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How Do First-Year Engineering Students Experience Ambiguity in Engineering Design Problems: The Development of a Self-Report Instrument

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Abstract

Design is widely recognized as a keystone of engineering practice. Within the context of engineering education, design has been categorized as a type of ill-structured problem solving that is crucial for engineering students to engage with. Improving undergraduate engineering education requires a better understanding of the ways in which students experience ill-structured problems in the form of engineering design. With special attention to the experiences of first-year engineering students, prior exploratory work identified two critical thresholds that distinguished students' ways of experiencing design as less or more comprehensive: accepting ambiguity and recognizing the value of multiple perspectives.

The goal of current (work-in-progress) research is to develop and pilot a self-report instrument to assess students' relation to these two thresholds at the completion of an ill-structured design project within the context of undergraduate engineering education. The specific research questions addressed in this study are 1) if the piloted self-report instrument can be used to identify discrete constructs, and 2) how these constructs align with prior qualitative research findings.

The objective of this study was addressed using a quantitative exploratory research design. Items for the self-report Likert-scaled instrument were designed to distinguish student experience that either accept or reject the presence of ambiguity and the value of multiple perspectives. The instrument was disseminated to a total of 214 first-year engineering students. Exploratory factor analysis was used to identify the constructs that emerge from the self-report data, and these constructs were checked for alignment with the previously identified thresholds.

The results of this investigation will be used to help advance progress towards an easily administered instrument able to assist engineering educators with the identification of students in need of intervention or explicit instruction related to critical aspects of learning engineering design. The instrument could also be used to track student growth over time, and, with further development, to provide evidence for ABET student outcomes.

Introduction

Design is recognized as the keystone of engineering practice [1]. As engineering educators, we must continuously use research to inform our design of meaningful learning experiences that support students' experiences with engineering design practice. A wide amount of information and strategies for designing such learning experiences have been published. For example, Crismond and Adams [2] provide a rather comprehensive review of this topic in their Informed Design Teaching and Learning Matrix. Previous research by the first author (not yet published) used phenomenography to develop categories to characterize the variation in experiences of first-year engineering students engaging in engineering design projects. Results include the identification of two key axis of variation in introductory design experiences: reaction to ambiguity and view of multiple perspectives. Specifically, students who had more comprehensive introductory design experiences 1) recognized and accepted ambiguity as a part of engineering problem solving and 2) valued the perspectives of others including their own peers.

Previous work supports the investigation of these two critical aspects of ill-structured problem solving or design. In general, the problems that engineering students are preparing to engage with are complex and ill-structured, possess unique constraints, and require novel application of mathematical and scientific principles [3-8]. Sheppard, Macatangay and Colby [1] have identified a need for more opportunities for students to engage in design within undergraduate education. Research on the experience of students when they are required to engage with design problems has revealed that ambiguity (or lack of information) is often a source of frustration for students [9]. However, “problem setting” is an important skill for effective design problem solving [10]. While students’ initial encounter with ambiguity in problem solving may result in frustration, with repeated exposure these feelings will be resolved and students will show improvement with practice [11].

How students engaging in design come to appreciate the value of multiple perspectives has also been studied in within the engineering education domain. Bucciarelli [12] places an emphasis on the social process of navigating individual perspectives required when individuals engage in design. Downey and Lucena [13] describe engineering students as looking to instructors for information, which has been established by authority, instead of serving themselves as sources of interpretation. Our focus on students coming to see multiple perspectives (their own, that of the user, that of their design teammates, etc.) as valuable also aligns with Perry’s concept of epistemological development [14], which characterizes development as transitioning from a dualistic perspective to a recognition of multiple perspectives and the contextual nature of knowledge.

The goal of this work is to contribute to the research area of engineering students learning design through the development of an instrument to specifically measure the perspectives held by engineering students. Previous work identified four qualitatively different classifications related to each critical aspect of the student experience (ambiguity and multiple perspectives), and the focus of this work-in-progress instrument was to confirm the items’ ability to measure students’ perspectives on either extreme (rejection or acceptance) of these two relevant aspects of ill-structured problem solving. As a first step, we developed 55 items and collected responses from 214 first-year engineering students in an introductory course that included design learning. These responses were subjected to exploratory factor analysis in order to refine and improve the instrument towards a classroom assessment that is easy to deploy as a measure of engineering students’ critical perspectives when engaging in engineering design.

Methods

Based on an ongoing research agenda to understand the variety of experience of first-year engineering students asked to engage in engineering design, the first author drafted 55 Likert-scale items to assess students' reaction to ambiguity and view of multiple perspectives. These items were meant to capture four categories of variation within both aspects of importance (ambiguity and multiple perspectives). The items were then subjected to review by several engineering students and engineering faculty for preliminary screening and face validation. After resulting revisions, the 55 items were administered anonymously to 149 first-year engineering students at a small, private Midwestern university and 65 students at large, public Midwestern university. Exploratory factor analysis was used to determine how many discernable factors emerged from the data, and how these factors translate to students' attitudes toward ambiguity and multiple-perspectives while engaging in design activities.

The responses were collected via paper and pencil surveys in the classroom following an open-ended design activity. The EFA procedures cannot be performed with missing values, therefore missing values were either replaced or eliminated prior to analysis. The following procedures were used to prepare the raw data for analysis. If a participant circled in between 2 numbers, their response was rounded up. If a participant skipped 1-2 items, the missing value was replaced by the local mean. Otherwise, responses with long strings of missing values or an unlikely pattern of responses (e.g., all responses with the same value) were eliminated. As a note, we did observe that participants with incomplete surveys generally stopped after responding to 20-25 items. This may be an indication of ideal length to eliminate survey fatigue. However, there were 20 items on the first page of the paper and pencil survey, so these result may vary if the survey was offered online.

In addition, EFA procedures are sensitive to sample size. Due to the relatively small sample size of this pilot, the second author reduced the overall pool of 55 items to a pool of 20 items. This was done by a simple selection process of promoting items with the best clarity and eliminating items that were potentially ambiguous. This reduced our ability to distinguish with the intentional level of gain size, so our result focus just on the extremes of each axis—the instrument was able to measure if students are more inclined to accept or resist ambiguity and multiple perspectives.

The EFA was performed using the IBM SPSS software. Factors were retained based on a minimum eigenvalue of 1.0. The rotation used was verimax, which does not permit high correlation between factors. Additionally, a cut-off value of 0.40 was used to assign individual items to a factor. Items with factor scores greater than 0.30 for multiple factors were eliminated from the analysis.

Results

A total of 4 iterations of EFA were performed until a stable four-factor model was achieved with a total of 12 items, which explained 60.8% of the total variance. Below are the resulting factors followed by the items that compose each factor.

Factor 1: *Resistance to Ambiguity*

1. I feel frustrated when I am given a problem that is ambiguous
2. When working on a design project, I find myself wishing the instructor would tell me what they want me to do
3. Problems that are ambiguous make me worry that I won't get a good grade

Factor 2: *Acceptance of Ambiguity*

4. Engaging in design projects is important for my transition from high school problem solving to engineering problem solving
5. As an engineering student, I have to learn how to work on problems that have never been solved before
6. A design team has to communicate their individual ways of seeing a problem before any progress can be made

Factor 3: *Resistance to Multiple Perspectives*

7. The way that people view problems differently makes it hard to get anything done
8. Design projects are more work because it is hard to get everyone to agree
9. I feel frustrated when my teammates have different ideas about how to solve a problem than I do

Factor 4: *Acceptance of Multiple Perspectives*

10. Everyone has something valuable to contribute to any engineering design problem
11. Working with others has revealed to me that I don't always have the best ideas
12. I prefer to work with others on design projects

Overall, this represents a reasonably good factor model. Further analysis, such as confirmatory factor analysis or other confirmatory methods are needed to address scale validity. An EFA analysis alone is not enough to provide evidence of valid and reliable instrument.

Internal reliability of each was measured by Cronbach's alpha for each of the four factors and for the instrument overall. The reliability ranged from 0. 614 to 0.672 for the four factors and was 0.602 for the instrument overall. In general, this shows a marginal level of internal reliability, which is something that will need to be addressed in further iterations of the instrument.

Discussion

In general, our analysis did result in four discrete factors that reflect the acceptance or resistance to two distinctive aspects of ill-structured problem solving: ambiguity and multiple perspectives. With further development, an instrument of this nature could be used by classroom instructors to gauge where students are with respect to major thresholds in how they experience ambiguity and multiple perspectives in team-based design problems. If students are identified as resisting ambiguity and/or lacking an understanding of the value of multiple perspectives, specific interventions could be designed to promote growth for those students in this area. With larger sample sizes, comparisons could be made across groups. In the same respect, a longitudinal use of this instrument could track the progress of undergraduate engineering students from their cornerstone to their capstone design experiences. There is also potential for this instrument to prompt student reflection on their experiences with classroom design tasks.

Future Work

Further development of this instrument is required. For example the reduction of 55 items should be reviewed in a more systematic way than what was feasible for this pilot study. Further revision of final survey items to improve clarity may also be required to improve internal reliability of the instrument. Face validity was addressed in the generation of the original 55 items, but additional validity measures, such as confirmatory factor analysis and correlations to other known measures of related student attitudes, are needed to build a more robust argument for the validity of this scale.

With further development of this instrument, we hope to provide a useful tool for the engineering education community to assess the progress of their students at any level with respect to two critical aspects of learning to engage in design: reaction to ambiguity and understanding of multiple perspectives. This tool may also be used to track the changes in student perceptions related to design over time or to measure the impact of introductory, on-going, or senior-level design experiences throughout engineering curricula at a variety of institution types.

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