception and Interactions with DEFT Modifications

| | Class A 2016 (DEFT V2 n=10) | Class A 2017 (DEFT V4 n=12) |
|---|---|---|
| Students satisfaction with DEFT | 60% | 91.66% |
| Students who perceived pressure to inflate hours in activity logs | 60% | 9% |
| Students who claimed to be completely honest in activity logs and peer evaluations | 50% | 100% |
| Mean instructor rating of teams (Min = 1; Max = 5) | 3.06 (SD 0.928) | 2.84 (SD 0.723) |
| Mean student peer evaluation (Min = 1; Max = 5) | 3.83 (SD 0.756) | 3.76 (SD 0.943) |

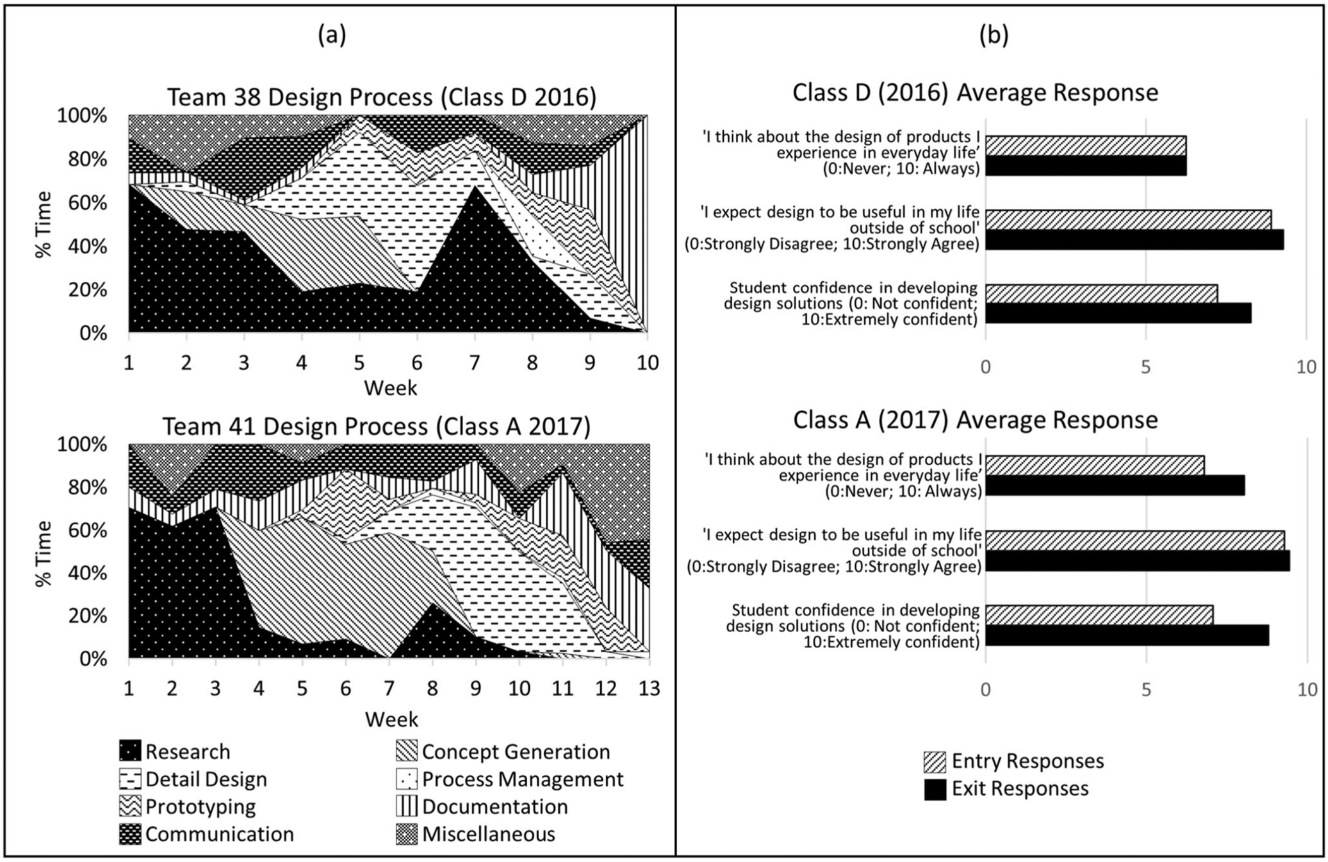


Fig. 4. Example data collected through the DEFT system. (a) Design process plots for two student teams. These plots allow comparisons between teams within a single class, or comparisons between classes. (b) Extracts of entry and exit questionnaire data from two classes. These data allow changes in student responses over the duration of a class to be visualized.

Class A, 60 percent of students perceived pressure to inflate their project hours as a result of knowing that their instructors could view their activity logs, and only 50 percent of students claimed to be honest in completing their activity logs. This finding raised concerns about the validity of the design process data. However, these students also indicated that when they inflated their hours, they tended to do so consistently across all activities. As a result, the instructor and student reports were designed to present only the relative allocation of time between tasks, in which the time spent on each activity is expressed as a percentage of the overall time spent on the project. In versions 3 and 4 of DEFT, it was made clear to student users that the system would only provide instructors with this relative breakdown of activities. When DEFT version 4 was used in the 2017 offering of Class A, only 9 percent of students indicated that they perceived pressure to inflate the time spent on activities, and 100 percent of students claimed to be honest in completing their activity logs. While it is still expected that at least some students will exaggerate the amount of time spent on project activities, the focus on the relative distribution of time is hoped to minimize the effect of such exaggeration.

### 3.3 Uses of DEFT Data

Beyond its role in encouraging student reflective reporting and enabling frequent feedback between instructors and students, a major aim of DEFT is to support improvements to engineering design education by providing data for instructors and education researchers. The system collects data that can be used to compare outcomes of multiple offerings of a single class or compare across similar design classes at different universities (Fig. 4). Engineering design is inherently variable across different projects, but DEFT creates a framework for comparison across multiple projects and classes. Data from DEFT classes are accessible to instructors after their classes have finished, allowing comparison with other data (e.g., project grades) to identify relationships between teaching methods, student design processes, and learning outcomes. Instructors can view student performance ratings throughout the class and match those with time process data from student activity-logs (Fig. 4a) to get an understanding of where students are using their time during the class and how that affects student performance. Additionally, by viewing data from the entry and exit questionnaire, instructors can view how students feel about the class and their own abilities after taking the class (Fig. 4b). For example, if students report low confidence in their ability to "communicate a design", an instructor may give more focus to lessons on presentations or written reports in subsequent versions of the class.

For researchers, DEFT provides a tool to study how design is taught, learned, and practiced in various learning environments. The system is not intended as a replacement for methods such as ethnography and protocol analysis studies. Rather, it is intended to augment such methods by providing an additional source of data. To study the impact of team dynamics on design processes, researchers can compare trends in student peer scores across semesters. Students tend to rate each other very highly, so teams that are having internal problems might see a sharp decrease in peer ratings from one week to the next. Comparing individual activity-log plots to team-wide activity-log plots allows researchers to see where students are working together on solutions and where they are working separately. Additionally, DEFT collects contextual data about students and classes, such as discipline, student level, demographics, learning objectives, and class size, allowing the data gathered through DEFT to be used to compare design classes with different learning environments. The data collected by DEFT can be used to study a variety of research questions, such as the differences in design processes in large design classes versus small classes, the impact of project timelines on design processes, the effect of teaching methods on student attitudes, and the impact of student team makeup on design processes.

## 4 Conclusions

This article has presented the DEFT system, which was developed in response to the needs of instructors, students, and researchers in project-based engineering design education. The aim of the DEFT system is to provide a valuable teaching and learning tool, while also gathering research data on design processes and providing rich, contextual detail of learning environments. The system is now being made freely available to users at https://www.deft-project.com; all interested researchers and design instructors are invited to use DEFT and to provide feedback to help shape the future of the system.

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