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An assessment tool to determine the appropriateness of engineering design projects for gender bias, ambiguity, and major relatedness

by

Shubham Prashant Khoje

A thesis submitted to the graduate faculty

in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

Major: Industrial Engineering

Program of Study Committee:
Gül E. Okudan Kremer, Major Professor
Jo Min
Jarad Niemi

The student author, whose presentation of the scholarship herein was approved by the program of study committee, is solely responsible for the content of this thesis. The Graduate College will ensure this thesis is globally accessible and will not permit alterations after a degree is conferred.

Iowa State University

Ames, Iowa

2018

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DEDICATION

I would like to dedicate my thesis to my parents, Mrs. Pranali Khoje and Mr. Prashant Khoje, for their unconditional love and support.

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ABSTRACT

Engineering design learning is one of the critical 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, major relatedness 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. To manage these issues, this study performed a preliminary work to build an evaluation tool that properly assesses engineering design projects. The evaluation tool is based on a measurement system that helps educators to evaluate the appropriateness of the design projects through designated questionnaires. The assessment tool for design projects 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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CHAPTER 1. INTRODUCTION

The engineering curricula in recent times follow the criteria set by the Accreditation Board of Engineering and Technology (ABET; 2016). Several engineering institutions in the United States obtain this accreditation so that they can be confident that their programs meet the necessary standards. Among the several criteria for accreditation, some include student outcomes, which are the end results expected from the students after completion of program of study in college. Some of these student outcomes revolve around solving engineering problems while applying their engineering knowledge and designing skills. Therefore, engineering design courses, where they can apply the theoretical knowledge to practice, are taught to the students starting from the first-year level until they graduate (Knight, Carlson, & Sullivan, 2007). To promote this design experience and improve their creative problem-solving skills, design projects are being incorporated on a large scale in the college curriculum through the use of project-based learning (De Graaff & Kolmos, 2003; Soman, Gupta, & Shih, 2016).

The design projects implemented in project-based learning (PBL) present real-world problems to the students. Perrenet, Bouhuijs, and Smits (2000) described PBL as project tasks that are closer to professional reality and application of knowledge acquired in the courses. This provides industrial exposure by helping them in making the connection between the theory learned in class to professional practice. Traditionally, design courses involving PBL are implemented at the senior-year level in engineering and are called capstone design courses. However, design project courses known as cornerstone projects are being implemented to provide real-world problem experiences in the first year, which has been shown to improve the retention of students (Knight et al.,

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2007). The projects in the PBL also support student learning by developing problem analysis and problem-solving skills (Du & Kolmos, 2009). These design projects give the students direct experience of the engineering problem compared to the traditional lecture method of teaching, which also helps in improving student learning and motivation (Mills, 2003).

Although PBL has several advantages through engineering design projects, there are disadvantages that come along when the design projects are not properly developed for these students. The first disadvantage is that of gender bias, which occurs when a design project is perceived to be more skewed to one gender compared to another (Okudan, Bilén, & Wu, 2003). One of the factors for this perceived gender bias may be due to the stereotype that engineering is a masculine field (Lingle, 2007; Shinar, 1975). For example, a design project that is related to a rocket-propelled grenade can be perceived to be more relatable by male students compared to female students and can have a negative effect on the female students. Okudan and Mohammed (2006) indicated gender bias can discourage students from a particular gender resulting in less enthusiasm in the engineering curriculum and leaving the engineering field. The gender gap in undergraduate engineering is wide, as indicated by the low female enrollment of only 19% (Engineering Workforce Commission, 2014). Reducing the gender bias of the design projects may help to reduce the gender gap in engineering fields.

Another barrier in student learning is due to the major relatedness of the design project. It occurs when the domain of the design project assigned to the student and the major of the student's interest do not match with each other and might cause motivation loss. Most engineering first-year students do not have a declared major; however, they

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have interests in some of the specific engineering majors such as mechanical, industrial, and chemical engineering. Their interest in a particular engineering domain influences their perception of a design project (Okudan, Mohammad, & Ogot, 2006). An important aspect of engineering design projects involving real-world problems is that they are generally interdisciplinary in nature, which is useful to engage the students in their learning process. “Relatedness” refers to the connection the student makes between his or her major and this interdisciplinary project in the course. However, if the student is unable to connect the major of his or her interest with the project context, it can become a barrier in the student’s learning experience (Richter & Paretti, 2009b). For example, a project related to designing an automobile component such as a suspension is more related to industrial and mechanical engineering compared to chemical and electrical engineering, which causes students in chemical and electrical engineering to feel less motivated due to the lack of connection between the focus of the project and their interest and may also be another reason for attrition (Santiago et al., 2012). Thus, it is necessary to consider this issue in the selection of the design projects for the first-year student to accommodate the student’s interests and prevent attrition.

The third disadvantage to students’ learning due to a poorly developed design project is the project ambiguity. Ambiguity is the lack of information to describe a particular problem (Dringenberg & Wertz, 2016). The design projects assigned to the students are real-world problems and are open-ended. These open-ended problems are helpful for motivating the students and provide a good learning environment (Baillie & Fitzgerald, 2000). However, open-ended questions are inherently ambiguous and can be difficult for students to understand (McNeill, Douglas, Koro-Ljungberg, Therriault, &

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Krause, 2016). Ambiguity in design projects may also arise due to the abstractness of concepts that may be difficult to visualize. For example, designing a fume hood involves airflow concepts that are difficult to visualize for the students, therefore, becoming ambiguous to solve (Okudan et al., 2003). Design project courses have been shown to affect self-efficacy and student motivation due to lack of clarity of the design task and problem (Lima, Carvalho, Assunção Flores, & Van Hattum-Janssen, 2007; Mohammed, Okudan, & Ogot, 2006; Okudan et al., 2006). These problems can be challenging to the students due to their ambiguous nature. Tauritz (2012) stated the right amount of ambiguity has a positive effect on student learning. In other words, the design projects given to the students should not be too ambiguous and abstract that students lose motivation and neither should they be too straightforward with simple solutions for them not to feel challenged.

The disadvantages of an engineering design project related to gender bias, major relatedness, and project ambiguity may lead to motivation loss among the students, affect their learning experiences, and may also cause them to leave the engineering domain. With the growing attrition rates in the engineering domain (Baillie & Fitzgerald, 2000; Ohland et al., 2008), it is essential to consider these barriers when selecting an appropriate design project to increase students' engagement and retention in the engineering field. This work focused on the cornerstone design projects in the first year of the engineering curriculum in a design course. Based on a simple scoring method, the appropriateness of the design project was assessed and categorized according to gender bias, major relatedness, and ambiguity level. It is hoped this will help engineering

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educators to appropriately assign the design projects to the students and may improve their engagement and motivation.

1.1 Objective and Research Questions

The primary purpose of this thesis was to develop an assessment tool that would help in understanding the appropriateness of a design project and aid the faculty to determine the gender bias, ambiguity level and major relatedness of the design project. The objective was to build a questionnaire which would be given to the educator of an engineering design class. The educator would use this tool to assess his design project before it is given to the students. The assessment would act as a guide to the educator to decide for any modifications necessary in the design project. This assessment tool would focus mainly on three aspects of an engineering design project; gender bias, major relatedness, ambiguity level.

The research questions associated with the work are as follows:

- What are the subfactors for the three main factors of an engineering design project: gender bias, major relatedness, and ambiguity level?
- How can one determine the appropriateness of an engineering design project with regard to gender bias, major relatedness, and ambiguity level?

1.2. Thesis Organization

In Chapter 2, the existing publications pertaining to the design projects in engineering education are examined. It describes the advantages of these projects in engineering curriculum over traditional methods of theory based courses. The chapter also identifies the disadvantages that arise if the design projects were not properly

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developed for the engineering students. It is summarized by identifying the gaps in the literature and the need for an assessment tool for engineering design projects. Chapter 3 gives a detailed methodology of tackling the disadvantages; gender bias, ambiguity, and major relatedness. In chapter 4, the results of the exploratory factor analysis are discussed to build the questionnaire, furthermore, it also describes the scoring method used in the assessment tool.

The effectiveness of the assessment tool is demonstrated in Chapter 5 with a case study about first year design project given to engineering students and how an instructor can use the tool in their design courses. Chapter 6 presents the conclusion of the thesis and discusses the shortcomings and future opportunities of research on the topic.

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CHAPTER 2. LITERATURE REVIEW

In this chapter, studies related to the background for developing the assessment tool for design project appropriateness were examined to understand and work toward addressing the research questions outlined in Chapter 1. The literature review is divided into five sections. Section 2.1 provides the importance of design studies in the engineering curriculum and highlights the benefits of PBL. Section 2.2 emphasizes the importance of engineering design project to manage the problem of gender bias. Section 2.3 offers the literature regarding the barrier of major relatedness of the engineering project to student learning. Section 2.4 shows the ambiguity-related literature on the design projects and the existing literature on the assessment of engineering design projects.

2.1. Design Courses in the Engineering Curriculum

Engineering design is a crucial part of the engineering learning process, and the engineering students require designing skills to help toward the degree program (Cheville & Bunting, 2011). These designing skills taught to modern engineering students, using traditional in-class teaching, are insufficient to prepare them for real-world engineering applications. Research has shown engineering graduates are inadequately prepared to meet the demands of the field in global issues (Todd, Sorensen, & Magleby, 1993; Wulf & Fisher, 2002). Mills (2003) demonstrated the traditional engineering curriculum and “chalk and talk” pedagogy cannot meet the demands set by the accreditation criteria and the industry, so a more hands-on and project-based curriculum introduced in the early years of the curriculum are beneficial in satisfying these demands.

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However, Astin (1993) stated only 43% of the engineering students in their first year go on to complete their degree. According to the results published by Higher Education Research Institute in 2010, the attrition rates are significantly higher for first-year students in science, technology, engineering, and mathematics (STEM) fields compared to the non-STEM fields. Even among the STEM fields, the attrition rate in the engineering discipline is considerably high (42%; Chen, 2013). Of these students, 20% left post-secondary education without a degree or certificate, and 21% of students switched to a different major field category Figure 1.

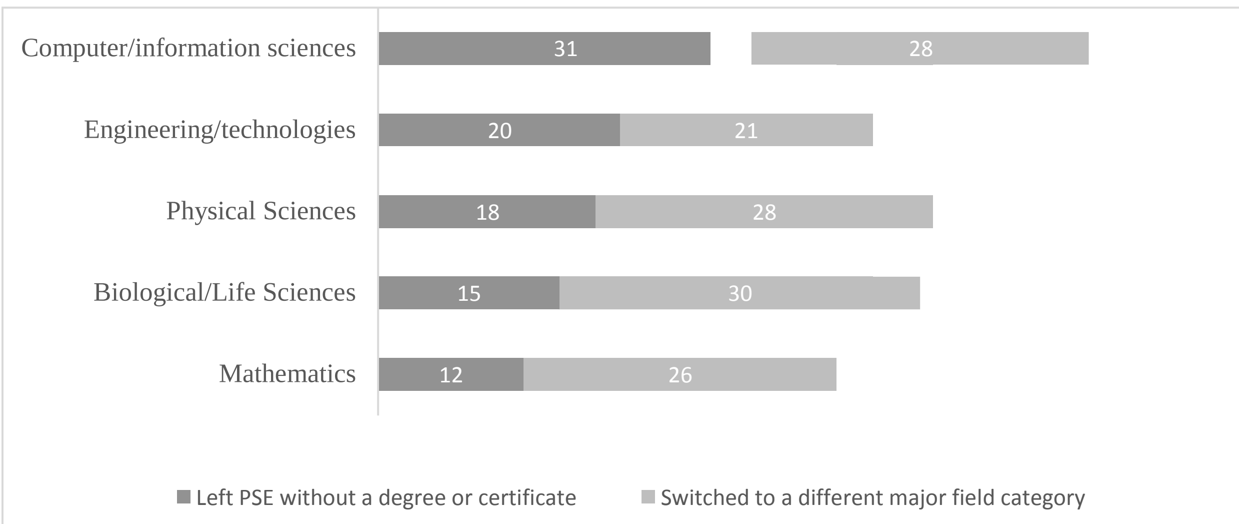

Figure 1. Attrition percentages for bachelors' students in STEM discipline.

To improve student retention, Tinto (2006) asserted faculty have the responsibility to successfully educate students, and there needs to be increased focus on the ways in which faculty can enhance student learning, which will, in turn, lead to student retention. Engineering programs with design courses appear to improve retention, student satisfaction, and student learning (Dym, Agogino, Eris, Frey, & Leifer, 2005). The design experience that the student gets from these courses enhances their academic

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engagement by improving the enthusiasm of working on a real-life problem. Therefore, there is an increased emphasis on providing design experience through integrated project-based learning throughout the engineering curriculum (Soman et al., 2016). Calabro, Kiger, Lawson, and Zhang (2008) revealed design project courses in the first year showed more favorable responses from students compared to traditional lecture methods. As a result, design courses with design projects that are sponsored by the industry are increasingly used in the engineering curriculum at the freshman level (Moskal, Knecht, & Lasich, 2002).

According to the ABET criteria for the evaluation cycle 2017-2018, the program outcomes and objectives 3.a and 3.c require engineers to "apply knowledge of math and science," "design a system or component," and "work in multidisciplinary teams." A good example of assessment of these criteria is through graded design projects in the introductory, junior, and senior capstone design courses (Spurlin, Rajala, & Lavelle, 2008). PBL provides an assessment medium that incorporates real-world problems and supports engineering students to learn from practice. The engineering students are able to relate to these real-world problems in their design project, and the relevance of these projects makes the design experience of the students enjoyable (Palmer & Hall, 2011). Student-centric activities in the form of PBL support improving student engagement and reducing attrition (Crosling, Heagney, & Thomas, 2009; Knight et al., 2007). Moreover, most of the engineering courses are theoretical in nature, which can act as a demotivating factor for the students. The motivation of the students can be improved through project-based learning, practical work, and active design projects (Baillie & Fitzgerald, 2000).

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Therefore, project-based learning is being introduced widely in the engineering curriculum to improve the motivation of the students and reduce the attrition rates.

Despite these advantages of project-based learning in the engineering curriculum, a few issues come along with the engineering design projects. The three major factors of an industrial design project's appropriateness for the first-year level are gender bias, domain relatedness, and ambiguity (Okudan et al., 2006). The following subsections discuss these issues in detail.

2.2. Gender Bias in Design Projects

Gender diversity has always been a problematic issue in the field of engineering. Gender stereotyping has resulted in the domain of engineering to be male-oriented. Women face a number of issues regarding authority and identity because of this stereotyping (Jorgensen, 2002). This discourages aspiring female engineers from entering the field of engineering. Also, the perception of specific design tasks to be more oriented to a particular gender can result in gender bias. This gender bias can make the design project skewed toward a specific gender and cause motivation loss among the students of that gender, and they leave the engineering domain (Okudan & Mohammed, 2006). For example, a design project with automobiles is more likely to be interesting to males compared to females, and this relevance may develop positive experiences.

To improve the female involvement in the engineering domain, Du and Kolmos (2009) suggested there is a need to develop effective teaching methods to help develop the skills that are more relevant with the real-world application and this can be achieved by utilizing PBL. Changes in the instructional methods can enable the persistence of both male and female students to pursue an engineering career (Amelink & Meszaros, 2011).

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First-year courses that are creative compared to traditional courses have shown to be effective in recruiting female students in engineering (Patterson, Campbell, Busch-Vishniac, & Guillaume, 2011) and the faculty must take steps to improve these classes. Ro et al. (2016) suggested to increase the female confidence in design skills, the faculty must find new ways to adjust the curriculum because the instructional approaches affect the gender differences in learning outcomes. Therefore, we need to study this aspect of gender bias in design projects to help the faculty develop the design projects in the first-year design course to be inclusive to both the genders. Managing the problem of gender bias by using design projects has shown to prevent motivation loss among engineering students and reduce attrition.

2.3. Major Relatedness in Design Projects

The design projects given to the students who are undecided about their major can lead to motivation loss if the design projects are not in the domain of their interest. Santiago et al. (2012) agreed that students leave the engineering major because their interests do not match with the said major. Therefore, the design project needs to be relevant to the students' major. PBL courses that involve interdisciplinary projects have a positive effect on students. They improve problem-solving skills and give a different perspective on the other discipline involved. These multidisciplinary projects are useful to engage the students in the learning process thereby improving retention (Koch, Dirsch-Weigand, Awolin, Pinkelman, & Hampe, 2017). These projects can also benefit the recruitment of female students due to raised subject awareness from other disciplines (Alpay, 2013). Therefore, design projects should have an interdisciplinary perspective to improve the motivation and retention of students in the engineering field. Students are

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sometimes not able to find a connection between their specific chosen major and the project, which causes a barrier in their learning (Richter & Paretti, 2009b). However, these interdisciplinary projects are beneficial for improving student engagement and the learning process; therefore, these design projects must be adequately developed to accommodate the interests of the students from multiple majors.

2.4. Ambiguity in Design Projects

Upon graduating from college, engineering students face real-world problems in the professional environment. These problems deal with uncertainty and are often open-ended and/or ill-structured and are different from problems in a classroom environment (Jonassen, Strobel, & Lee, 2006). Božić, Pavlović, Čizmić, and Tramullas (2014) studied the issues and challenges faced by engineering students when they face real-world problems, and one of the challenges was dealing with ambiguity where there may be multiple approaches to solving a problem and students do not obtain one correct and right solution to the problem. Ambiguity has also shown to cause frustration among the students when there is a lack of information about a topic (Dringenberg & Wertz, 2016). Therefore, the design projects should have the appropriate amount of ambiguity for students to feel more motivated to work on real-world problems (Tauritz, 2012).

Students need to be trained to deal with ambiguous situations to be prepared for real-world scenarios. It has been shown that students are capable of dealing with complex and ambiguous problems when they are properly guided by their instructors (Riis et al., 2016). There are tools to detect the ambiguity in a text (e.g., ARM, LOLITA) that use lexical tools to analyze and detect grammar and keywords. A major drawback of these software is that they are only as good as their program and that bad programming can

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lead to erroneous results. To determine if a potential uncertainty identified by the linguistic tool presents an actual problem, it ultimately needs human intervention (Berry, Bucchiarone, Gnesi, Lami, & Trentanni, 2006). Moreover, there are suggestions about developing measures to evaluate students' experiences with ambiguity (Dringenberg & Wertz, 2016). Therefore, there is the need to create a tool that helps the instructors to help students manage ambiguity in a design project. Developing this tool might improve student learning, and in turn, lead to reducing attrition loss in design courses.

2.4. Summary

It can be seen from the above literature review that the three issues of gender bias, major relatedness, and project ambiguity with the design projects are evident. Calabro and Gupta (2015) indicated curriculum developers should focus their attention to avoid any issues in the delivery of a new project in a first-year design course. Also, course instructors should craft effective problems for the students to prepare them for the real world with several factors involved (Hamid, Hassan, Yusof, & Hassan, 2005). Therefore, design projects need to be assessed appropriately by the instructors before they are delivered to students. This assessment is intended to help the instructor to design the project accordingly and manage the three disadvantages.

Although numerous frameworks are available to evaluate engineering design projects at the end of the semester to assess student performance (Atman, Chimka, Bursic, & Nachtmann, 1999; Palmer & Hall, 2011), for program and course assessment (Finelli & Wicks, 2000; Nicholls, Wolfe, Besterfield-Sacre, Shuman, & Larpkiattaworn, 2007), no framework or assessment tool exists to evaluate the design project based on the three factors mentioned above before it is given to the students. There is a need to

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develop an assessment tool that supports the course instructor in determining the appropriateness of the engineering design project based on gender bias, major relatedness, and project ambiguity. The tool developed in this study assesses a design project for the three issues and helps to determine the gender bias, major relatedness, and project ambiguity level for a given engineering design project.

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CHAPTER 3. METHODOLOGY

This chapter introduces a methodology to develop an assessment tool for determining the appropriateness of the engineering design projects. The primary goal of this work was to help the engineering design course instructor to determine the level of gender bias, major relatedness, and project ambiguity for a given design project. The first step was to perform factor analysis of the data obtained from a survey conducted at Penn State University that investigated the effects of gender bias, student's ambiguity tolerance, and major relatedness on students' self-efficacy. Factor analysis was conducted to determine the latent variables (i.e., factors in the survey). The second step was to determine the subfactors for each of the factors. In the next step, calculations were performed to determine the weights for these subfactors to determine their influence on the respective factors. These weights were then utilized to enter into the scoring method. The final score determined by the scoring method can be compared with the levels pre-defined for each factor to decide the appropriateness of the design project. The outline for developing the tool is given in the flowchart in Figure 2.

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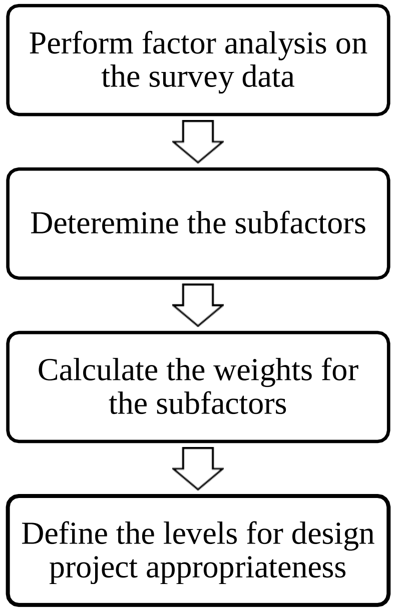

Figure 2. Methodology flowchart.

3.1 Factor Analysis

Exploratory factor analysis (EFA) is a statistical method used to determine the relationship between observed variables and the latent variables. A latent variable is an unobservable variable that needs to be interpreted by grouping the observed variables together based on their correlations with each other (Everitt & Hothorn, 2011). These latent variables are also called factors, and EFA helps to identify a meaningful structure of the data from the correlation between the observed variables. We performed EFA on the data collected at Penn State University.

3.1.1 Survey description

A survey (see Appendix A) was administered to the students of a first-year design course (EDSGN100) at Penn State University, the IRB memo is presented in Appendix B. The students in this course were given an industry-sponsored design project to work on over the semester. At the end of this course, they answered a survey regarding their

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experiences about working on the design project in the course. The questions on the survey asked students to indicate level of agreement on a five-point Likert scale between one (strongly disagree) and five (strongly agree). There were 63 such Likert scale-based questions; an additional 6 survey questions were open-ended and demanded a worded response from the students. The survey took approximately 15 minutes to complete and to motivate the students, extra credit was given to participate in the survey.

3.1.2 Survey participants

The survey was taken by 129 students (88 male and 41 female) who enrolled in an introductory engineering design course. The majority of the students (23.3%) indicated their major was mechanical engineering, followed by aerospace engineering and biomedical engineering with 14%. Students belonging to chemical, industrial, and civil engineering combined accounted for 29.5% of the total students. Only 2 students were undecided about their major/intended major, which accounts for 1.6% of the total students. The remaining students (14%) belonged to other majors such as nuclear, mining, engineering sciences, and computer sciences. Figure 3 depicts the distribution of the students according to their major/anticipated major.

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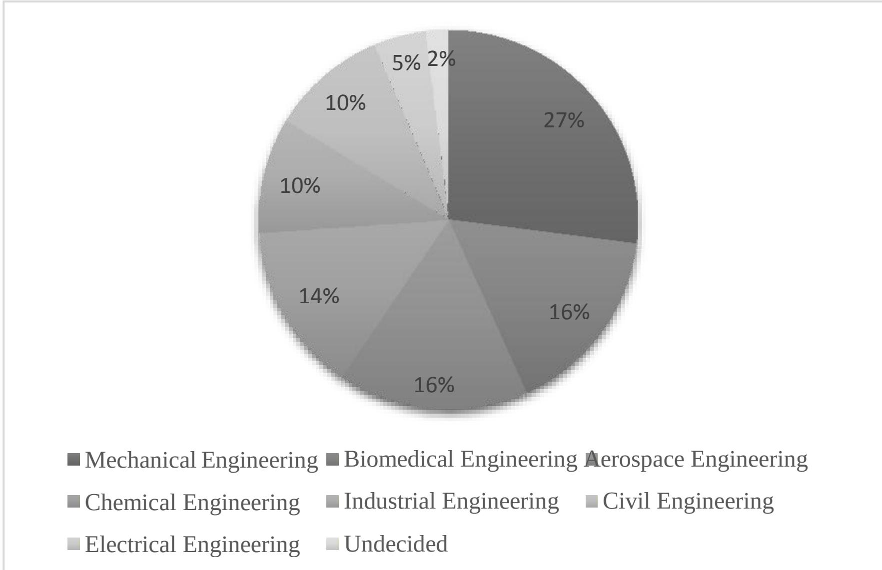

Figure 3. Percentage of students based on their major/anticipated major.

3.1.3 Data analysis

To perform the analysis, we had data from 129 students on 63 variables. Some of the values (0.37%) were missing randomly, so we performed mean imputation on the missing values. Therefore, these missing values in the data were replaced with the mean value of the responses for a particular question. After the data were cleaned an EFA was performed on the Likert scale data as a part of the statistical procedures. To perform a reliable factor analysis, the sample size must be large enough (Pett, Lackey, & Sullivan, 2003). To determine whether the sample size was large enough the Kaiser-Meyer-Olkin measure of sampling adequacy was used (Pett et al., 2003). For the Kaiser-Meyer-Olkin measure of sampling adequacy (Kaiser, 1974), the following values were placed on the results:

- 0.00 to 0.49—unacceptable,
- 0.50 to 0.59—miserable,
- 0.60 to 0.69—mediocre,

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- 0.70 to 0.79—middling,
- 0.80 to 0.89—meritorious, and
- 0.90 to 1.00—marvelous.

In addition to the KMO, Bartlett's test was used to test the hypothesis that there was no difference between the correlation matrix and an identity matrix. This test helped to identify whether the correlations among the variables we obtained from the data were significant and could be used for structure detection.

3.1.4 Determining the number of factors

Factor analysis does not give the number of factors in the underlying structure. Therefore, factor extraction was conducted. The extraction was done by a correlation matrix with eigenvectors, which are a linear representation of the variance that variables share (Pett et al., 2003). There are two common ways to determine the number of factors for extraction. The first method is to retain all the factors that have eigenvalues greater than one. However, when all factors with eigenvalues over one are selected, it may lead to too many factors being retained (Costello & Osborne, 2005). The other method is the scree diagram, which is a representation of the eigenvalue vs. the number of factors. In the scree diagram, the number of factors to be decided is the number corresponding to the "elbow" in the curve (Everitt & Hothorn, 2011).

3.1.5 Factor loading and rotation

Factor loadings ranged from −1 to 1 and represented the correlations between a question and a factor. These factor loadings were used in the interpretation of the factors, for example, more substantial loadings related a factor to the corresponding observed variables more than a question with a lower loading and from these, and we inferred a

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meaningful interpretation for each factor. Rotation is a mathematical process where the axes of factors are rotated to fit the actual data points better and to make the factors more easily interpretable. There are two different types of rotation; orthogonal rotation is used when factors are assumed to be independent and oblique rotation is used when the factors are expected to correlate.

3.1.6 Elimination of the items

Once we had a set of factor loadings, we grouped the questions with higher factor loadings together to reveal the latent variable (i.e., factor). Factor loadings higher than 0.6 were considered to be high and above 0.4 were regarded as moderate (Hair, Black, Babin, Anderson, & Tatham, 1998). The decision to eliminate the questions was based on these factor loadings. The questions that loaded less than 0.4 were not closely related to the factor, and thus, we excluded those questions. The factor analysis was rerun after removing the questions to confirm that the correct number of latent factors was selected.

3.2 Determining the Subfactors

The EFA presents the underlying structure of the data collected from the students regarding their perceptions about the design project. After elimination of the questions at the end of the EFA, the questions that remained were more related to the latent factors since they had high factor loading values. These high loading questions were used to develop the subfactors for the main factors. Further, the questions for the assessment tool were developed based on the selected subfactors for each factor. The subfactors developed from the survey questions that were related to the project characteristic factors were combined with studies in the literature to provide face validity to the EFA results.

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3.3 Calculate the Weights for the Subfactors

The subfactors that we obtained from the EFA did not have the same effect on the factor. To calculate the weights for the subfactors, the analytical hierarchical process (AHP) was used. The AHP process was developed by Saaty in 1990, as a multi-criteria decision-making approach that is widely used in ranking and prioritization of the alternatives. It is a quantitative comparison method based on pairwise comparison of the different alternatives. The process was initiated by performing a pairwise comparison matrix of the subfactors. The comparison took into consideration the preferences of the decision maker (i.e., the course instructor). In our case, these subfactors were rated against each other by an educational expert who had experience in the engineering education field. These ratings were based on the scale developed by Saaty, the scale represents the numbers one to nine to show the magnitude of the relation between the subfactors. The explanation for each scale is given in Table 1. However, to measure the consistency in their ratings, the consistency index (CI) was defined as follows:

$$CI = \lambda - n/(n-1)$$

Where λ was the principal eigenvalue and n was the number of subfactors. In the next step, the consistency ratio was calculated by comparing the CI of the pairwise matrix to the consistency index of a random matrix. A random matrix was constructed entirely randomly and was expected to be inconsistent. The random index (RI) is the average CI of 500 random matrices calculated by Saaty for matrices of the size 1 to 10 and can be found in Saaty (2005). According to Saaty (2005), a consistency of 0.10 or less is considered acceptable. To calculate the weights for the subfactors, the eigenvalues of the

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comparison matrix were calculated by taking the n^{th} root of the product of the elements in a row, where n was the number of subfactors. These eigenvalues were then normalized to one to obtain the weight of the subfactors. They were the priorities developed from the comparison matrix to determine the relative importance of each subfactor. The weights calculated were used in conjunction with the questions developed from the subfactors to build the assessment tool.

Table 1. Saaty's scale for comparison

Scale	Degree of Preference	Explanation
1	Equally	The two compared elements contribute to the goal equally
3	Moderately	Experience and judgment slightly favor one element over other
5	Strongly	Experience and judgment strongly favor one element over other
7	Very strongly	An activity is strongly favored, and its dominance demonstrated in practice
9	Extremely	The evidence favoring one over the other is of the highest possible affirmation
2,4,6,8	Intermediate values	When compromise is needed

3.4 Scoring Method

The evaluator assigned a score on a five-point Likert scale (one indicating strongly disagree and five indicating strongly agree) for each question. Each individual score was multiplied by the weights, which were determined by AHP process to calculate a weighted score for that subfactor. By taking the weighted average of subfactors in Equation 1, the appropriateness level of the design project for each factor (i.e., gender bias, major relatedness, and ambiguity) was determined. In Equation 1, w_i was the weight of each subfactor, x_i was the evaluating score of the expert, and $\bar{x}$ showed the final score of each factor.

$$\bar{x} = \frac{\sum_{i=1}^{n} wixi}{wi} \tag{1}$$

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3.5 Levels to Determine the Appropriateness

The scoring method gave a final score $\bar{x}$, for each of the factors based on the instructors' responses to the questions. We defined the levels to gauge the appropriateness of the design project for each factor of gender bias, ambiguity level, and major relatedness. Since the instructor scores the questions on a five-point Likert scale, with two points (one, two) disagree and (four, five) agree, on each side of the neutral level (three), we determined the three levels for appropriateness on a scale similar to the five-point scale. The levels for each of the factors are defined as follows.

3.5.1 Gender bias of the design project

Weak gender bias: The design project is weakly associated with the properties perceived to be related to the gender bias of a design project.

Neutral gender bias: The project is neither strongly nor weakly associated with the properties perceived to be related to the gender bias of a design project.

Strong gender bias: The design project is strongly associated with the properties perceived to be related to the gender bias of a design project.

Table 2. Assessment score intervals for gender bias of a design project

< 2.5	2.5-3.5	> 3.5
Weak gender bias	Neutral gender bias	Strong gender bias

3.5.2 Ambiguity level of the design project

Weak ambiguity level: The design project is weakly associated with the properties perceived to be related to ambiguity.

Neutral ambiguity level: The project is neither strongly nor weakly associated with the properties perceived to be related to ambiguity.

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Strong ambiguity level: The design project is strongly associated with the properties perceived to be related to ambiguity.

Table 3. Assessment score intervals for ambiguity level of a design project

< 2.5	2.5-3.5	> 3.5
Weak ambiguity level	Neutral ambiguity level	Strong ambiguity level

3.5.3 Major relatedness of the design project

Weak major relatedness level: The design project is weakly associated with the properties perceived to be related to the major relatedness of a design project.

Neutral major relatedness level: The project is neither strongly nor weakly associated with the properties perceived as the major relatedness of a design project.

Strong major relatedness level: The design project is strongly associated with the properties perceived to be related to the major relatedness of a design project.

Table 4. Assessment score intervals for major relatedness of a design project

< 2.5	2.5-3.5	> 3.5
Weak major relatedness level	Neutral major relatedness level	Strong major relatedness level

The levels of appropriateness for the three factors depicted in Table 2, Table 3, and Table 4 act as the guideline when the instructor evaluates a particular design project. The final score obtained after using the assessment questionnaire shall be compared with these levels to determine the gender bias level, ambiguity level and major relatedness level of an engineering design project.

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CHAPTER 4. RESULTS

This chapter is divided into three sections. Section 4.1 explains the results from the EFA, section 4.2 describes the selection of subfactors and section 4.3 explains the results for the weight calculation for the subfactors.

4.1 Exploratory Factor Analysis

4.1.1 Sampling adequacy

The Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy for data that we collected had a value of 0.75. Using the result values presented by Kaiser (1974), the KMO value generated from this dataset of 0.75 was high enough to run a factor analysis on these data. Bartlett's test of sphericity, which tests the correlation matrix against an identity matrix, was significant ($p < .05$) and the data were incompatible with the hypothesis that there was no difference between the correlation matrix and an identity matrix. This incompatibility could be interpreted as providing evidence against the hypothesis (Wasserstein & Lazar, 2016) indicating that the correlation matrix was significantly different than an identity matrix and it was appropriate to use the factor analysis method on this dataset.

4.1.2 Determining the number of factors

The first method of choosing the number of factors was using the eigenvalues and any factor having an eigenvalue greater than one was retained. However, this resulted in retaining 17 factors for the given dataset, which is quite large. Therefore, the scree diagram method Figure 4 was used to determine the number of factors. There is an elbow after four factors. Thus, we chose four factors to sufficiently describe the underlying structure of the data.

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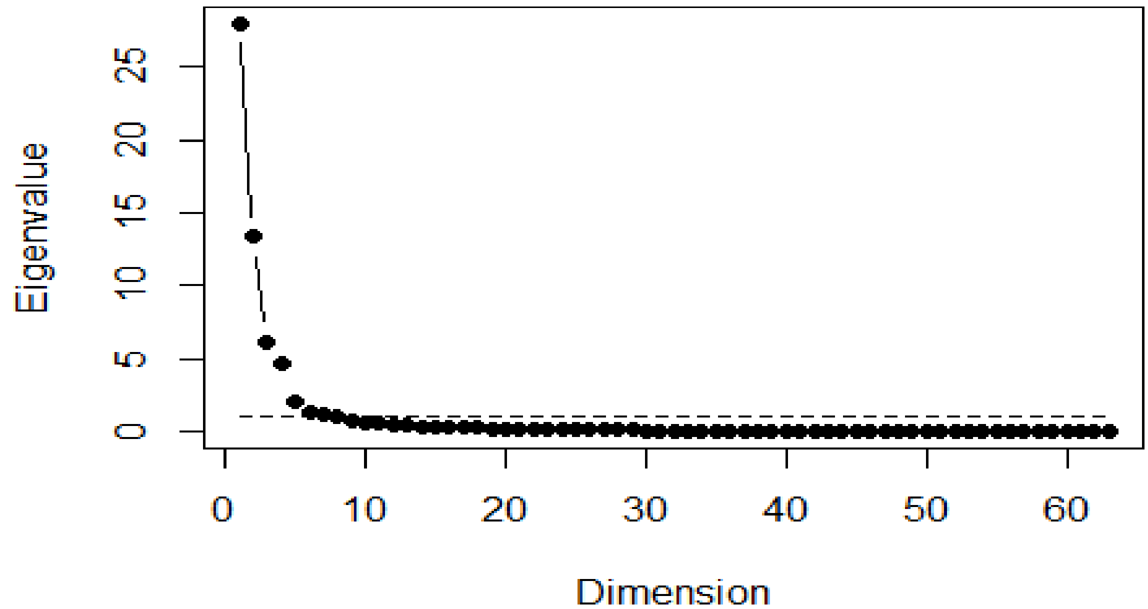

Figure 4. Scree plot to determine the number of factors

4.1.3 Factor rotation and loading

Orthogonal rotation using varimax rotation is the most commonly used method (Gorsuch, 1983) in factor analysis and we rotated the factors using this method. After rotation, we obtained factor loading on the questions for each factor. Initial factor loadings are presented in Table 5.

Table 5. Initial factor loading

No.	Questions	Factor Loadings			
		I	II	III	IV
1	I don’t tolerate ambiguous situation well.			−0.51	
2	I find it difficult to respond when faced with an unexpected event.			−0.41	
3	I don’t think new situations are any more threatening than familiar situations.				
4	I am drawn to situations, which can be interpreted in more than one way.			0.55	
5	I would rather avoid solving a problem that must be viewed from several different perspectives.			−0.50	
6	I try to avoid situations, which are ambiguous.			−0.65	
7	I am good at managing unpredictable situations.			0.47	
8	I prefer familiar situations to new ones.			−0.46	
9	Problems which cannot be considered from just one point of view are a little threatening.				

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Table 5. (continued)

10 I avoid situations, which are too complicated for me to easily understand.		−0.58
11 I am tolerant of ambiguous situations.		0.57
12 I enjoy tackling problems, which are complex enough to be ambiguous.		0.66
13 I try to avoid problems, which don't seem to have one "best" solution.		−0.51
14 I often find myself looking for something new, rather than trying to hold things constant in my life.		
15 I generally prefer novelty over familiarity.		
16 I dislike ambiguous situations.		−0.56
17 Some problems are so complex that just trying to understand them is fun.		0.56
18 I have little trouble coping with unexpected events.		
19 I pursue problem situations which are so complex that some people call them "mind-boggling."		0.53
20 I find it hard to make a choice when the outcome is uncertain.		
21 I enjoy an occasional surprise.		0.42
22 I prefer a situation in which there is some ambiguity.		0.51
23 I am satisfied with the way my team worked together.	0.87	
24 Team members have worked better together now than when the team was formed.	0.71	
25 Team members are more aware of the group dynamics now than when they joined the team.	0.74	
26 Being a part of this team has helped members appreciate different types of people.	0.65	
27 Overall, I am satisfied with team performance on projects.	0.88	
28 If we have had another engineering project, this team should not continue to function as a team.	−0.66	
29 If I could have left this team and worked with another team, I would have.	−0.80	
30 I would not hesitate to participate in another project with the same team members.	0.78	
31 This team is not capable of working together as a unit.	−0.70	
32 I am satisfied with this team compared to teams I have been on in the past.	0.72	
33 Our team has tackled difficult work assignments enthusiastically.	0.73	
34 Team members have adapted their schedules to meet one another's demand.	0.72	
35 Our team have supported and encouraged team members with problems.	0.77	
36 Team members have helped each other with their tasks.	0.77	
37 Team members have respected one another and show understanding.	0.74	
38 Team members have given their opinion when it concerned with important issues.	0.60	
39 Members have maintained a positive attitude about the team.	0.76	
40 We have effectively talked through disagreements about ideas/opinions in my group.	0.77	
41 We have effectively talked through disagreements about procedures (the way we get work done) in my group.	0.68	
42 We have effectively dealt with interpersonal friction/ personality clashes in my group.	0.40	
43 The members of this group have excellent skills in team-working and communication.	0.85	

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Table 5. (continued)

44 I have real confidence in my group's ability to perform well on projects.	0.83			
45 This group did/has not done as well as other groups in my class.	−0.74			
46 Some members in this group did not do/ have not done their jobs well.	−0.64			
47 I have had to work closely with my teammates to do my work properly.				
48 The project my group worked on was associated with a masculine or feminine product or object (e.g., guns, rockets, explosives make me think of males).		0.82		
49 The project my group worked on was associated with a masculine or feminine experience (e.g., cooking makes me think of females).		0.80		
50 The project my group worked on was associated with a masculine or feminine institution (e.g., the military makes me think of males).		0.87		
51 The project my group worked on was associated with a masculine or feminine action related (e.g., teaching makes me think of females).		0.82		
52 The project my group worked on was associated with a masculine or feminine interest related (e.g., war affects everyone, but men tend to be more interested).		0.84		
53 The project my group worked on was associated with a masculine or feminine idea generation (e.g., the ideas were mostly contributed by the males).		0.75		
54 The project my group worked on was associated with a masculine or feminine background knowledge (e.g., females know how to socially work in a group).		0.83		
55 The project my group worked on was associated with a masculine or feminine female composition (e.g., the group was all male).		0.49		
56 The industrial sponsored project this semester relates to my major/anticipated major.				0.53
57 The industrial sponsored project has motivated/inspired me to learn.				0.82
58 The skills I learned through this industrial sponsored project has helped me easily decide/choose/or stay with my major.				0.75
59 The satisfaction I have felt throughout this industrial sponsored project has helped me easily decide/choose or stay with my major.				0.81
60 This industrial sponsored project will positively impact the way I evaluate the course and course instructor at the end of the semester when the SRTE (Student Rating of Teaching Effectiveness) is conducted.				0.76
61 This industrial sponsored project will positively impact the way I evaluate the course instructor at the end of the semester when the SRTE (Student Rating of Teaching Effectiveness) is conducted.				0.70
62 The industrial sponsored project this semester has positively impacted me to stay with my major/anticipated major.				0.75
63 I found certain aspects of the design project to be related to my chosen discipline.				0.46

From the initial factor loadings in Table 5, we observed that the questions loaded on the factors in a distinct pattern with a factor loading higher than 0.4. The questions that loaded less than 0.4 were eliminated, as they were not related to any factor. Based on

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the loadings, we eliminated questions 2, 3, 9, 14, 15, 18, 20, and 47. The factor analysis is rerun after performing the elimination to check again for factor loadings. The factor loadings after elimination are presented in Table 6.

Table 6. Factor loading after elimination

No.	Questions	Factor Loadings			
		I	II	III	IV
1	I don’t tolerate ambiguous situation well.			−0.53	
2	I am drawn to situations, which can be interpreted in more than one way.			0.54	
3	I would rather avoid solving a problem that must be viewed from several different perspectives.			−0.50	
4	I try to avoid situations, which are ambiguous.			−0.65	
5	I am good at managing unpredictable situations.			0.41	
6	I prefer familiar situations to new ones.			−0.43	
7	I avoid situations, which are too complicated for me to easily understand.			−0.56	
8	I am tolerant of ambiguous situations.			0.60	
9	I enjoy tackling problems, which are complex enough to be ambiguous.			0.67	
10	I try to avoid problems, which don’t seem to have one “best” solution.			−0.49	
11	I dislike ambiguous situations.			−0.59	
12	Some problems are so complex that just trying to understand them is fun.			0.54	
13	I pursue problem situations which are so complex that some people call them “mind-boggling.”			0.52	
14	I enjoy an occasional surprise.			0.43	
15	I prefer a situation in which there is some ambiguity.			0.55	
16	I am satisfied with the way my team worked together.	0.87			
17	Team members have worked better together now than when the team was formed.	0.71			
18	Team members are more aware of the group dynamics now than when they joined the team.	0.74			
19	Being a part of this team has helped members appreciate different types of people.	0.64			
20	Overall, I am satisfied with team performance on projects.	0.87			
21	If we have had another engineering project, this team should not continue to function as a team.	−0.66			
22	If I could have left this team and worked with another team, I would have.	−0.81			
23	I would not hesitate to participate in another project with the same team members.	0.78			
24	This team is not capable of working together as a unit.	−0.70			
25	I am satisfied with this team compared to teams I have been on in the past.	0.72			
26	Our team has tackled difficult work assignments enthusiastically.	0.72			
27	Team members have adapted their schedules to meet one another’s demand.	0.72			
28	Our team have supported and encouraged team members with problems.	0.77			

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Table 6. (continued)

29 Team members have helped each other with their tasks.	0.77		
30 Team members have respected one another and show understanding.	0.74		
31 Team members have given their opinion when it concerned with important issues.	0.60		
32 Members have maintained a positive attitude about the team.	0.76		
33 We have effectively talked through disagreements about ideas/opinions in my group.	0.77		
34 We have effectively talked through disagreements about procedures (the way we get work done) in my group.	0.68		
35 We have effectively dealt with interpersonal friction/ personality clashes in my group.	0.40		
36 The members of this group have excellent skills in team-working and communication.	0.85		
37 I have real confidence in my group's ability to perform well on projects.	0.83		
38 This group did/has not done as well as other groups in my class.	−0.74		
39 Some members in this group did not do/ have not done their jobs well.	−0.64		
40 The project my group worked on was associated with a masculine or feminine product or object (e.g., guns, rockets, explosives make me think of males).		0.82	
41 The project my group worked on was associated with a masculine or feminine experience (e.g., cooking makes me think of females).		0.81	
42 The project my group worked on was associated with a masculine or feminine institution (e.g., the military makes me think of males).		0.87	
43 The project my group worked on was associated with a masculine or feminine action related (e.g., teaching makes me think of females).		0.82	
44 The project my group worked on was associated with a masculine or feminine interest related (e.g., war affects everyone, but men tend to be more interested).		0.84	
45 The project my group worked on was associated with a masculine or feminine idea generation (e.g., the ideas were mostly contributed by the males).		0.75	
46 The project my group worked on was associated with a masculine or feminine background knowledge (e.g., females know how to socially work in a group).		0.83	
47 The project my group worked on was associated with a masculine or feminine female composition (e.g., the group was all male).		0.49	
48 The industrial sponsored project this semester relates to my major/anticipated major.			0.53
49 The industrial sponsored project has motivated/inspired me to learn.			0.82
50 The skills I learned through this industrial sponsored project has helped me easily decide/choose/or stay with my major.			0.75
51 The satisfaction I have felt throughout this industrial sponsored project has helped me easily decide/choose or stay with my major.			0.82
52 This industrial sponsored project will positively impact the way I evaluate the course and course instructor at the end of the semester when the SRTE (Student Rating of Teaching Effectiveness) is conducted.			0.76
53 This industrial sponsored project will positively impact the way I evaluate the course instructor at the end of the semester when the SRTE (Student Rating of Teaching Effectiveness) is conducted.			0.70

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Table 6. (continued)

54	The industrial sponsored project this semester has positively impacted me to stay with my major/anticipated major.	0.75
55	I found certain aspects of the design project to be related to my chosen discipline.	0.46

Based on the factor loading in Table 6, we observed a distinct pattern of questions loading on four different factors. We grouped the questions loading on each factor together to interpret these factors. The first factor included questions asked to the students related to their perceptions about working in a team environment and tried to gauge their willingness to work with a team of students. Thus, factor I with loadings on these questions indicated the measure of *student's collective efficacy*. The second factor included questions about the students' perceptions about the design project related to gender. Thus, factor II, with positive loading on these questions, indicated the measure the *gender bias of the design project*. The third factor asked the students about their willingness to work in an ambiguous and abstract environment. Therefore, factor III with loadings on this set of questions indicated the *students' tolerance to ambiguity*. Similarly, factor IV indicated the *students' perceptions about the major relatedness of the design project*.

The latent factors derived from the EFA are as follows:

- students' collective efficacy,
- gender bias of the design project,
- students' tolerance to ambiguity, and
- students' perceptions about the major relatedness of the design project.

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4.2 Selection of Subfactors

The questions that remained after elimination were used along with literature studies to determine the subfactors for the three major factors. These questions had high values of loadings on the factors and were more related to the respective factor. Also, the scope of this work revolved around the characteristics of a design project regarding three factors of ambiguity, gender bias, and major relatedness of the project, so we focused on the three latent factors: II, III, and IV.

4.2.1 Gender bias of the design project

Questions, Q 40 to Q 47 on the survey were related to the latent factor of gender bias in the design project. These questions were used to determine the subfactors for the gender bias factor. Okudan and Mohammed (2006) conducted a study to investigate the gender orientation of design task domains and developed a set of attributes for design tasks. They conducted the study in a first-year design course and collected responses about the design task gender perception from the students. This study indicated the responses for the students could be coded to seven attributes, which align with the seven questions on the survey for latent factor II. Thus, these seven questions were the subfactors for the gender bias factor. These attributes are given in Table 7.

4.2.2 Ambiguity level of the design project

Questions Q1 to Q15 on the survey were related to the latent factor for students' tolerance to ambiguity and were used to determine the subfactors for ambiguity level. The industry-sponsored projects assigned to the students were real-world problems and were complex, open-ended, and required consideration of diverse criteria; they were

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known to be inherently ambiguous (Jonassen et al., 2006). Some of the attributes of problems engineers should solve include having more than one correct solution due to being open-ended, and being complex and unpredictable, which align with questions Q5, Q9, and Q10 on the ambiguity factor.

"End user needs" was one of the factors needed to execute a project successfully and the goals of a project needed to be defined clearly to meet project success without being able to be interpreted in multiple ways (Chan, Scott, & Lam, 2002; Jonassen et al., 2006). This property of clearly defined goals aligned with Q2 on the survey. Representations and diagrams play an important role in engineering problem solving; these problems can be simplified using diagrams. However, ill-structured representations and diagrams lead to ambiguity (Goel, 1992; Johri, Roth, & Olds, 2013; Jonassen et al., 2006) and it is necessary to have clear representations. In a study to determine the barriers to creativity in engineering problem solving, Kazerounian and Foley (2007) explained how ambiguity is a good factor for students to solve problems. The ambiguity is necessary to develop innovation, and therefore, a student develops innovative solutions in the presence of ambiguity. Gaver, Beaver, and Benford (2003) described ambiguity to be a property of an interpretive relationship. The ambiguity of information arises from the way information is presented, and the context of the problem needs to be explained to reduce ambiguity. This property of context aligned with question Q6 on the survey. The subfactors for ambiguity are given in Table 7.

4.2.3 Major relatedness of the design project

Q48 to Q55 on the survey were related to the students' perceptions about the major relatedness of the design project. However, these questions did not specifically

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question the students about the project characteristics. Therefore, we used studies in the literature to develop the subfactors for major relatedness. Holland (1997) proposed a theory to explain college students' selection of an academic major. It described that people and their working environments could be categorized into one of six types: realistic, investigative, artistic, social, enterprising, and conventional. Students actively seek out and select majors that are compatible with their personality types and are more likely to flourish in an academic environment that is congruent with their personality types. This congruency between the student and the corresponding academic environment was positively related to student engagement and student learning (Pike, Smart, & Ethington, 2012). Based on Holland's classification of the academic environment, mechanical and electrical engineering majors were categorized as realistic; aerospace, chemical, and civil engineering majors were categorized as investigative; and the industrial engineering major was categorized as enterprising. These environments have prominent features assumed to reinforce the students' learning in the corresponding environment. These features of the academic environments; the nature of the project activity; the competency learned in the environment, and self-perception of values were distinct for each of Holland's academic environments. These features were then paired to the engineering majors according to the environment to be used for the subfactors of the major relatedness factor. Table 7 shows the subfactors for the major relatedness factor. The questionnaire (see Appendix C) provided to the instructor was developed based on the subfactors established in this section.

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Table 7. Subfactors for the three main factors

Main Factor	Subfactors	
Gender bias	Product	Interest
	Institution	Idea generation
	Experience	Background knowledge
	Action	Composition
Ambiguity level	Ill-structured representations	Innovation
	More than one solution to a problem	Vague or undefined goals
	Context explanation	
Major relatedness	Project activity	Self-perception of values
	Competency	

4.3 Weight Calculation for the Subfactors

The first step to determine the weights of the subfactors using AHP was to obtain comparisons between the different subfactors. Educational experts were asked to rate the subfactors against each other based on Saaty's scale described in Table 1. The comparison matrices for gender bias, ambiguity level, and major relatedness are given in, Table 8, Table 10, and Table 12 respectively. The consistency ratio was calculated after the comparison to check whether the educators were consistent in their ratings of the attributes.

Table 8. Comparison table for gender bias subfactors

	Product	Institution	Experience	Action	Interest	Idea Generation	Background Knowledge	Composition
Product	1	5	3	3	5	7	7	9
Institution	1/5	1	1/7	1/5	1/3	3	3	5
Experience	1/3	73	1	2	5	7	7	7
Action	1/3	5	1/2	1	5	7	7	7
Interest	1/5	3	1/5	1/5	1	5	5	5
Idea generation	1/7	1/3	1/7	1/7	1/5	1	3	2
Background knowledge	1/7	1/3	1/7	1/7	1/5	1/3	1	2
Composition	1/9	1/5	1/7	1/7	1/5	1/2	1/2	1

To calculate the consistency ratio, we first calculated the CI for gender bias subfactors to be 0.13. The value for the RI for a matrix of 8 variables was 1.41 (Saaty, 2005)., The consistency ratio (CR) as 0.092, where CR = CI/RI. According to Saaty

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(2005), a consistency of 0.10 or less can be considered acceptable. Since the CR was less than 0.10, we could say the comparison was consistent with the gender bias factor. We then calculated the principal eigenvectors of the comparison matrix to help us calculate the relative weights of the subfactor. The normalized weights of each subfactor of gender bias were as follows.

Table 9. Normalized weights for gender bias sub factors

Subfactor	Product	Institution	Experience	Action	Interest	Idea Generation	Background Knowledge	Composition
Normalized weight	0.33	0.06	0.24	0.20	0.09	0.03	0.03	0.02

Table 10. Comparison table for ambiguity level subfactors

	Goal	Context	Diagram	More than one solution	Innovation
Goal	1	2	5	6	7
Context	1/2	1	5	6	7
Diagram	1/5	1/5	1	5	5
More than one solution	1/6	1/6	1/5	1	3
Innovation	1/7	1/7	1/5	1/3	1

The CI for ambiguity subfactors was calculated to be 0.13. The value for the RI for matrices of 5 variables was 1.12 (Saaty, 2005, p. 374). Next, we calculated the CR, which was the ratio of CI and RI. For the ambiguity subfactors, a CR of 0.09 that is less than 0.10 was considered acceptable (Saaty, 2005). We concluded the pairwise comparisons that were performed were consistent for ambiguity subfactors. The principal eigenvectors of the comparison matrix helped to compute the normalized relative weights of the attributes.

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Table 11. Normalized weights for ambiguity level subfactors

Subfactor	Unclear Goal	Context	Ill-Structured Diagram	More than One Solution	Innovation
Normalized weight	0.441	0.334	0.132	0.058	0.035

Table 12. Comparison table for major relatedness subfactors

	Project Activity	Competency	Self-Perception of Values
Project activity	1	5	7
Competency	1/5	1	3
Self-perception of values	1/7	1/3	1

To calculate the CR, which is the ratio of CI and RI, CI for major relatedness subfactors was calculated to be 0.13. The value for the RI for matrices of 3 variables was 0.58 (Saaty, 2005, p. 374). Therefore, the CR was the 0.05. According to Saaty, a consistency of 0.10 or less could be considered acceptable. Therefore, the major relatedness pairwise comparison was consistent. The principal eigenvectors of the comparison matrix were calculated to help determine the normalized relative weights of the attributes.

Table 13. Normalized weights for major relatedness subfactors

Subfactor	Project Activity	Competency	Self-perception of Values
Normalized weight	0.73	0.18	0.08

The normalized weights developed in Table 9, Table 11, and Table 13 act as guidelines for the sub-factors of gender bias, ambiguity level and major relatedness factor respectively. These weights are multiplied to the instructor scores for each respective question in the questionnaire (see Appendix C) to get a final score. The functioning of the assessment tool is explained in the chapter 5 with the help of a case study.

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CHAPTER 5. CASE STUDY

In this section, a case study was conducted to understand the implementation of the assessment tool developed in this study. The scenario involves the author performing the function of the instructor and replicating the classroom environment where the instructor was tasked with delivering a design project to the class. Before delivering the design project to the class, it was evaluated using the assessment tool. The project description was rated based on the questions on the assessment tool for the factors of gender bias, ambiguity, and major relatedness. Based on the rating, a final score was calculated to determine the level of appropriateness and compared with the students' perceptions about the same project for the three factors. The following project description was taken from an engineering design course offered to first-year engineering students at Penn State University delivered in the spring semester of 2017.

5.1 Project Description

In 2012, a large rare-earth element ore deposit was discovered deep beneath the Pocono Mountains in Pennsylvania. This deposit, which is rich in the elements Neodymium (Nd), Europium (Eu), Terbium (Tb), Dysprosium (Dy), and Yttrium (Y), is the largest ever discovered, and it would allow the United States to overtake China with regard to rare-earth element reserves and production. The ore is located approximately 10,000 meters beneath the Earth's surface, and over the last 5 years, mine infrastructure has been established to allow for ore extraction. Due to the depth of the ore, mine infrastructure development proved to be extremely challenging, as air quality and temperature were difficult to control. Despite a large amount of ventilation infrastructure (including heating, ventilation, and air conditioning systems to cool the air), several mine

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workers died during development due to carbon monoxide poisoning or heat-related ailments. Because of this, the Pennsylvania government has introduced new regulations regarding air quality for workers, which will make it impossible to use emissions-based equipment (e.g., diesel, natural gas) during the production phase of the mine. The mine was set up as a block cave operation and was intended to utilize load haul dump vehicles and haul trucks to extract and transport the ore to the surface for processing. Deviation or pursuit of a change from this mining method would be extremely costly and delay production for years. The Pennsylvania government has put out on open bid for an engineering company to develop a strategy to extract the ore cost-effectively and in the most environmentally-friendly manner. This could include vehicles with alternative power sources or new methods that could exploit the current mine setup. One government official stated special consideration would be given to bidders that could create jobs while ensuring worker safety with regard to environment (e.g., air quality, temperature) and general work hazards (e.g., crashes, cave-ins)

Each design team should research and develop a strategy to meet the bid objectives of the PA government. For your concept, consider alternatives to traditional mining methods and extraction equipment and provide recommendations with an emphasis on impact to:

- *emissions/regulatory/environmental requirements,*
- *safety,*
- *costs (e.g., fuel, infrastructure),*
- *public opinion, and*
- *productivity.*

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Known parameters and assumptions

- *The rare-earth element concentration is uniform throughout the ore deposit.*
- *The rare-earth ore is worth $10,000/ton extracted.*
- *The haul truck ramp from the extraction level to the surface processing plant is 8 km long at a constant 10% grade.*
- *The block cave draw points can provide 10 metric tons of fragmented ore per 10 metric tons extracted.*
- *There are 100 draw points in the mine.*
- *The average distance between a draw point and haul truck pickup locations is 300 meters.*

Project deliverables

Note: Your instructor will clarify her or his expectations for these deliverables and respective due dates:

- *a technical report containing the following elements,*
- *the rationale for the recommendation,*
- *description of alternative concepts and their evaluation,*
- *systems diagram(s),*
- *concept of operations,*
- *environmental analysis,*
- *assessment of important aspects of your system for feasibility and adoption, including public opinion,*
- *the economic viability of the system,*

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- *computer-aided drafting drawings, and*
- *model or prototype of a component of the overall system.*

Additional resources

- *EDSGN 100 project website*

  http://sedtapp.psu.edu/design/design_projects/edsgn100/fa15
- *GE Transportation website*

  http://www.getransportation.com/
- *GE battery load haul dump YouTube link*

  https://www.youtube.com/watch?v=3p5OBo3sh1g
- *Block cave mining YouTube links*

  https://www.youtube.com/watch?v=MVDAw56s5dU

  https://www.youtube.com/watch?v=5woCaxXB7Jk
- *Underground equipment links*

  http://mining.sandvik.com/en/products/equipment/underground-loading-andhauling/underground-trucks

  http://mining.sandvik.com/en/products/equipment/underground-loading-and-hauling

  http://www.gefairchild.com/PDF/full-brochure.pdf

  https://www.getransportation.com/mining#mining-equipment

5.2 Gender Bias of the Design Project

The instructor (author) rated the questions related to the gender bias of the design project on the assessment tool as follows.

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Table 14. Score assignment to design project for gender bias

On a scale of 1 (strongly disagree)-5 (strongly agree) rate the following questions	Score	Weights	W Values
The project activity is associated with a masculine or feminine product or object (e.g., guns, rockets, explosives make me think of males).	3	0.33	1.00
The project activity is associated with a masculine or feminine institution (e.g., the military makes me think of males).	4	0.06	0.23
The project activity is associated with a masculine or feminine experience (e.g., cooking makes me think of females).	4	0.24	0.97
The project activity is associated with a masculine or feminine action (e.g., teaching makes me think of females).	4	0.20	0.78
The project activity is associated with a masculine or feminine interest (e.g., war affects everyone, but men tend to be more interested).	4	0.09	0.36
The project activity is associated with a masculine or feminine idea generation (e.g., the ideas were mostly contributed by the males).	1	0.03	0.03
The project activity is associated with a masculine or feminine background knowledge (e.g., females know how to socially work in a group).	3	0.03	0.08
The project activity is associated with a masculine or feminine composition (e.g., the group was all male).	1	0.02	0.02
Final score.		3.47	

These scores reflected the way instructor perceived the design project while answering each question. The w values are the scores that are multiplied by the weights. Using the equation 1, the instructor evaluated the project for gender bias to 3.47. This score was compared to the levels in Table 2, indicating the project to be of neutral gender bias. The mean of the responses for the students' perceptions of the gender bias of the design project was 2.58, from the survey responses, which indicated the project was perceived to be of neutral gender bias by the students. These neutral gender bias results for the instructor, indicate that the design project was not biased towards any particular gender which matches the students' perception about the design project.

Table 15. Assessment of the design project for gender bias

No.	Project Term	Project Topic	Project Sponsor	Students' Perception	Instructors' Perception
1	Spring 2017	Mining	General Electric	Neutral gender bias	Neutral gender bias

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5.3 Ambiguity Level of the Design Project

The instructor (author) scored the questions related to the ambiguity level of the design project on a scale of one to five where one indicated strongly disagree and five indicated strongly agree. Based on the scoring method, we developed a score for the instructor.

Table 16. Score assignment to the design project for ambiguity level

On a scale of 1 (strongly disagree)-5 (strongly agree) rate the following	Score	Weights	W Values
The design project has vaguely defined or unclear, multiple, conflicting goals	4	0.44	1.76
The design project representations/illustrations are ill-structured (e.g., The diagram can be interpreted in a number of ways)	3	0.13	0.40
The design project problem will have more than one correct solution	4	0.06	0.23
The design project problem challenges the students to develop innovative solutions (e.g., Textbook approach can be a traditional problem-solving approach)	4	0.04	0.14
The design project problem needs explanation in terms of the context of the problem	3	0.33	1.00
Final score			3.53

In the instructor's perceptions of the design project, after using the assessment tool the instructor evaluated the project for ambiguity level to be neutral. The mean of the responses for the students' perceptions of the major relatedness of the design project was 3.53, from the survey responses, which indicated the project ambiguity level was perceived to be neutral by the students. These results indicate that the design project perception by the instructor was identical to the students' perception and did not need any changes.

Table 17. Assessment of the design project for ambiguity level

No.	Project Term	Project Topic	Project Sponsor	Students' Perception	Instructors' Perception
1	Spring 17	Mining	General Electric	Neutral ambiguity level	Neutral ambiguity level

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5.3 Major Relatedness of the Design Project

The following table depicts the ratings given by the instructor (author) on the questions related to the major relatedness of the design project in the assessment tool.

Table 18. Score assignment to the design project for major relatedness

On a scale of 1 (strongly disagree)-5 (strongly agree) rate the following	Score	Weights	W Values
The project activity is associated with machines, tools, and materials	4	0.73	2.92
The project activity is associated with the creation and use of knowledge	4	0.73	2.92
The project activity is associated with manipulation of others to obtain the organizational goals of the company	4	0.73	2.92
The design project will help the students acquire technical skills, mechanical skills, and manual competencies	4	0.19	0.75
The design project will help the students acquire mathematical skills, analytical abilities, and scientific abilities	3	0.19	0.57
The design project will help students acquire managerial skills, leadership skills, and persuasive abilities	4	0.19	0.75
The project environment encourages the students to perceive themselves as cautious, critical, complex, curious, independent, precise, rational, and scholarly	4	0.08	0.32
The project environment encourages the students to perceive themselves as practical and productive	4	0.08	0.32
The project environment encourages the students to perceive themselves as aggressive, ambitious, energetic, extroverted, optimistic, popular, sociable, talkative	2	0.08	0.16
Final score			3.88

The mean of the responses for the students' perceptions of the major relatedness of the design project was 3.02 from the survey, which indicated the project was perceived to be of neutral major relatedness by the students. In the instructor's perceptions of the design project, after using the assessment tool the instructor evaluated the project for major relatedness to be of strong major relatedness.

Table 19. Assessment of the design project for major relatedness

No.	Project Term	Project Topic	Project Sponsor	Students' Perception	Instructors' Perception
1	Spring 2017	Mining	General Electric	Neutral major relatedness	Strong major relatedness

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Having a strong level of major relatedness in this case indicated that the project description may be highly interesting for the students in the engineering majors that include mechanical, electrical, aerospace, civil, chemical, and industrial engineering. However, if students in this class have interest in other engineering majors then this particular design project might not be of interest that might lead to motivation loss.

Through this case study, we compared the assessment of a given design project from the instructor's perspective as well as the students' perspectives. The results showed the assessment of the design project using this tool indicated a similar evaluation of the project for the gender bias and ambiguity factors. However, for the major relatedness factor, the evaluations were different indicating that the project might have needed some changes from the instructor before delivering it to the students. These changes could be in the form of adding certain project activities which may spark interest in student of different majors. This particular class had several students with interest in biomedical engineering field, therefor adding design project activities with biomedical engineering focus could possibly help gain the interest of these students.

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CHAPTER 6. CONCLUSION AND FUTURE WORK

6.1. General Conclusion

The engineering curriculum in part, responds to ABET criteria, which specify the students should be efficient in engineering design. To help the students with these outcomes, design courses were incorporated into the curriculum starting in the first year. These courses had cornerstone design projects, which helped the students learn about real-world problems and connected with the theory learned in the class. However, in some cases, they might have been plagued with problems that decreased student self-efficacy and motivation, which could lead to student attrition. These problems had been associated with three main criteria that were taken into consideration herein, namely, gender bias, ambiguity level, and major relatedness. Appropriately developed cornerstone design projects created to assuage a high level of ambiguity and gender bias, a particular domain of interest, might improve student's engagement and reduce the attrition among the engineering students.

This study provided an assessment tool in the form of a questionnaire having three main sections, each addressing gender bias, ambiguity level, and major relatedness of the design project respectively. To develop these questions, a survey was conducted at Penn State University in a design course for first-year engineering students in the spring semester of 2017. Factor analysis was performed on the response from this survey to determine the subfactors for each of the criteria. To determine the relative importance of these subfactors, weights were calculated using the prioritization method of AHP. These weights were utilized in conjunction with the questions formulated from the subfactors to constitute the assessment tool.

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A case study was presented to demonstrate the effectiveness of the assessment tool. To decide the appropriateness of an engineering design project, the educator answered a series of questions, each question was scored using a Likert scale (one = strongly disagree to five = strongly agree) regarding the perceptions about the design project. The final score for each section was compared to the levels of appropriateness to evaluate for the main factors; gender bias, ambiguity level, and major relatedness. The case study provided insight into the functioning of the assessment tool in a classroom environment. The preliminary work in the development of this thesis was presented at the IISE conference in May 2018 (Khoje et al. 2018).

Finally, based on this assessment tool the course instructor will effectively able to determine the appropriate project for first-year students and make the project inclusive to the students irrespective of the major of interest and gender. The use of this tool for the appropriate assignment of the design project may help to improve student engagement and motivation in the design course and, in turn, eliminate the barriers to the student learning. Based on the simple scoring method the educator would be able to determine the level of gender bias, degree of ambiguity, and the major relatedness of the design project, which would help to make broad modifications in the design project before it is delivered to the students of a first-year design course.

6.2. Future Work and Limitations

Based on the current tool, the engineering educator was able to identify the level of appropriateness for the three factors. Future work would be to develop detailed guidelines to help engineering educators make necessary modifications in the design

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project to meet the desired level of appropriateness. These guidelines could be in the form of specific modification strategies for gender, ambiguity, and major that the instructor might implement in the project to attain the desired level of gender bias, major relatedness, and ambiguity level.

The weights developed from the pairwise comparison performed in the AHP analysis in this study could act as guidelines for instructors using this assessment tool. However, if the instructor were not satisfied with these values of weights, she could be encouraged to perform the comparison as per her perception. This gives the instructor the freedom to use the questionnaire without the constraints of the weights determined as guidelines.

This assessment tool can further be recommended to be used for homework and assignments given to the students in the class. This could help the instructors to develop the coursework appropriately to be delivered to the students. For example, the initial homework and assignments could be on the lower levels of ambiguity, and as the class progresses, they might be more ambiguous.

The assessment tool considers the perception of a single instructor delivering a course. However, when a design course is taught by multiple instructors, it may be difficult for the group to come to a unanimous score on the questionnaire. In those cases, the group of instructors could meet and discuss their individual perceptions of the score and come to an amicable conclusion after discussion to answer each question. This would help the large design courses in group settings to determine the level of appropriateness.

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APPENDIX A. SURVEY

Title of Project: Instrument Development to Assess Design Project Appropriateness for Domain Relatedness, Ambiguity Tolerance, and Genderedness
Project Sponsor: NSF (National Science Foundation) Award 1611961

Principal Investigator (PI): Dr. Xinli Wu
CO-PIs: Dr. Kathy Jackson and Dr. Gül E. Kremer

Telephone Number: 814-863-1537

We are asking you to participate in our research study that will help improve our design teaching. Your participation will involve taking a survey, and is voluntary. You can choose not to partake. You can agree to take part and may end your participation at any time. Your decision will not be held against you. Please ask questions about anything that is unclear to you. Please take your time to make your choice.

If you choose to participate in this research study, you will be asked to complete the survey.

No personal identifiers will be collected for the survey. The results will only be traced to a participant number. Any quotes used from surveys will be coded in the written results using only randomly assigned numbers to refer to the participants.

The survey will take approximately 15-20 minutes. By consenting to participate, **you will receive an extra credit** for EDSGN100. An alternative for getting extra credit will be available upon request. As an alternative, you can attend a presentation on the topic of research and submit a short reflection on the topic. The date will be provided by your instructor.

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Please call the PI of the research study, Xinli Wu at 814-863-1537 if you:

- Have questions, complaints or concerns about the research.
- Believe you may have been harmed by being in the research study.

Do you agree to participate in this research study?

● I agree.

○ I disagree

Please rate the extent to which you agree or disagree with the following items using the following scale:

	1. Strongly disagree	2.Disagree	3.Neutral (Neither agree nor disagree)	4. Agree	5. Strongly agree
1. I don't tolerate ambiguous situation well.	○	○	○	○	○
2. I find it difficult to respond when faced with an unexpected event.	○	○	○	○	○
3. I don't think new situations are any more threatening than familiar situations.	○	○	○	○	○
4. I'm drawn to situations, which can be interpreted in more than one way.	○	○	○	○	○
5. I would rather avoid solving a problem that must be viewed from several different perspectives.	○	○	○	○	○
6. I try to avoid situations, which are ambiguous.	○	○	○	○	○
7. I am good at managing unpredictable situations.	○	○	○	○	○
8. I prefer familiar situations to new ones.	○	○	○	○	○
9. Problems which cannot be considered from just one point of view are a little threatening.	○	○	○	○	○
10. I avoid situations, which are too complicated for me to easily understand.	○	○	○	○	○
11. I am tolerant of ambiguous situations.	○	○	○	○	○

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12. I enjoy tackling problems, which are complex enough to be ambiguous.	O	O	O	O	O
13. I try to avoid problems, which don't seem to have only one "best" solution.	O	O	O	O	O
14. I often find myself looking for something new, rather than trying to hold things constant in my life.	O	O	O	O	O
15. I generally prefer novelty over familiarity.	O	O	O	O	O
16. I dislike ambiguous situations.	O	O	O	O	O
17. Some problems are so complex that just trying to understand them is fun.	O	O	O	O	O
18. I have little trouble coping with unexpected events.	O	O	O	O	O
19. I pursue problem situations which are so complex that some people call them "mind boggling."	O	O	O	O	O
20. I find it hard to make a choice when the outcome is uncertain	O	O	O	O	O
21. I enjoy an occasional surprise.	O	O	O	O	O
22. I prefer a situation in which there is some ambiguity.	O	O	O	O	O
23. I am satisfied with the way my team worked together.	O	O	O	O	O
24.Team members have worked better together now than when the team was formed.	O	O	O	O	O
25 . Team members are more aware of group dynamics now than when they joined the team.	O	O	O	O	O
26.Being a part of this team has helped members appreciate different types of people.	O	O	O	O	O
27. Overall, I am satisfied with team performance on projects.	O	O	O	O	O
28.. If we have had another engineering project, this team should not continue to function as a team.	O	O	O	O	O
29. If I could have left this team and worked with another team, I would have.	O	O	O	O	O

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30. I would not hesitate to participate on another project with the same team members.	○	○	○	○	○
31. This team is not capable of working together as a unit.	○	○	○	○	○
32. I am satisfied with this team compared to teams I have been on in the past.	○	○	○	○	○
33. Our team has tackled difficult work assignments enthusiastically.	○	○	○	○	○
34. Team members have adapted their schedules to meet one another's demands.	○	○	○	○	○
35. Our team have supported and encouraged team members with problems.	○	○	○	○	○
36. Team members have helped each other with their tasks.	○	○	○	○	○
37.Team members have respected one another and show understanding.	○	○	○	○	○
38.Team members have given their opinion when it concerned important issues.	○	○	○	○	○
39. Members have maintained a positive attitude about the team.	○	○	○	○	○
40.We have effectively talked through disagreements about ideas/opinions in my group.	○	○	○	○	○
41.We have effectively talked through disagreements about procedures (the way we get work done) in my group.	○	○	○	○	○
42.We have effectively dealt with interpersonal friction/personality clashes in my group.	○	○	○	○	○
43.The members of this group have excellent skills in team-working and communication.	○	○	○	○	○
44. I have real confidence in my group's ability to perform well on projects.	○	○	○	○	○

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45. This group did has not done as well as other groups in my class.	○	○	○	○	○
46.Some members in this group did not dohave not done their jobs well.	○	○	○	○	○
47. I had have had to work closely with my teammates to do my work properly.	○	○	○	○	○
48.The project my group worked on was associated with a masculine or feminine product or object (e.g., guns, rockets, explosives make me think of males).	○	○	○	○	○
49.The project my group worked on was associated with a masculine or feminine experience (e.g., cooking makes me think of females).	○	○	○	○	○
50.The project my group worked on was associated with a masculine or feminine institution (e.g., the military makes me think of males).	○	○	○	○	○
51. The project my group worked on was associated with a masculine or feminine action related (e.g., teaching makes me think of females).	○	○	○	○	○
52. The project my group worked on was associated with a masculine or feminine interest related (e.g., war affects everyone, but men tend to be more interested).	○	○	○	○	○
53.The project my group worked on was associated with a masculine or feminine idea generation (e.g., the ideas were mostly contributed by the males).	○	○	○	○	○
54.The project my group worked on was associated with a masculine or feminine background knowledge (e.g., females know how to socially work in a group).	○	○	○	○	○
55. The project my group worked on was associated with a masculine or feminine composition (e.g., the group was all male).	○	○	○	○	○
56.The industrial sponsored project this semester relates to my major/anticipated major.	○	○	○	○	○
57. The industrial sponsored project has motivated/inspired me to learn.	○	○	○	○	○

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58. . The skills I learned through this industrial sponsored project has helped me easily decide/choose/or stay with my major.	○	○	○	○	○
59. The satisfaction I have felt throughout this industrial sponsored project has helped me easily decide/choose or stay with my major.	○	○	○	○	○
60. This industrial sponsored project will positively impact the way I evaluate the course and course instructor at the end of the semester when the SRTE (Student Rating of Teaching Effectiveness) is conducted.	○	○	○	○	○
61. This industrial sponsored project will positively impact the way I evaluate the course instructor at the end of the semester when the SRTE (Student Rating of Teaching Effectiveness) is conducted.	○	○	○	○	○
62. The industrial sponsored project this semester has positively impacted me to stay with my major/anticipated major.	○	○	○	○	○
63. I found certain aspects of the design project to be related to my chosen discipline.	○	○	○	○	○

For the last item of the previous question (I found certain aspect of the design project to be related to my chosen discipline), please elaborate on your response. What aspect?

Please identify your perceptions regarding your industry-sponsored design project that you just completed.

- ○ 1. Very Masculine Project
- ○ 2. Masculine Project
- ○ 3. Gender Neutral Project (Neither Masculine nor feminine)
- ○ 4. Feminine Project
- ○ 5. Very Feminine Project

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Why did you answer the preceding multiple choice question the way that you did?

Who would you regard as having greater expertise on this task?

- 1. Primarily Men
- 2. Men
- 3. Men & Women Equally
- 4. Women
- 5. Primarily Women

Why did you answer the preceding question (Who would you regard as having greater expertise on this task?) the way that you did above?

What is your gender?

- Male
- Female
- Other

What is your major or anticipated major?

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Who is your project sponsor?

What grade do you think that **you (individually)** will earn in this course?

From 0-100%, please indicate how certain you are that you will be able to earn that grade in the box next to your choice.

- A
- A-
- B+
- B
- B-
- C+
- C-
- D
- F

Thank you so much for your participation!!!

Please feel free to write any comments you have about the survey below.

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APPENDIX B. IRB MEMO

PENNSTATE

IRB Program
Office for Research Protections

Vice President for Research
The Pennsylvania State University
205 The 330 Building
University Park, PA 16802

Phone : (814) 865-1775
Fax: (814) 863-8699
Email : orprotections@psu.edu
Web : www.research.psu.edu/orp

EXEMPTION DETERMINATION

Date: July 7, 2016

From: Joyel Moeller, IRB Analyst

To: Xinli Wu

Type of Submission:	Initial Study
Title of Study:	Instrument Development to Assess Design Project Appropriateness for Domain Relatedness, Ambiguity, and Genderedness
Principal Investigator:	Xinli Wu
Study ID:	STUDY00005092
Submission ID:	STUDY00005092
Funding:	National Science Foundation
Documents Approved:	• Focus group questionnaires (Version 2), Category: Data Collection Instrument • HRP591__07/06/2016 (Version 5), Category: IRB Protocol • Instructor post-survey questionnaires (Version 2), Category: Data Collection Instrument • Instructor pre-survey questionnaires (Version 2), Category: Data Collection Instrument • NSF--Proposal (Final Version), Category: Sponsor Attachment • Student post-survey questionnaires (Version 2), Category: Data Collection Instrument • Student pre-survey questionnaires (Version 2), Category: Recruitment Materials • Student Pre-Survey questionnaires (0.02), Category: Data Collection Instrument

The Office for Research Protections determined that the proposed activity, as described in the above-referenced submission, does not require formal IRB review because the research met the criteria for exempt research according to the policies of this institution and the provisions of applicable federal regulations.

Continuing Progress Reports are **not** required for exempt research. Record of this research determined to be exempt will be maintained for five years from the date of this notification. If your research will continue beyond five years, please contact the Office for Research Protections closer to the determination end date.

Changes to exempt research only need to be submitted to the Office for Research Protections in limited circumstances described in the below-referenced Investigator Manual. If changes are

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being considered and there are questions about whether IRB review is needed, please contact the Office for Research Protections.

Penn State researchers are required to follow the requirements listed in the Investigator Manual (HRP-103), which can be found by navigating to the IRB Library within CATS IRB (http://irb.psu.edu).

This correspondence should be maintained with your records.

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APPENDIX C. ASSESSMENT QUESTIONNAIRE

Gender Bias

No.	On a scale of 1 (strongly disagree)-5 (strongly agree) rate the following	Score
1	The project activity is associated with a masculine or feminine product or object (e.g., guns, rockets, explosives make me think of males)	
2	The project activity is associated with a masculine or feminine institution (e.g., the military makes me think of males).	
3	The project activity is associated with a masculine or feminine experience (e.g., cooking makes me think of females).	
4	The project activity is associated with a masculine or feminine action (e.g., teaching makes me think of females)	
5	The project activity is associated with a masculine or feminine interest (e.g., war affects everyone, but men tend to be more interested).	
6	The project activity is associated with a masculine or feminine idea generation (e.g., the ideas were mostly contributed by the males).	
7	The project activity is associated with a masculine or feminine background knowledge (e.g., females know how to socially work in a group).	
8	The project activity is associated with a masculine or feminine composition (e.g., the group was all male).	

Assessment score intervals for gender bias of the design project

< 2.5	2.5-3.5	> 3.5
Weak gender bias	Neutral gender bias	Strong gender bias

Major Relatedness

No.	On a scale of 1 (strongly disagree)-5 (strongly agree) rate the following	Score
1	The project activity is associated with machines, tools, and materials	
2	The project activity is associated with the creation and use of knowledge	
3	The project activity is associated with manipulation of others to obtain the organizational goals of the company	
4	The design project will help the students acquire technical skills, mechanical skills, and manual competencies	
5	The design project will help the students acquire mathematical skills, analytical abilities, and scientific abilities	
6	The design project will help students acquire managerial skills, leadership skills, and persuasive abilities	
7	The project environment encourages the students to perceive themselves as cautious, critical, complex, curious, independent, precise, rational, and scholarly	
8	The project environment encourages the students to perceive themselves as practical and productive	
9	The project environment encourages the students to perceive themselves as aggressive, ambitious, energetic, extroverted, optimistic, popular, sociable, talkative	

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Assessment score intervals for major relatedness of the design project

< 2.5	2.5-3.5	> 3.5
Weak major relatedness level	Neutral major relatedness level	Strong major relatedness level

Ambiguity

No.	On a scale of 1 (strongly disagree)-5 (strongly agree) rate the following	Score
1	The design project has vaguely defined or unclear, multiple, conflicting goals	
2	The design project representations/illustrations are ill-structured (e.g., The diagram can be interpreted in a number of ways)	
3	The design project problem will have more than one correct solution	
4	The design project problem challenges the students to develop innovative solutions (e.g., textbook approach can be a traditional problem-solving approach)	
5	The design project problem needs explanation in terms of the context of the problem	

Assessment Score intervals for ambiguity level of the design project

< 2.5	2.5-3.5	> 3.5
Weak ambiguity level	Neutral ambiguity level	Strong ambiguity level

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