An Evaluation Framework for Engineering Design Projects for Gender Bias, Domain Relatedness, and Ambiguity: Development

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Abstract
Engineering design learning is one of the key components for an engineering degree; thus engineering design projects are commonly included in engineering curricula to help students cultivate design thinking and creative problem-solving skills. However, an engineering design project is prone to the following issues if it is not appropriately provided to engineering students. First, gender bias can occur when the design project is perceived to be more skewed to one gender in comparison to the other. Second, domain bias can occur when the discipline of the design project is not related to the chosen major and interest areas of a student. Third, ambiguity can arise from the lack of clarity on design objectives and the scope. These issues can lead to diminished engagement and self-efficacy for engineering students. In order to tackle these issues, this study performs a preliminary work to build a framework that appropriately assesses engineering design projects. The evaluation framework is based on a measurement system that helps educators to evaluate the appropriateness of the design projects through designated questionnaires. The framework for design projects proposed in this study would help engineering educators to better prepare and revise their design projects, so that the engineering design projects can improve student engagement and learning performance.

Keywords
Design Projects, First-year Engineering, Gender, Domain, Ambiguity

Disciplines
Engineering Education | Operations Research, Systems Engineering and Industrial Engineering

Comments

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Abstract

Engineering design learning is one of the key components for an engineering degree; thus engineering design projects are commonly included in engineering curricula to help students cultivate design thinking and creative problem-solving skills. However, an engineering design project is prone to the following issues if it is not appropriately provided to engineering students. First, gender bias can occur when the design project is perceived to be more skewed to one gender in comparison to the other. Second, domain bias can occur when the discipline of the design project is not related to the chosen major and interest areas of a student. Third, ambiguity can arise from the lack of clarity on design objectives and the scope. These issues can lead to diminished engagement and self-efficacy for engineering students. In order to tackle these issues, this study performs a preliminary work to build a framework that appropriately assesses engineering design projects. The evaluation framework is based on a measurement system that helps educators to evaluate the appropriateness of the design projects through designated questionnaires. The framework for design projects proposed in this study would help engineering educators to better prepare and revise their design projects, so that the engineering design projects can improve student engagement and learning performance.

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1. Introduction

Recent engineering curricula are based on the announced requirements of Accreditation Board of Engineering and Technology (ABET) for effectiveness in engineering education [1]. These requirements focus on expected outcomes from engineering students after taking a course in college. Capability for engineering design is one of these outcomes, and design projects are being incorporated to the curricula in order to help engineering students achieve this outcome, and mostly in settings of project-based learning [2]. Engineering design courses employ design projects not only at a senior level (i.e., capstone projects) but also at a freshman level (i.e., cornerstone projects). These courses have been
shown to be effective for learning design activities by providing opportunities for engineering students to experience and solve real-world problems [3]. However, several issues have been commonly addressed in engineering education to properly develop design projects for engineering students. First, gender bias can occur when a design project task is perceived to be more skewed to one gender versus another [4]. The gender bias can discourage students of a particular gender to have less enthusiasm and leave the engineering domain [5]. Second, domain bias can occur when the discipline of a design project is not related to the chosen major of students for the project [6]. This may cause the students to leave the engineering field if their interests do not match with the domains associated with the design projects. Finally, the ambiguity of design projects can result in the lack of understanding of design problems addressed in the projects. If the ambiguity level of a project is high, it may lead to a decrease in self-efficacy [6]. However, design projects should also have a right amount of uncertainty in forming design activities as creativity may arise when students face uncertain design problems [7]. In order to tackle these issues, this study performs preliminary work to develop a framework that assesses design projects with consideration of gender bias, major relatedness and ambiguity factors. The evaluation framework is based on a scoring technique that engineering educators will be able to evaluate to determine the appropriateness of their design course projects through designated questionnaires. This study would be a basis to further complete an evaluation framework for design projects, and thereby it will help engineering educators to better prepare and revise their design projects for better student engagement and learning performance.

2. Literature Review

Engineering design is a crucial part of the engineering learning process, and the engineering students require designing skills to help them throughout the courses in their degree program [8]. These designing skills taught to the modern engineering students, using the traditional in-class teaching, are insufficient to prepare them for real world engineering applications. Research has shown that engineering graduates are inadequately prepared to meet the demand of global engineering issues [9, 10]. Mills [11] demonstrates that the traditional engineering curriculum and ‘chalk and talk’ pedagogy cannot meet demands of the ABET criteria and industry. Calabro et al. [12] reveal that design project based courses in a freshman year shows more favorable responses from students as compared to traditional lecture methods. Design projects sponsored by industrial companies are therefore being increasingly used in an engineering curriculum at the freshman level [13]. Project-based design courses have student centric activities in the form of Project Based Learning (PBL), which improves student engagement and reduces attrition [14, 15]. PBL also supports students to develop problem analysis and problem solving skills. [16]. Despite the advantages of PBL in the engineering curriculum, there are several common issues with regards to the appropriateness of design projects at the first-year level: gender bias, domain relatedness and ambiguity [6].

Gender diversity has always been an issue in the engineering field and women face a lot of problems regarding authority and identity because of stereotyping [17]. Project-based learning has shown to improve female involvement in engineering [16] and design projects may help increase gender diversity in engineering. However, in some design projects the perception of certain design tasks being more oriented to a particular gender can result in gender bias. This gender bias can cause the motivation loss of engineering students and may make the students leave engineering domains [4]. For example, a design project with automobiles is more likely to be interesting to males as compared to females and this relevance develops positive experiences to the male students as compared to female students. Gender bias of a design project may therefore cause motivation loss among students and increased attrition, and therefore, it is essential that these design projects are not gender biased [4].

Because most real world design projects are interdisciplinary in nature, students sometimes may not be able to connect the project (or its context) with their chosen major, potentially causing a barrier in their learning [20]. Santiago and Hensel [19] agree that students leave the engineering major because their interests do not match with what they have been exposed to. However, design projects have shown to improve retention when students enrolled in a team-oriented, real-world project that is applicable to their chosen major; in such conditions students are more likely to persist in their major as compared to those exposed to a project outside of their discipline [18]. This shows that design projects play a major role in engineering design learning and therefore, the design project needs to be relevant to students’ major so that they improve engagement and motivation among the engineering students.
In their handbook, Berry et al. [21] defined ambiguity as “the capability of being understood in two or more possible senses or ways”. For design projects, ambiguity in the project description can demotivate the student and have an impact on their leaning. Measures exist to quantify ambiguity level through the use of natural language processing software like the general purpose LOLITA [22] and ARM developed by NASA [23]. However, a potential ambiguity problem detected by a linguistic tool needs human intervention to determine if the potential problem is a real problem [24]. This indeed can be likened to the way a course instructor provide the necessary intervention by assessing the ambiguity level of the design project. In design projects, ambiguity rises from uncertainty and the right amount of uncertainty helps in the learning process [7]. The design projects should therefore have the appropriate amount of ambiguity in order for the students to feel motivated to work on open-ended problems, which can in turn lead to reducing the attrition loss in the engineering design courses.

3. Methodology

A questionnaire for the evaluation framework of design projects is developed based on three main criteria (i.e., gender bias, domain relatedness, and ambiguity) and their associated components. A survey was conducted at a large midwestern university on an engineering design course over two semesters in the freshman year. The design course uses industry sponsored design projects to help the students gain real word experience and exposure. Over 200 students participated in the survey and responded to 63 questions. The students were asked to rate their answer on a 5-point Likert scale between 1 (strongly disagree) and 5 (strongly agree).

A confirmatory factor analysis was conducted on this data to affirm the factors hypothesized while building the instrument. The five hypothesized factors were: student’s self-efficacy, team-efficacy, student’s tolerance to ambiguity, student’s perspective of the gender bias of the project, student’s perspective of the domain relatedness of the project. Statistical analyses revealed that gender bias, domain relatedness and ambiguity were among the significant factors that were rightly hypothesized so. From this analysis, we conclude that these three factors affect the student performance in design project courses. We do not consider the remaining two factors of student’s self-efficacy and team efficacy herein as they do not focus on the design project appropriateness. In order to determine the components for gender bias, the questions in an existing survey instrument that focuses on the impact of gender bias in a design project setting were adopted. The components for ambiguity level of the design projects were determined from the existing literature.

Holland’s theory of career choices has been widely used across the engineering domain for discipline specific studies. Holland [25] developed six model environments (i.e., Realistic, Investigative, Artistic, Social, Enterprising, Conventional) for classifying various occupations and said that people thrive in environments which are congruent with their personality. These environments have salient features namely: competency, perception of values and project activity, which further categorize the engineering major into Holland’s environments. The categories are as follows: Realistic- mechanical and electrical engineering, Investigative- aerospace, chemical and civil engineering, Enterprising- Industrial Engineering. We use the features of these model environments for the components of our evaluation framework to develop guidelines for domain relatedness. The items for the three criteria of gender bias, ambiguity and domain relatedness are shown in Table 1.

The components for the criteria will be used in the scoring rubric, and determine the weights for the components by using Analytic Hierarchy Process (AHP), a multi-attribute value aggregation method. In this study, the judgments/inputs for the AHP comparison matrix have been provided by an education expert. Upon determining the weights for the attributes, we develop the questionnaire, which will be supplied to the design instructor who will then score them on a 5 point Likert scale. The final score will be calculated using simple weighted average formula. This final score will help the instructor to determine the appropriateness of the cornerstone design project. The developed questionnaire is shown in the appendix A.
Table 1: Main Criteria and Their Components for an Evaluation Framework of Design Projects

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Attribute</th>
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<tbody>
<tr>
<td>Gender Bias</td>
<td>Product</td>
</tr>
<tr>
<td></td>
<td>Institution</td>
</tr>
<tr>
<td></td>
<td>Experience</td>
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<td>Action</td>
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<td>Interest</td>
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<td></td>
<td>Idea generation</td>
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<td></td>
<td>Background knowledge</td>
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<td></td>
<td>Composition</td>
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<tr>
<td>Ambiguity Level</td>
<td>Ill structured representations</td>
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<td></td>
<td>More than one solutions to a problem</td>
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<td></td>
<td>Context explanation</td>
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<td></td>
<td>Incomplete information</td>
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<td></td>
<td>Vague or undefined goals</td>
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<tr>
<td>Domain Relatedness</td>
<td>Competency</td>
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<tr>
<td></td>
<td>Self-perception of values</td>
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<td></td>
<td>Project Activity</td>
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</tbody>
</table>

4. Conclusion/Future Work

The engineering curriculum is based on the ABET criteria which specifies that the students should be efficient in engineering design. In order to help the students with these outcomes, design courses are incorporated in the curriculum starting the first year. These courses have design projects, called cornerstone design projects; however, in some cases, they may plagued with problems decreasing student self-efficacy and motivation. These problems have been associated with three main criteria that are taken into consideration herein, namely, gender bias, ambiguity level and major relatedness. These problems can be reduced using active learning in the form of project-based learning. The cornerstone design projects therefore need to be assessed appropriately in order to improve engagement and reduce the attrition among the engineering students.

This paper provides a framework in the form of a questionnaire, which can be used by engineering educators to determine the appropriateness of design projects. An educator (instructor) can score a design project using this questionnaire and determine a score for the design project. A simple scoring technique will further be developed to determine the level of gender bias, level of ambiguity and the domain relatedness of the design project. Based on the current framework, we intend to develop guidelines to help engineering educators not only to identify the level of ambiguity, gender bias and domain relatedness of the design project but also modify the design project to have more gender-neutral, discipline-related and balanced in ambiguity level. Our subsequent papers will present implementation of this framework and the questionnaire.

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Appendix A: Questionnaire

<table>
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<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>The project activity to be associated with a masculine or feminine product or object (e.g., guns, rockets, explosives make me think of males)</td>
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<tr>
<td>The project activity to be associated with a masculine or feminine institution (e.g., the military makes me think of males).</td>
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<tr>
<td>The project activity to be associated with a masculine or feminine experience (e.g., cooking makes me think of females).</td>
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<tr>
<td>The project activity to be associated with a masculine or feminine action (e.g., teaching makes me think of females)</td>
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</tr>
</tbody>
</table>
The project activity to be associated with a masculine or feminine interest (e.g., war affects everyone, but men tend to be more interested).

The project activity to be associated with a masculine or feminine idea generation (e.g., the ideas were mostly contributed by the males).

The project activity to be associated with a masculine or feminine background knowledge (e.g., females know how to socially work in a group).

The project activity to be associated with a masculine or feminine composition (e.g., the group was all male).

How would you rate the project activity to be related to machines, tools and materials?

How would you rate the project activity being related to creation of knowledge?

How would you rate the project activities being related explicit, ordered, systematic manipulation of data to meet organizational demands?

How would you rate the project activities being related to manipulation of others to obtain the organizational goals of the company?

How strongly do you think the project will help student acquire mechanical and technical competencies?

How strongly do you think the project will help student acquire analytical, scientific and mathematical competencies?

How strongly do you think the project will help student acquire clerical, computational and business system?

How strongly do you think the project will help student acquire leadership, interpersonal, speaking, persuasive competencies?

How strongly do you think the students participating in this project will perceive themselves as practical and productive?

How strongly do you think the students participating in this project will perceive themselves as cautious, critical, complex, curious, independent, precise, rational and scholarly?

How strongly do you think the students participating in this project will perceive themselves as conventional outlook and concern for orderliness and routines?

How strongly do you think the students participating in this project will perceive themselves as aggressive, ambitious, energetic, extroverted, optimistic, popular, sociable, talkative?

The design project has vaguely defined or unclear, multiple, conflicting goals.

The design project representations/illustrations are ill structured (e.g., The diagram can be interpreted in a number of ways).

The design project has incomplete or unclear specifications to the problem.

The design project problem will have more than one correct solution.

The design project problem is not complex in terms of number of variables involved.

The design project problem challenges the students to develop innovative solutions (e.g., Textbook approach can be a traditional problem solving approach).

The design project problem needs explanation in terms of the context of the problem.

References