# An Evaluation of an Engineering Design Class using Mixed Methods Techniques

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Project-based design classes are increasingly common in undergraduate engineering programs. However, educators face challenges in developing and implementing structured programs that allow for the inherently open-ended nature of design processes while ensuring that students achieve the intended learning objectives. In part, these challenges are due to difficulties in monitoring student activities in classes where each student may pursue a different design problem and solution, and where the majority of class activity takes place outside of scheduled contact hours. To date, it has been almost impossible for educators to directly compare the actual design processes followed by students working on different teams, to each other and to intended learning objectives.

This paper presents a method for evaluating the efficacy of project-based design classes. It describes a case study using data from a project-based engineering design class in a graduate engineering program. The research consisted of an interview with the lead instructors of the classes (n=1), observation of the class weekly progress, and design process data of four student teams (n=12) gathered using a web-based tool, the Design Evaluation and Feedback Tool (DEFT). The data was used to evaluate the experiential learning course by analyzing the time and activities student underwent. The paper concludes by outlining modifications that will be made to the class based on this analysis. It is hoped that other design educators and researchers could benefit by using the proposed framework for the evaluation of project-based design classes. Future work involves using this analysis framework to compare and analyze design classes from two different universities in different countries, to understand the impact of the educational environment on student learning and design activities.

## I Introduction

Project-based design classes are a common element of an engineering degree program, as they provide experiential learning opportunities. Design problems facilitate students' implementation of their theoretical learning into practical application of solving open-ended, uncertain problems, developing their critical thinking, problem-solving and creative skills [1, 2]. These ill-structured problems are typically in stark contrast to students' prior experience of close-ended problems with specific solutions in typical engineering science classes [1, 3, 4]. This paper is concerned with a graduate engineering design classes which involve students undertaking a significant, semester-long design project. These classes are not focused on teaching fundamental engineering science knowledge, but on providing an opportunity to rehearse professional design knowledge with guidance from an expert instructor.

Due to the inherent uncertainty and complexity of design problems, a project-based design course is challenging to develop and implement, and requires substantial personnel and resource support from the leaders of engineering departments and schools [5]. One challenge in design education is the evaluation of project-based courses; it is difficult to measure the impact of such courses on student learning. To successfully measure the influence of experiential learning on tacit knowledge, two types of data are desirable: data describing the activities and experiences of the students; and data describing the changes in student knowledge as a result of these experiences. Unfortunately, collecting either type of data in a project-based design class is non-trivial.

Collecting data on design processes is difficult in general. The most favored data collection methods are protocol analysis and ethnographical research methods. Ethnography is effective at gathering data on authentic design processes [6, 7]. However, it is difficult to apply this method in an educational context, considering that large quantities of the design activities are conducted outside of the classroom. Protocol analysis is useful for collecting data on specific elements within a project, and the set-up of a study typically consists of creating a contrived design project constrained by an arbitrary timeframe [8, 9]. This has yielded insights into the psychological processes involved in design, however it is time consuming, and is not always appropriate for data collection or analysis of design classes [10], nor useful for instructors attempting to evaluate their own classes. A design-specific e-journal is available to collect project-based design data from authentic class projects [11]. The data is very rich in context as the students treat it like an electronic design notebook, however it requires researchers and expert designers to retrospectively code the tasks that were documented in the journal, and does not collect quantitative data regarding time distribution of students on design processes, or gather data on student self-efficacy in design.

There is an assortment of tools intended to monitor student understanding of class content through in-class quizzes [12], and to capture students' conceptual understanding of engineering concepts [13-15]. Other tools collect intermittent peer evaluations [16], and student self-efficacy in design skills [17]. However, these tools do not give a direct measure of students' design process learning, nor do they collect the process-related data needed for educators to investigate the effect of the students' experiential learning of design processes. There are also instructor self-efficacy tools that cover general teaching tasks [18], specific academic areas such as science [19] and the teaching of design engineering within STEM and third level education [20, 21]. However, these tools are only intended to measure instructors' perception of their own teaching abilities and cannot provide a direct measure of the learning outcome of students.

Thus, there is a need for a new framework in evaluating a project-based design class that is taught using experiential learning methods. This is almost impossible in this type of design class, as the experiential learning activity (the project) is the same as the assessment activity. This paper does not solve the problem of directly measuring learning outcomes from project-based design experiences, but presents an additional new method for evaluating this type of class. An implicit assumption of experiential learning environments is that a correlation exists between time spent on an activity and learning related to that activity. The evaluation method that we present here involves collecting data on the instructor's expectations of how students in a project-based design class spend their time, and comparing this to data describing the actual work processes of students throughout a semester-long project. Our proposal is that this evaluation method of a project-based design class could be used in conjunction with the other teaching tools described. The following section describes the methods used to identify, gather and analyze the data, and provides a description of the case-study class.

## II Methods

In this research data was gathered through observations of students in their learning environment, DEFT (the Design Evaluation and Feedback Tool, https://www.deft-project.com), and interviews with the lead instructor focusing on the class's desired learning objectives and their expectations of time spent by students on design activities. The analysis consists of the comparison of the quantitative data of actual time spent versus the instructor's expected time spent.

### The Design Class and Participants

The course was selected because of the emphasis on the teaching design processes and activities through experiential learning by applying theories and processes into practice through a group design project. The module is part of a postgraduate program for engineering management, and is 13 weeks long. It uses a combination of lectures and team meetings between the students and instructors. The course was delivered by two instructors, both with substantial experience in product and mechanical design. The content and structure of the lectures supported each stage of the design process that students underwent.

Contact time between students and instructors consisted of nine one-hour lectures, nine one-hour tutorials and two two-hour student presentations. The design project began in the second week, spanning 12 weeks of the module. The research participants consisted of 12 mature students, ten men and two women. Each with industrial experience in engineering of between five and twenty years. Their engineering backgrounds were varied, with only one having prior product development experience, while the remaining eleven consisted of mechanical, electrical and civil engineers.

Student deliverables consisted of both group and individual assignments and are detailed in Table 1. Students were randomly assigned into four teams of three and each team was given the same brief. The project brief, amounting to 75% of the students' grades, required students to identify and design a solution for an unmet need for parents of young children, aged between 0-36 months. The solution could be focused for either the parent or child, but it had to deliver a significant lifestyle, health or convenience benefit to the parent, and also have a maximum manufacturing cost of €300 (approx. $370). Unusually, for an engineering design course, both products and services were accepted for proposed solutions.

The brief was deliberately designed to be open-ended to facilitate student engagement with users and stakeholders, and force students to critically identify their solution direction, based on their user-focused research. Students were expected to develop their concept through involving stakeholders, developing prototypes, and validating solutions through user feedback.

*Table 1 The list of student deliverables and deadlines for the case study design class.*

| Group/Individual | Assignment | % of grade | Deadline (Week) |
|---|---|---|---|
| Group | Process Model Selection | 7.5 | 2 |
| | Research and Voice of Customer Report | 20 | 4 |
| | Design Specifications (Functional Requirements) | 7.5 | 5 (draft) and 9 |
| | Concept Presentation | 10 | 6 |
| | Final Design Presentation | 15 | 10 |
| | Final Design Report | 15 | 11 |
| Individual | Design Debate | 5 | 0 |
| | Reflective Essay No.1 | 10 | 5 |
| | Reflective Essay No. 2 | 10 | 11 |

## Data Collection Methods

DEFT is a web-based system that facilitates frequent student reporting of their design activities and peer reviews, and instructor feedback through short, weekly questionnaires. The system generates weekly reports for both types of users by collating the weekly questionnaire responses from both instructors and students. The weekly reports consist of written and visual representations of students' design processes and team dynamics. DEFT is intended to support teaching and learning in project-based classes, to serve as an aid for instructors in evaluating and improving their project-based design classes, and to provide a new data collection method for education researchers [21].

The quantitative data gathered in the design class, such as the student weekly activities, the student entry and exit survey data regarding their prior experience in design and their attitudes towards design, and the instructor weekly feedback of the teams' project progression are a key focus of this data analysis. The DEFT data is self-reported by the students and efforts have been made to validate the accuracy of this data, in particular with the student coding of their design activities. Two researchers, both involved with the delivery of the class, validated the suitability of the codes by independently coding authentic student activities for the duration of the class. A percentage agreement of 97.54% was reached between the researchers and the students' codes, with a Cohen's Kappa of 0.8915, resulting in an almost perfect agreement.

Qualitative data was collected by the lead researcher, in two methods. The lead researcher observed weekly group meetings between the instructor and students. The discussions were recorded in written notes, with the data consisting on the verbally reported activities of the students, their perceived progress and challenges faced on the project and advice given by the instructor. This data was analyzed and used primarily for data triangulation for this research.

An interview was conducted with the lead instructor and was audio recorded. The interview was structured into three sections with the first section discussing the detail of the goals and learning objectives of the design class, how the instructor knew if these were achieved, and what methods of evaluating the success of a class are used.

The second section of the interview, the instructor provided quantitative estimations of three aspects of the student experiences in the design class. These were: 1) How much time they expected the students to spend on design activities, 2) Where do students might face difficulties within the design process and 3) The change between the student entry and exit self-efficacy questionnaires.

The third section of the interview consisted of reviewing the instructor's estimations and the data collected by DEFT on each of the three aspects of the student experiences, and developing modifications for the class in the subsequent year. All data collected was approved by the Harvard University Committee on the Use of Human Subjects in Research and the University College Dublin Human Research Ethics Committee.

## III Results and Discussion

During the interview, the instructor provided quantitative estimations of expected time lengths that the students spend on design activities, and where students might face difficulties within the design process.
The framework used to analyze this data set flows occurs in three steps:

1. The expected and actual time spent by student on each activity.
2. The expected and actual weeks where problems arise in a design project.
3. The expected and actual changes in student self-efficacy of design skills and processes as a result of the class.

Figure 1 identifies three activities with a large discrepancy between the instructor's estimations and the students' actual time spent by students. These are "Research", "Testing and Gathering Stakeholder Feedback" and "Documentation". The instructor expected that students would spend 35% of the time researching, 30% of their time testing, and 15% of their time documenting their work through assignments and presentations. However, students

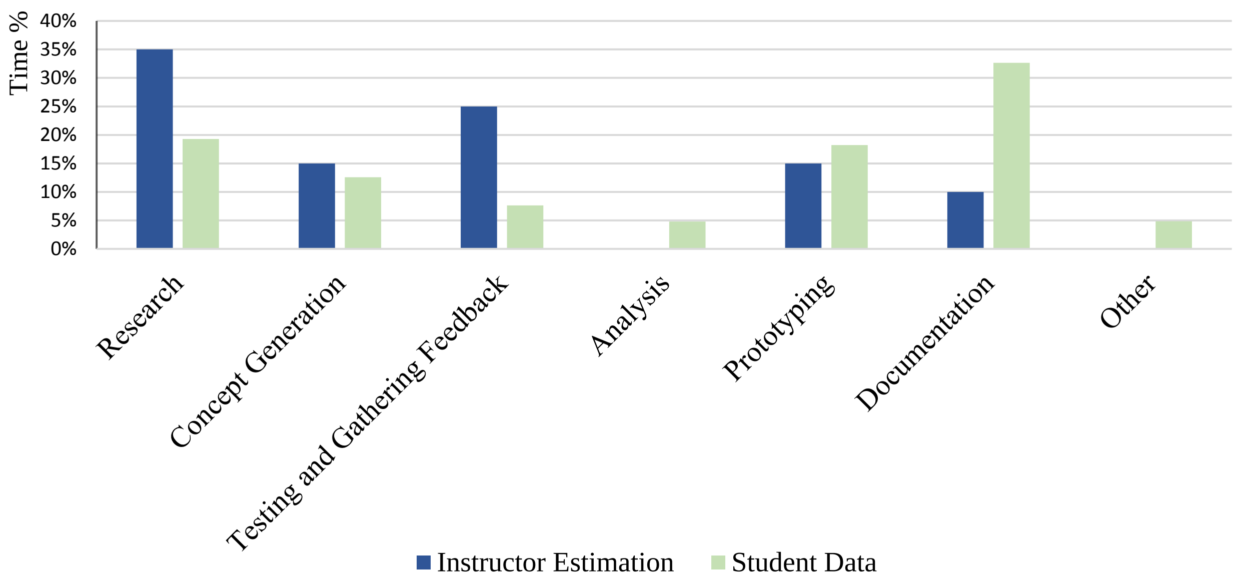


*Figure 1. The comparison of the instructor's expectations of the distribution of time spent by students on design activities within the project, and the students' self-reported distribution of design activities data.*

actually spent 19.28% of their time researching, 7.64% of their time testing and 32.64% of their time documenting their work. This indicates that students are not spending time on key design learning objectives, such as stakeholder testing or research, but spending time on their graded assignments.

When this is compared to the relative distribution of the activities throughout the class weeks, documentation features more than the instructor expected, in particular in weeks two, four, five, and six where students had the assignments due of "Design Process Selection", "Personal Reflection No. 1", and the "Concept Presentation". Researching featured largely in weeks two and three, but reduced substantially by week four, which was unexpected by the instructor. In week 4, the students' focused on documentation with 32.64% of that specific week's activities.  This is an understandable change of focus considering the "Research and Voice of the Customer Report" was due in week four.

Testing played a small role in the class's overall design process, but featured in weeks two until week 10, although only consisted of 2-10% of any week's activities. The frequency of testing across the weeks of the projects was expected by the instructor, however the overall percentage of the time spent on testing was substantially less that what the instructor desired. Any analysis activities, such as Finite Element Analysis, were unexpected by the instructor, due to the module's emphasis on problem identification and conceptualization.

The interview disclosed two core learning objectives; (1) develop client management skills through problem-solving with stakeholders, and (2) develop design process skills. These two objectives are considered essential and transferable skills for an engineering manager. These learning objectives are evaluated by assessing students' achievement in gathering input from stakeholders, iterating concepts based on stakeholder feedback, allowing the project and

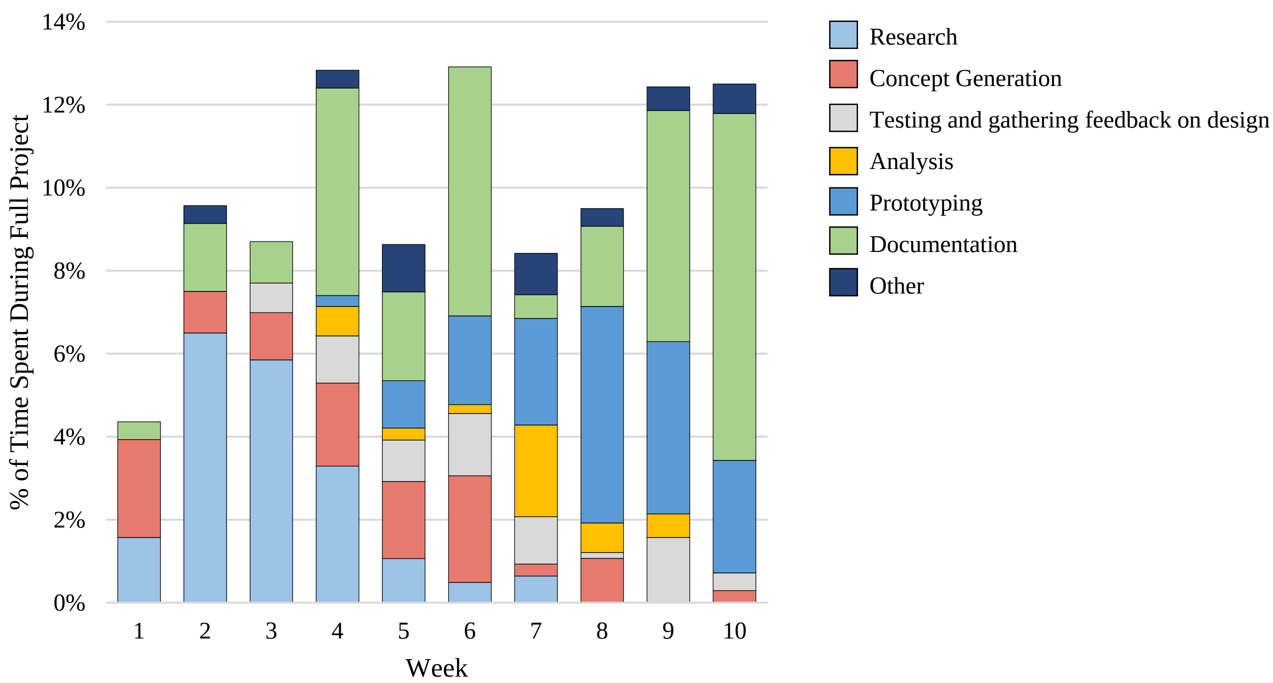


*Figure 2. A breakdown of the students' design activities for each week of the design project.*

solution to be chartered by the stakeholder, all whilst documenting their processes in assignments.

These learning objectives are evaluated by assessing students' achievement in gathering input from stakeholders, iterating concepts based on stakeholder feedback, allowing the project and solution to be chartered by the stakeholder, all whilst documenting their processes in assignments. This highlighted the belief that if the learning objectives are achieved, then the assignments have been fulfilled. However, the researcher observed that specific assignments, such as the design process selection and the design specifications, were considered by students as "tick-the-box-assignments" and were not reviewed by the students post submission despite the usefulness for the progress of the project. For example, all teams identified a process model that they expected to be useful for their design process such as a stage-gate process, however no teams implemented or discussed their selected process after week four. All teams proceeded to plan their projects based on the assignment deadlines, rather than their selected process model. Observation also identified that the selected process models may not have been applicable for their resultant projects, but this was due to the student teams' inexperience in design to select a relevant model.

A similar finding was observed for the design specification assignment. The purpose of this document is to translate functional requirements into specifications, to ensure there was documented rationale for their designs. However, students did not use the assignment as a useful tool for their design process. They focused on the presentation of this document, rather than the gathering and validation of the design specifications through testing. The translation of functional requirements into specifications was challenging for the students, but it fundamentally stemmed from their lack of experience in the development of functional requirements. There was no assignment for students to develop functional requirements, therefore, they did not complete this step sufficiently, resulting in their struggled efforts of generating design specifications and lack of referral to the design specifications in the final team reports.

Table 1 explains that no grade is allocated for the teams' progression (captured through the weekly instructor DEFT questionnaires) throughout the design process or for prototyping. It was observed that some teams who spent substantial effort on their designs and prototyping, created a validated design solution but less substantive assignments, resulting in a lesser grade. Other groups that submitted high quality assignments received higher grades, despite having very little emphasis on prototyping and testing. Prototyping and testing are considered fundamental activities and was encouraged during the weekly instructor and team meetings, however as a grade is not allocated for these activities, the uptake on the prototyping varied between teams. This strategizing of students to focus on deliverables rather than the experiencing of the design process is common amongst students, with Scardamalia identifying that students *"minimize time to complete tasks, and the most likely way to do this is by trimming away activities that do not directly yield the deliverable product. In the case of research papers, this means minimizing research… In the case of a reflective essay, this means minimizing reflection."* [23].

The interview also reviewed instructor's perceptions of problems faced by the student groups with the design processes. The instructor estimated, based on their prior experience of teaching design, to identify the weeks of the project that he considered problems to occur amongst the student groups. He identified weeks 5-6 and 9-10, explaining that during weeks 5-6, the students had concept presentations and their personal learning reflection due in these weeks, and during weeks 9-10, they had their final presentation and report deadlines approaching, which usually caused dynamic issues amongst teams as pressure mounted. This was then compared to an analysis of the weekly peer evaluations of the student groups. A problematic issue was identified and counted, when either one or multiple team members were ranked substantially lower than their peers. Weeks that were identified as being most problematic for groups were weeks five, seven, eight and nine. With a 33% match of estimated problem occurrence and actual occurrences, the most obvious finding from this analysis is that students experience dynamic challenges for most of the latter half of the project. This isn't caused by a single outlier team, but multiple teams experienced challenges throughout these weeks.

In addition to this, it was observed that there was a variance in abilities of students to critically reflect on their activities or the design process that they were undergoing. The student reflection reports confirmed this spectrum of reflective capabilities, although it was noted that this particular cohort of students repeatedly asked what the purpose of the reflective reports were and subsequently asked for guidance in completing them.

## Proposed Class Modifications

There are no simple solutions in addressing the problem of evaluating project-based design classes. However, this paper shows a framework that may be used to help retrospectively evaluate if student activities are reflective of the desired experiences for the learning of design processes.

Students require assignments to focus their learning, but the question is, does the inclusion of too many assignments detract from the intended learning experience? The data gathered in this class suggests that some assignments are perceived by students as "tick-the-box" exercises, and do not add value to the learning experience of the key learning objectives. To address this, the list of assignments for this class will be reduced to a minimum quantity of group and individual assignments. The "Process Model Selection", the "Design Specifications", and the "Design Debate" assignments will be removed as independent assignments. Design specifications in particular needs to be removed as an independent assignment and more emphasis placed on the translation of user needs into functional requirements during the "Research and Voice Of Customer Report". This is a vital step that provides a foundation for students to develop solutions, and contributes to the attainment of the desired learning objectives.

The individual grade for debating the design integrity of specific products does not contribute sufficiently towards the learning objectives, nor did the small contribution of 5% to their overall grade incentivize students to complete it well, consequently it will be removed from the assessment deliverables.

*Table 2 Proposed assessment deliverables for the subsequent class*

| Group/Individual | Assignment | % of grade |
|---|---|---|
| Group | Research and Voice of Customer Report | 25 |
| | Concept Presentation | 0 |
| | Prototyping | 15 |
| | Final Design Presentation | 15 |
| | Final Design Report (including testing results) | 25 |
| Individual | Reflective Essay No.1 | 10 |
| | Reflective Essay No. 2 | 10 |

To encourage students to test and iterate their design, testing will be an emphasized component of the final report. The instructor weekly rating of team progress, documented by DEFT, and prototyping efforts will also be included as part of the team assessment model to fairly assess groups who focus on the design process rather than just the assignments. The proposed structure for deliverables for this class can be found in Table 2. To further reduce the focus of students on documentation for deliverables, it suggested that a suitable page limits are applied to all written assignments. It is also suggested that students may benefit from receiving a more refined structure to guide their reflective reports, by providing them with suggested open-end questions to stimulate an effective reflection.

By using this framework and supporting data to evaluate the efficacy of this class, it has been possible to propose a new structure of the deliverables. It is still expected that the focus of the students will still remain on attaining and using the deliverables to guide their design process, but the new structure of deliverables is expected to improve the attainment of the learning objectives. The modified class will be implemented in the Fall Semester of 2018 and will be further assessed using the same framework.

## IV Conclusion

The evaluation of a design class’s learning objectives is difficult to complete due to the inherent uncertainty of design processes and the tacit learning that occurs is difficult to quantify. However, by using the data from the DEFT tool and the framework for analyzing the data, it is possible to objectively evaluate and compare expectations and authentic student data, draw conclusions regarding the impact of class assignments on learning objectives quickly and succinctly, and identify areas for improvement.

This particular analysis suggests that a design class’s assignment quantity should be reduced to a minimum to further facilitate and focus students’ experiential learning of design processes. It is hoped that this tool and suggested framework will be of use to instructors in the future with tracking progression within a design class and evaluating their classes after completion, and researchers who are engaged in improving engineering design education.

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