

Student focus and prioritisation of design parameters in first-year Engineering design projects

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Structured abstract

BACKGROUND

Research on engineering design is a core area of concern within engineering education and a fundamental understanding of how engineering students approach and undertake design is necessary in order to develop effective design models and pedagogies. Understanding the factors related to design experiences in education and how they affect student practice can help educators as well as designers to leverage these factors as part of the design process.

PURPOSE

This study investigated the design practices of first-year engineering students' and their experiences with a first-year engineering course design project. The research questions that guided the investigation were: 1. *From a student perspective, what design parameters or criteria are most important?* 2. *How does this perspective impact subsequent student design practice throughout the design process?*

DESIGN/METHOD

The authors employed qualitative multi-case study methods (Miles & Huberman, 1994) in order to answer the research questions. Participant teams were observed and video recorded during team design meetings in which they researched the background for the design problem, brainstormed and sketched possible solutions, as well as built prototypes and final models of their design solutions as part of a course design project. Analysis focused on explanation building (Yin, 2009) and utilized within-case and cross-case analysis (Miles & Huberman, 1994).

RESULTS

We found that students focused disproportionately on the *functional* parameter, i.e. the physical implementation of their solution, and the *possible/applicable* parameter, i.e. a possible and applicable solution that benefited the user, in comparison to other given parameters such as *safety* and *innovativeness*. In addition, we found that individual teams focused on the functional and possible/applicable parameters in early design phases such as brainstorming/ ideation and sketching. When prompted to discuss these non-salient parameters (from the student perspective) in the final design report, student design teams often used a post-hoc justification to support how the final designs fit the parameters that they did not initially consider.

CONCLUSIONS

This study suggests that student design teams become fixated on (and consequently prioritize) certain parameters they interpret as important because they feel these parameters were described more explicitly in terms of how they were met and assessed. Students fail to consider other parameters, perceived to be less directly assessable, unless prompted to do so. Failure to consider other parameters in the early design phases subsequently affects their approach in design phases as well. Case studies examining students' study strategies within three Australian Universities illustrate similarities with some student approaches to design.

KEYWORDS

Engineering design education, design parameters, first-year design experiences

Introduction

The National Academy of Engineering (2004) defines engineering as “design under constraint” (p.7). Engineering design is creating and designing within the constraints of nature, cost, safety, reliability, environmental impact, manufacturability, maintainability, and many other factors (Wulf, 1998). One aspect of constraint in design is its limiting and directing nature (Newell & Simon, 1972; Stokes, 2001). While constraints surrounding the design problem limit and direct choice (Chua & Iyengar, 2008), designers still face numerous choices throughout the design process. However, when faced with too many choices, the evaluation and selection process becomes costly in terms of the resources used. March and Simon (1958) specifically consider time and attention scarce resources in decision-making. To effectively direct these resources, we need to identify and understand which aspects of design occupy designers’ time and attention.

The purpose of this study was to understand how the parameters related with an engineering course design project shaped student practices by investigating the types of parameters associated with the design project. We employed a qualitative study of first-year engineering students working on a design project and investigated the aspects of the design project that were salient to students, i.e. what they focused on or continued to revisit, in order to ultimately understand the relationship between the characteristics of the design project and student design practices. The research questions address these components of the design project and their effect on student design practice; specifically, these questions are:

1. *From a student perspective, what design parameters or criteria are most important?*
2. *How does this perspective impact subsequent student design practice throughout the design process?*

Methodology

A case study approach was used in this investigation, where researchers observed student design teams during individual team meetings over the course of a class design project. The qualitative case study approach was driven by our research questions (Borrego, Douglas, Amelink, 2009) and focused on investigating students’ approach to design within a real-life context (Yin, 2003). In using this methodology, our purpose was to examine this context in detail by focusing on a smaller group and to achieve trustworthiness (Lincoln & Guba, 1985; Chism, Douglas, & Hilson, 2008) through triangulation, i.e. use of multiple data sources. (Borrego et al., 2009). The teams were composed of four students per team with 1 female and 15 male volunteer participants. The course instructor formed teams based each student’s choice to participate in the study. Teams in the course who chose not to participate in this study were assigned the same design project and all teams presented project updates and reports in class.

Context and data collection

The design project for first-year students helps students develop knowledge regarding the engineering design process, sustainability, and teamwork fundamentals. All students enrolled received the assignment for an eight-week team design project. The aim of the project was for students to develop an awareness of current energy research efforts for improving sustainability and the impact of these innovations on the environment and society by researching and developing a design solution that utilized a renewable energy source. Objectives for the design project, as part of the course, required students to demonstrate ability to:

- 1) Apply the principles of sustainability to the design of a product, system or process.
- 2) Apply the design process to solve an engineering problem as part of team.
- 3) Effectively describe your team’s product and convey your team’s challenges, solutions, and reasoning both orally and in writing.

The course structured the project assignments to facilitate students' progression through the design process. Students were also provided with an explanatory document/ information document of the design project that detailed required components of the project. This document given to the students described the objectives and requirements for each assignment associated with its respective phase of the design process. The document also explicated the assessment criteria as it related to the objectives for the course project. For example, students were assessed on teamwork through team evaluations and the assignments associated with each phase of the design process were assessed in order to evaluate students' ability to apply the design process to solve an engineering problem.

In this study, discerning the specific parameters given to students in the document was important to analysing and understanding how students approached the design process and how these given parameters affected their design practices. These parameters specifically included design solution 1) functionality, 2) safety, 3) innovation, 4) use of renewable energy source(s), 5) applications to education or entertainment, as well as 6) an ability to generate inquiry in renewable energy sources. They were assessed as part of the final design demonstration and report. Functionality, use of renewable energy source(s), and innovation were weighted more than the other parameters in the final assessment

Researchers observed and video recorded teams on a weekly basis through individual team meetings, where teams generally discussed or worked on different phases of the design project. We performed one round of data collection that encompassed team meetings over the eight-week period of the design project and resulted in approximately 29 hours of observations. Each design team meeting observation was video-recorded as data in addition to the observer's field notes. One of the advantages of video data is that the fixed camera viewpoint records a consistent view of the setting and action (Heath, Hindmarsh, & Luff 2010). Recordings of individual teams in a consistent setting across the duration of the design project allowed researchers to analyse each team and their respective design practices concurrently and consistently.

Focus group/ debriefing interviews were also performed at the completion of the project to capture team member perceptions regarding their experiences with the design project. A semi-structured interview protocol was applied in the focus group interviews to guide the set of questions asked to each team, but at the same time it allowed for any follow-up or clarifying questions. Three of the four teams in this study chose to participate in the individual team interviews. One limitation was that we were not able to collect data regarding Team 3's responses to direct questioning about the project.

Data analysis

We used a multi-case study approach (Miles & Huberman, 1994) to analyse individual cases as well as potential cross-case patterns regarding student design practices to ultimately describe, understand, and explain the phenomena surrounding design practice in educational settings. The multiple case study approach investigates several cases to identify patterns and understand the phenomena under investigation (Creswell, 2002; Stake, 2006; Yin, 2003).

Analysis focused on explanation building (Yin, 2009) and utilized within-case and cross-case analysis (Miles & Huberman, 1994). Eisenhart (1989) suggests a two-part analysis where in the first step the researcher analyzes the within-case data by listing events and critical incidents and/or creating taxonomies and networks of the data. Then, in the second step, he or she looks for explanation and causality. The analytical approach of this study was employed to investigate important design parameters and their effect on design practices within cases and then across cases, following the analytical guidelines of Miles & Huberman (1994) and Eisenhart (1989). The use of multiple data sources (Borrego et al., 2009), i.e. observer field notes, video recordings of team meetings, and focus group interview responses, was a method to ensure the trustworthiness of the qualitative methodology.

Results

The salient parameters, from a student perspective, of the design project were identified in terms of how often these aspects came up, i.e. discussion, and if they had an impact on subsequent design decisions or practices over the course of the project. Quotations and excerpts from team design meetings are provided to support the findings and all names used are pseudonyms.

Project parameters

Our summary on these findings highlight common themes which were present in team design meetings and related to the project parameters as defined by the project document. Other emergent parameters that the teams considered were also identified and defined in Table 1. Specifically, these parameters were:

Table 1: Types of parameters applied by student design teams

Parameter	Definition or Explanation
Functional ¹	Physical implementation of a renewable energy source.
Safe ¹	Not harm anyone who uses it; have a minimal adverse effect on the environment.
Innovative/ Interesting ¹	Unique design; creativity of the concept and implementation.
Renewable Energy Source ¹	Highlight one or more key components of a renewable energy source.
Educate/ Entertain ¹	Educate, entertain, and generate further inquiry and interest in renewable energy sources.
Possible/ Applicable ²	A possible and applicable solution that benefits or addresses the needs of a user.

¹Parameters given in the design project information document

²Emergent parameters from student design team discussions

Assessment of the final design included teams' consideration and application of the parameters given in the information document. The functional, innovative, and renewable energy source parameters were equally weighted, but weighted more than the safe and educate/ entertain parameters. While incorporating additional project parameters, e.g. possible/ applicable, was not directly encouraged as part of the course or any related project assignments, design teams received peer and instructor feedback on design project updates during the class. This type of peer feedback typically prompted the design teams to consider additional parameters or aspects brought up by other students or the instructor in the class.

How students addressed specified or given project parameters

Across all teams the common parameters that students focused on were the *functional* and *possible/ applicable* parameters.

While all teams also utilised a renewable energy source in their design solution, this concept was not prevalent or important to the students when trying to conceptualise design solutions. In other words, teams did not consider using any sources other than a renewable energy. Furthermore, they only considered renewable energies listed in the project document (solar, wind, hydropower, biomass, or geothermal). One outcome of teams using a mutual, given list of possibilities was that teams came up with similar ideas during the brainstorming meeting, but had differing methods of implementation for these ideas. Specifically, Teams 1 and 3 both contemplated an idea that used a renewable energy source to power road lights.

However, Team 1 considered using geothermal and Team 3 considered using either solar or wind energy. Similarly, Team 1 and Team 3 also contemplated an electric or circular saw, but Team 1 wanted to use hydropower and Team 3 wanted to use solar. Additionally, Team 1 ideated a lawnmower powered by biomass and Team 3 wanted to power the lawnmower using solar energy. Another similarity between Teams 1 and 3, which differed from Team 2 and Team 4's approach, was that Team 1 and Team 3 chose to brainstorm using all the suggested renewable energies, i.e. solar, wind, hydropower, biomass, and geothermal. This was different from Team 2 and Team 4's approach where they only brainstormed ideas using the renewable energy source they chose to research for the research report (example of a team design artefact). What led these teams to gravitate to certain ideas and reject others was their perception of whether or not they could make the design functional, e.g. "But how would we build it?" "How would we make it work?"

All teams set goals and worked toward making a functional device. They also all arrived at what they perceived to be a final functioning model. Teams 1 (solar canopy), 2 (hydro-powered bridge light), and 4 (hydro-powered urinal) represented the functional aspect of their design by lighting an LED, and Team 3 (solar cooker) justified the functionality of their design by reaching a specific temperature to cook a marshmallow. How students perceived the feasibility of their design solutions, based on the functional parameter, differed between teams. For example, Teams 2 and 4 both conceived the idea to produce the hydro-powered urinal, but Team 2 rejected this solution because they were not able to conceptualize how it would ultimately function. Team 4 on the other hand did not work under the assumption that the idea was unfeasible based on functionality and chose this idea for their final design solution based on the interesting/ innovative parameter, e.g. an "awesome idea." However, they used the scalability concept to limit their search and reject other options they discovered during the research phase of the design process:

Team 4, Craig: "There weren't too many options because there aren't many ways in which water can produce power. The research we did was mostly, we found mostly it was water wheels or sometime of rocking mechanism with a generator. Those were used really on the large scale with waves or the tide and stuff like that. We were pretty limited with our designs. Most of ours were waterwheels."

Another common theme across teams related to their interpretation of the functionality parameter was whether or not team members assumed they could construct a scalable model for the final design. Teams 1, 2, and 4 built scaled models of a canopy, bridge, and urinal, while Team 3 was the only team to build their design to scale. This concept of scalability in team design practices impacted how they chose or eliminated design ideas, but was not consistent across all design possibilities. For example, both Teams 1 and 2 considered a solution that utilized hydropower to produce electricity for a yacht (Team 1) or sailboat (Team 2), but rejected these ideas because they perceived them to be unfeasible based on building the final model. However, they built their final designs, i.e. the solar canopy and the hydro-powered bridge light, as scaled-down models. The following excerpts from Team 1's design meetings illustrate their perceptions regarding design ideas and functionality.

Team 1, Sketch Meeting:

Eddie: "I kind of like my yacht idea."

Cory: "What was that?"

Eddie: "I thought of this one. You build a bottom of a boat, right? So say you're cruising along and underneath is a little turbine that moves. That turbine that spins is going to just collect the energy from the spinning water. You're already using energy to spin it, so this is just collecting it sort of. And that collected energy; you can use it to power the electricity on board."

Cory: "I don't know how we'd do it though; It'd be pretty cool though."

The impact of emergent parameters on teams' final designs

While building a working or functional model of their conceptual design was a driving force for all teams throughout design meetings, the possible/ applicable parameter also impacted student design practices, mainly with respect to how they evaluated various solutions and chose the final design solution. For example, all teams considered final design ideas that met the needs or benefited a user. Team 1's discussion during their meeting, in which they focused on writing the research report, is an example of how teams identified user needs based on personal experience or hypothetical situations. Specifically, Team 1 framed their decision to design the solar canopy based on Kelly's need for power outlets when lying out by the pool or beach. Similarly, during the brainstorming design phase, Team 3 referenced personal experiences including working on a deck over spring break and needing tools, e.g. a power drill, that did not lose power or could be easily recharged. Team 2 and Team 4 reflected in their focus group interview that they chose ideas that were beneficial to certain user groups. Interestingly, while Team 4 felt restricted in terms of building a working model and staying under budget, at the same time, they perceived their design as beneficial on a larger scale. *"Plus if they implemented it for every urinal it would add it up. I mean one urinal might not produce that much power but implement it in one that has the most bathrooms"* (Channing, Team 4, Focus Group Interview).

Overall, teams guided their conceptualization of design ideas by identifying user needs, where the user was either himself or herself or a user group that could benefit from their proposed design idea. Additionally, a common theme across all teams was a post-hoc consideration of the other parameters that were not addressed until later phases, including the final design report. Specifically, the final design report prompted students to discuss and write about the other parameters such as safety, e.g. *"Please discuss the ethical implications of the design you chose."* And *"Could the user or another person be injured by your design? If so, what measures have you taken to prevent such injury?"* When prompted by the questions in the design document, teams were initially not able to identify or explain these parameters in relation to their design. This also generally resulted in team members suggesting to one another that they "make up" material to address these concepts in the final design report.

Team 3, Final Design Report Meeting:

Andy: "Help me out with the ethical—."

Ian: "Let me just finish this up."

Brett: "Just start making stuff up."

One outcome of prompting design teams to think about design parameters that they did not initially consider was that it did lead teams to discuss the overarching issue of sustainability and environmental effects. Later in Team 3's final design report meetings (after the discussion on making up material to write about ethics), they continued to think about their design in terms of its impact on the environment.

Overall, we found that the common themes across teams were that they focused on 1) the functionality parameter and 2) the possible/ applicable parameter and generally did not consider other parameters until prompted to do so. This usually occurred in the later design phases. In general, teams guided their design practices of generating possible design solutions by considering user needs and then evaluating final design solutions by how feasible it was to produce a functional model.

We can see parallels between students' focus group discussions in this study and comments from focus groups conducted as part of a study of their approaches to learning implemented at three Australian universities (Boles, 2009). In that study, students' preference for project based learning came down to the use of currently relevant examples even in theoretical discussions. Any technique that allowed students to relate new information to what they knew already, and to what they conceived their ultimate profession to be, was considered helpful in perusing their studies, and hence deserved more attention. Further, the integration

of detail with the global understanding of a problem or body of knowledge was an important influencing factor. While students like to work through well-organised material to a well-defined conclusion, they would like more of the 'big picture' to help them make sense of the details. There is a clear parallel here with their preference for real-world connections and applicability, as these provide another way to situate the detail.

Conclusions

The study described in this work was designed to understand first-year engineering student design practices and how various aspects of the design project affect those practices. The data showed that students often focused on explicit constraints given in the project document when they did not understand the design artefact requirements, e.g. parameters related to safety or ethics. For example, design teams often had trouble interpreting or defining the design problem so they leaned toward the explicit constraints, e.g. utilising a renewable energy source. However, we see in this study that students met or attempted to meet the given requirements of the design project and fit the given parameters.

The findings from this study suggest that first-year students will work within the explicit statements or requirements of the design document, i.e. do or attempt to do what they are instructed to do with respect to the requirements of the design project. In some cases, these parameters were also weighted more in the assessment so student focused on these parameters as a method to meet the evaluation criteria.

Design educators can capitalise on this finding by designing parameters that better fit the intentions or objectives related to the design artefacts and the design process. For example, if participants were unclear about how to approach design and address all possible parameters they focused on more explicit aspects and failed to consider other possible parameters. Being explicit about the parameters and requirements associated with design artefacts may prevent students from feeling compelled to "make something up" in subsequent phases of the design process, while at the same time helping students to structure an approach that takes into account or consider all the parameters associated with the design project. Results from case studies examining students' study strategies within three Australian Universities illustrate similar student approaches. Future work may consider the investigation of student approaches across multiple contexts in order to gain a more holistic view of student practices in various educational contexts.

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