An Investigation on the Effects of Ambiguity, Gender Orientation, and Domain Relatedness of Design Projects on Student Performance

Elif Elcin Günay
Sakarya University

Xiuyan Guo
Emory and Henry College

Kathy Lou Jackson
Penn State University

Xinli Wu
Penn State University

Gül E. Okudan Kremer
Iowa State University, gkremer@iastate.edu

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Abstract
Students in design courses work on projects that are influenced by ambiguity, gender orientation, and domain relatedness. This study investigates the impacts of these factors on student self-efficacy in order to increase retention in engineering disciplines. From a comprehensive literature review and feedback from engineering experts, an instrument is developed to assess student perceptions on tolerance to ambiguity (STA), project gender orientation (PGO), and project domain relatedness (PDR). Statistical analyses are conducted to examine the influence of STA, PGO, and PDR on student self-efficacy and collective efficacy. Results indicate that an increase in the gender orientation of the project decreases student self-efficacy. Furthermore, gender bias of the design project diminishes student tolerance to deal with ambiguous situations. Therefore, instructors should consider choosing more gender-neutral projects or make appropriate adjustments in project descriptions to minimize gender bias.

Keywords
design education, design teams

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

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Authors: Elcin Gunay, Xiuyan Guo, Kathy Jackson, Xinli Wu, Gül E. Okudan Kremer

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An Investigation on Effects of Ambiguity, Gender Orientation and Domain Relatedness of Design Projects on Student Performance

Elif Elcin Günay
Sakarya University
Department of Industrial Engineering, Sakarya University, Sakarya, 54050, Turkey
egunay@iastate.edu

Xiuyan Guo
Emory and Henry College
Office of the Institutional Research and Institutional Effectiveness
Emory, VA 24327
xguo@ehc.edu

Kathy Lou Jackson
Penn State University
Education Technology Services
University Park, PA 16802
klj11@psu.edu

Xinli Wu
Penn State University
School of Engineering Design, Technology and Professional Programs
University Park, PA 16802
xinli@psu.edu

Gül E. Okudan Kremer1
Iowa State University
Department of Industrial and Manufacturing Systems Engineering
gkremer@iastate.edu
ASME Fellow

ABSTRACT

1 Gül E. Kremer, gkremer@iastate.edu
Students in design courses work on projects that are influenced by ambiguity, gender orientation, and domain relatedness. This study investigates the impacts of these factors on student self-efficacy in order to increase retention in engineering disciplines. From a comprehensive literature review and feedback from engineering experts, an instrument is developed to assess student perceptions on tolerance to ambiguity (STA), project gender orientation (PGO) and project domain relatedness (PDR). Statistical analyses are conducted to examine the influence of STA, PGO, and PDR on student self-efficacy and collective-efficacy. Results indicate that an increase in the gender orientation of the project decreases student self-efficacy. Furthermore, gender bias of the design project diminishes student tolerance to deal with ambiguous situations. Therefore, instructors should consider choosing more gender-neutral projects or make appropriate adjustments in project descriptions to minimize gender bias.

INTRODUCTION

There is now wide understanding that the “sage on the stage” style of instruction has limitations in appropriately preparing students for the modern workplace. In the “sage on the stage” or transmittal form of teaching, King [1] assumes that the student brain can be likened to a container into which the professor pours in knowledge. In contrast, the constructivist theory of learning sees the instructor as the “guide on the side” facilitating student interaction and experience with the material, enabling knowledge construction and meaning to take place [2]. Project-based design learning environment provides this facilitated learning setting [3], and thus it is being used throughout the engineering curriculum to provide design experiences to students [4]. In many universities, engineering design courses feature project-based learning starting in the first year.
Several authors note that the structure of the curriculum can promote interdisciplinary collaborations [5-7]. Project-based design courses can bring students from various disciplines into a team. At the first year, another advantage of a project-based design course setting is it provides a platform for students to experience engineering fundamentals together even if their eventual disciplinary choices (i.e., chemical engineering vs. industrial engineering) are different. Moreover, design projects can enhance students’ motivation by increasing the enthusiasm of first year students through engagement with authentic industrial clients and problems originating from real-world applications. Design projects coming from industry provide an opportunity to see the real applications of their design solutions, and how the theory and practice come together.

There are numerous studies in the literature that attest to the benefits of project-based learning within design courses such as increasing the motivation, team working and communication skills [8], retention [9], and ability to implement design applications [4, 10]. Despite these advantages, some of which are provided above, if not designed well such project-based design experiences might have negative impacts on student learning and motivation. For example, Jones at el. [11] showed that at the end of the first year, engineering students’ expectancy and value related motivation constructs such as self-efficacy, success expectation, beliefs on importance of engineering, and usefulness of the engineering field decrease. An inappropriate design project may be the reason for the decrease in self-efficacy and students’ belief on the importance of the engineering field, since it is the only course where most freshmen
meet engineering applications with sufficient depth for the first time. There is also evidence on the correlation between increased self-efficacy and pursuing a career in engineering [12]. Inappropriate design projects that cause a decrease in student self-efficacy that may lead to their departure from the engineering field for other majors.

The U.S. Department of Education periodically reports on the attrition ratios of students who left post-secondary education without a degree or a certificate and who switched to a different major category. Figure 1 shows higher attrition ratios in computer/information science (59%), physical sciences (46%), biological sciences (45%), and engineering (41%) [13]. Okudan et al. [14] assert that “ambiguity,” “gender orientation” and “major relatedness” of the design project may increase this attrition rate from engineering fields to other disciplines due to these factors being seen as barriers to student success in design projects. Although their study provides preliminary results based on student views and comments, a comprehensive study is needed to clarify the effects of these potential barriers on student success in a design course. In this paper, we focus on gender orientation of design projects, relatedness of the project domain with the discipline that students want to pursue, and student preparedness to tackle open-ended and potentially ambiguous design projects as barriers to their success in design projects.

A design project may be skewed toward a gender due to its masculine or feminine tasks or subject matter, unintentionally disenfranchising one of the gender groups in the design learning setting [15]. For example, if a design project mainly focusses on male related interests such as designing the engine of a vehicle, it may
decrease the motivation of female students and discourage them from their pursuit of engineering as a career. Confirming this for males, they were shown to be unwilling to improve their competencies if they thought the project was related to feminine tasks [16]. Although it is important to understand the impact of gender orientation of the design project on student learning and performance, extant research on this topic is limited in many ways.

Major or domain relatedness of the design project is another potential barrier, which may decrease student motivation in design courses. When the project relates to a specific domain, students who want to pursue a career in that engineering specialization may feel more engaged while others may feel less motivated and lose interest. Richter and Paretti [7] showed that major bias of the project negatively affects student performance in interdisciplinary teams, specifically for those who do not want to get a degree in that field. Design projects should have multidisciplinary appeal so that both teamwork skills and the commitment of engineering students can be improved.

In the first year, engineering design projects are conducted by students who may lack sufficient domain specific knowledge. Moreover, when the projects originate from real-world applications, they are usually less structured and abstract and thus require open-ended complex problem solving skills from students. The ambiguity due to the lack of adequate domain knowledge or this unstructured and abstract form of the design project may cause loss of motivation, resulting in a less than ideal learning setting for many engineering students.
Student interests and the characteristics of the academic disciplines may also affect their tolerance to cope with barriers rooted in the design project description. Holland’s theory may be used to propose a link between student interests with the characteristics of academic disciplines. Holland’s theory focuses on assessment of individuals, their environments (i.e., academic major) and the interaction between the two. According to this theory, an individual’s selection of academic major is an expression of their interests and preferences. Per this theory, most people can be classified into one or more of the six theoretical types: realistic, investigative, artistic, social, enterprising, and conventional [17, 18]. For example, electrical and mechanical engineering are classified as realistic majors, whereas industrial engineering is enterprising [18]. As per Holland’s classification student characteristics across groups vary, and thus there may be differences among majors in coping with ambiguity. For instance, since electrical and mechanical engineering students are likely to be realistic (if their major choice is congruent with their interests), their tolerance to ambiguous situations may not be as high as their peers’ pursuing civil or chemical engineering who are classified as investigative. Moreover, gender specific characteristics and preferences may influence individual tolerance to ambiguity.

In this study, we investigate the following research questions: (RQ1) Which combination of predictors, STA, PGO, PDR and Holland’s classification best predicts student self-efficacy in terms of expected grades? (RQ2) Which combination of the predictors STA, PGO, PDR, gender, student confidence in expected grades, and student
expected grades best predicts student collective efficacy (SCE)? (RQ3) Does tolerance to ambiguity of different major groups classified by Holland and gender vary by PGO?

The goal of this work is to explore the effects of three barriers, “project ambiguity,” “project gender orientation,” and “project domain relatedness” on student success in engineering design projects. The results of this study will support educators in managing these potential barriers to self-efficacy and thus retention.

What follows is a summary of our review on ambiguity, major relatedness and gender bias as potential barriers to student self-efficacy and collective-efficacy. We then explain our research methodology and unfold the results organized as responses to the research questions posed. Last, we discuss the study results and limitations of the study.

REVIEW OF LITERATURE ON THE THREE BARRIERS

Our review included engineering design and engineering research manuscripts related to project ambiguity, project domain relatedness, and project gender orientation, and focused on them as potential barriers to student success in engineering design courses. We also highlighted relevant threads on student self- and collective efficacy.

Project Ambiguity

Although traditional problems (text-book problems) common in most engineering courses prepare students for different engineering applications, they are not sufficient to increase open-ended problem solving skills of students [19, 20]. Therefore, many engineering programs include industry-sponsored design projects in their design courses
to increase student creative thinking and open-ended problem solving skills. However, these industry-originated problems may be ambiguous for students due to lack of necessary information and a multitude of directions to pursue for solutions.

The term ambiguity refers to perceived insufficiency of information and is used to describe decisions for which the odds of an uncertain event are not precisely known [21]. Dringenberg [22] defined ambiguity as “uncertainty [that] exists about which concepts, rules, and principles are necessary for the solution or how they are organized.” The ambiguity level of industry-sponsored projects may be high for first year students, since they lack specific domain knowledge, tools and jargon. On the other hand, since these students are not bound by theoretical knowledge restrictions, they may be more creative in open-ended problem solving. Hullsiek [23] revealed that a student’s tolerance to ambiguity is moderated by the relationship between situation ambiguity (i.e., project ambiguity) and student creativity. Focusing on the relation of uncertainty to learning, Tauritz [24] reported that while too little or too much uncertainty blocks learning, some level of uncertainty motivates learning. Zheng et al. [25] showed how the uncertainty of the design projects could be reduced by concept selection tools in order to aid the student decision making process. Kazerounian [26] discussed that lack of ambiguity limits the creativity of the engineering students. However, there are many studies in the literature reporting ambiguity as a problematic issue with regards to open-ended problem solving [7, 19, 20, 22, 27].

According to Kahn and Sarin [21], individuals can be categorized as ambiguity averse, ambiguity seeking, or ambiguity indifferent based on their tolerance to
ambiguous situations. Mohammed et al. [28] conducted a study to see the effects of student tolerance to ambiguity on self-efficacy, collective efficacy, satisfaction with the group and conflict resolution. They showed that individuals with a higher tolerance to ambiguity acquire higher levels of collective efficacy, group satisfaction, and conflict resolution. Moreover, ambiguity-seeking students feel more motivated to work on open-ended projects rather than more straightforward projects. On the other hand, they have less self-efficacy, which was measured by students’ expected grades, compared to their ambiguity averse counterparts.

Dringenberg and Wertz [29] developed an instrument to assess how ambiguity and recognizing the value of multiple perspectives affect student acceptance or resistance to cope with open-ended design problems. The goal of the instrument is to track the development of students dealing with ambiguity and recognizing the value of multiple perspectives. Their instrument allows educators to make interventions for ambiguity adverse students to increase their open-ended problem-solving skills. These authors acknowledge though, that their study presents preliminary results and more data is needed to validate their instrument.

**Gender Orientation of the Design Project**

When students think that the project is skewed towards one gender, they may lose interest [30] or even change their discipline. Okudan et al. [14] reported that student evaluative ratings of the design course were low when students were conducting a military related project. However, the ratings were higher for more gender-neutral projects such as supply chain assembly and a human-powered folding trailer. The reason
was articulated as a potential gender bias to the military project. Additionally, Okudan et al. [15] argued when the tasks/topics students perform during a design course are perceived as gender oriented, students from the other gender lose motivation and interest to work on the project. The thing of focus and setting, including “product/object,” “experience,” “institution,” “action,” “background knowledge” and “gender composition”, constitute factors that may cause the design project to be perceived as gender oriented.

Moskal [31] and Moskal et al. [32] show female students may have less self-confidence in their first year of engineering; however, well-supported females with sound instructional methodologies may recognize their ability and be able to perform better. Amelink and Meszaros [33] demonstrate the positive experiences female students have during their education encourage them to attend and pursue engineering careers.

Despite the increase in the number of females in science and engineering, females are still underrepresented [34]. There are studies in literature to understand reasons why the ratio of females is low in the engineering field [35, 36]. A well-organized engineering design course (disinfected from biasing factors) may support to strengthen female student beliefs on their ability for success in engineering, and increase the number of females who pursue engineering as a career.

Major/Domain Relatedness of the Project

During the first year of engineering education, even if students are not admitted to a specific engineering major, they may have an interest in a specific engineering discipline.
When students perceive that the design project is not related to that discipline, their motivation in the project and thus self-efficacy may decrease. Support for this exists in prior literature. For example, Richter and Paretti [7] discussed “relatedness” as a potential barrier to student success in interdisciplinary teamwork. The term relatedness refers to a connection between a student’s major of interest and the project domain. Students are more successful when they are capable of identifying connections between their own disciplines and the project domain. Conversely, students lose motivation when they are not capable of finding similarities between their intended major and the project domain.

A project’s relevance to a student’s interest in a major could not be considered without potential gender biases. There are differences across engineering majors for perceived gender orientations. For instance, female students prefer to pursue careers in genetic and bioengineering, chemical, environmental, and industrial engineering. On the other hand, male students prefer to pursue careers in electronic, mechanical and civil engineering [37, 38]. A project related to chemical engineering may be ideal for most of the female students on the project team, whereas it may be less than ideal for most male students since there might not be a connection between their discipline of choice and the project domain.

**Self-efficacy and Collective-efficacy**

Self-efficacy, introduced by Bandura, is an individual’s belief on their capacity to perform a given task [39]. For teams, it is more appropriate to consider collective-efficacy that shows a team’s belief to perform as a whole [40]. For most design project
settings, because students work as a team to solve industry-originated problems, collective-efficacy is as important as self-efficacy. A preliminary study [14] showed the negative effects of project ambiguity, project gender orientation and project domain relatedness on student success; and asserted that such factors may decrease student self- and collective-efficacy. However, the study featured literature review-based hypotheses along with preliminary observations from a very limited sample. A follow on study [28] discussed the effect of student tolerance to ambiguity on their self- and collective-efficacy. Extant works also connected gender to student self-efficacy [12, 15, 41]. However, by and large, what exists is limited in revealing complex and potentially interdependent connections between ambiguity, gender orientation, and domain relatedness factors and self- and collective-efficacy in the context of engineering design projects. Our research intends to add to the state-of-the-art at this intersection.

METHODOLOGY

The purpose of this study is to collect data from first year engineering students and analyze it to understand their perceptions on how project ambiguity, domain relatedness, and gender orientation affect their self- and collective-efficacy. To achieve this goal, we first developed and validated a survey instrument. Subsequent to the data collection, binary logistic regression, linear regression and ANCOVA analyses were conducted as we sought responses to the research questions.

Instrument Development
The survey included 64 Likert-type questions that were organized in five subscales. The first 22 questions relate to student tolerance to ambiguity (STA), followed by 25 questions on student collective-efficacy (SCE). Eight questions were related to project gender orientation (PGO), an additional set of eight related to project domain relatedness (PDR), and one question assessed the project ambiguity level (PAL). There were three open-ended questions asking students to elaborate on their answers: “I found certain aspects of the design project to be related to my chosen discipline,” “Gender orientation of the project” and “Which gender had greater expertise on project tasks?” The last part of the survey includes student gender, anticipated major, expected course grade and confidence level in earning the expected grade. The 64 Likert-type questions of the survey are presented in Appendix A.

The first 22 questions use McLain’s Tolerance of Ambiguity instrument [42] to measure student readiness to ambiguous situations and open-ended problem solving. Among examples of STA subscale items are: “I don’t tolerate ambiguous situations well,” “I find it difficult to respond when faced with an unexpected event” and “I don’t think new situations are any more threatening than familiar situations.” The second part of the survey includes items of a scale developed in [43] to measure the beliefs and capabilities of a team to succeed at a given task. Among the items of this scale are: “I am satisfied with the way my team worked together” and “Our team has tackled difficult work assignments enthusiastically.” In the third part of the survey, questions on the gender orientation of the project were provided. This latter set was developed by the project team inspired by Okudan and Mohammed [15]’s earlier work on gender
orientation of design projects. In this part, questions were designed to measure student perceptions on their project’s bias towards a gender. Sample items for the PGO scale include: “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)” and “The project my group worked on was associated with a masculine or feminine experience (e.g., cooking makes me think of females).” In the last section of the survey, we added questions to gauge the PDR. These questions aimed to assess if there is a perceived relation between students’ chosen/anticipated major and the project’s disciplinary domain. Examples for this scale are: “The industrial sponsored project for this semester relates to my major/anticipated major” and “The skills I learned through this industrial sponsored project has helped me easily decide/choose/or stay with my major”.

On the Likert scale, a 1 indicated “strongly disagree” and a 5 indicated “strongly agree.” Some questions on the survey used reverse wording to get a stronger and more valid measure. Accordingly, these items are reverse coded for the analysis. Low points on these scales (i.e., student tolerance to ambiguity, collective efficacy, student perception on project gender orientation, project’s relevance to the chosen/anticipated major and project ambiguity level) show low STA, SCE, student perceptions on PGO and PDR.

Data Sources and Analysis

The online survey was administered at the end of the spring semester in 2017 at Penn State University. Survey participation was voluntary; in order to increase the number of participants, an extra course credit was offered to students. We surveyed
130 first year students (41 females and 89 males) who enrolled in an introductory engineering design course (EDSGN 100) and completed an industry-sponsored design project. The details of the design project and the curriculum of the course are included in Appendix B. There were only 0.72% missing values in the collected data, and the missing data pattern is random. We used mean imputation for the missing values. Student expected grades are used as the indicator of their self-efficacy [44].

On the survey, students indicated their expected grades and confidence in achieving these expected grades. Sixty students (46.15%) indicated that they were expecting an “A,” 44 (33.85%) were expecting an “A-,” while 25 (19.23%) of them were expecting a “B,” “B+” or “B-.” None of the students expected a grade of “C+” or “C-,” but one student was expecting to earn a “C-.” Students were confident they would achieve their expected grades; 57 (43.85%) of them were 90% confident in receiving their expected grade. We also collected data for their chosen major or anticipated major. While there were 24 different majors chosen, six of them were preferred to a higher degree: mechanical engineering, aerospace engineering, biomedical engineering, chemical engineering, industrial engineering and civil engineering. The majority of the students (22.31%) wanted to study mechanical engineering, followed by aerospace engineering (13.85%). Close behind were biomedical and chemical engineering with 13% and 12.31%. Last were industrial engineering and civil engineering with 8.46% each. Other majors (16.92%) were selected by less than five students and hence by a small percentage of the study population. The percentage of students who had not decided their major or answered this question was 4.61%.
After data collection, participant responses were categorized based on Holland’s type classification. In this categorization, we assume students’ anticipated major choice represents their dominant Holland type. Thus, students who chose mechanical and electrical engineering disciplines as their major were coded as realistic (group 1); students who chose aerospace, chemical, biomedical and civil engineering were coded as investigative (group 2); students who chose industrial, computer and communications engineering were coded as enterprising (group 3); lastly, students who chose architectural engineering were coded as artistic (group 4).

Validity analysis

Three different validity analyses (i.e., content, face and construct validity) were performed to verify if the developed survey instrument was measuring what it was intended to. The objective of these validation processes was to specify the clarity, accuracy and the relevancy of the content [41]. The content and face validity sought to uncover if the instrument covers the considered subjects sufficiently and appropriately. In order to accomplish this, the views and feedback of engineering education domain experts from Penn State and Iowa State were collected to critically review and revise the instrument.

For the construct validity, we performed confirmatory factor analysis (CFA) instead of exploratory factor analysis (EFA) since we adopted scales from the extant literature. As part of CFA, we used principal axis factoring extraction method and Varimax rotation with Kaiser Normalization rotations. We eliminated items that loaded less than 0.4 on any factor, except item 20 with a factor loading of 0.314. A total of 18
items were deleted after five iterations. The model appears to fit the data well, with CFI = 0.929 (>0.90), RMSEA = 0.054 (< 0.06), and with 90% CI (0.046, 0.062), SRMR = 0.080 (= 0.08). Based on the CFA, we observed a five-factor solution with expected loadings on STA, SCE, PGO, PDR and PAL. The items on these five factors and the fit statistics of the model are listed in Appendix C. The single item of PAL did not load on any factor, indicating that it did differ from other items and was measuring a unique construct. In the finalized survey, there were 8 items in the first factor (STA), 24 items for the factor SCE, 6 items under the factor of PGO, 7 items for PDR and 1 item for PAL. The developed instrument’s reliability measured in Cronbach Alpha for STA, SCE, PGO and PDR were 0.811, 0.965, 0.932 and 0.896, respectively. The overall reliability coefficient of the 46-item instrument is 0.899.

RESULTS

All the analyses were performed for the validated instrument (Appendix C) resulting from the CFA. Items under STA, SCE, PGO, and PDR were averaged and used as corresponding scale values. We did not calculate the average for the PAL scale since there was only one question for measuring the project ambiguity level; we used the participant response as captured for this item. Descriptive statistics of scales are reported in Table 1 for female and male students, separately.

A bivariate correlation matrix for the survey variables are listed in Table 2. Based on the results observed in Table 2, there are significant positive relationships between student confidence level for achieving their expected grades and STA and SCE. In
addition to these relationships, there is a significant negative relationship between PGO and STA. There is also a negative relationship between PDR and PAL. STA was not related to SCE, PDR or PAL as assessed by the correlation analysis. Student confidence levels for achieving their expected grade was not significantly related to PGO, PDR or PAL. Lastly, there was no statistically significant relationship between PGO, PDR and PAL.

Collected data was used to address the following research questions: (RQ1) which combination of the predictors STA, PGO, PDR and Holland’s classification best predicts student expected grade? (RQ2) which combination of the predictors STA, PGO, PDR, gender, student confidence of expected grades, and student expected grades best predicts SCE? (RQ3) Does tolerance to ambiguity of different major groups classified by Holland and gender vary by PGO?

RQ1: Which combination of the predictors STA, PGO, PDR and Holland’s classification best predicts student expected grade? We reported student expected grades as a binary variable (1=high and 0=low), the expected grades “A” and “A-” are coded as high grades and the rest of the grades were coded as low grades. We use this recoded grades data to investigate the effects of STA, PGO and PDR on receiving high grades. A binary logistic regression model was utilized to determine the impact of the four predictors (STA, PRO, PDR and Holland’s classification) on student expected grades. In our model STA, PGO, PDR and Holland classifications are the independent variables; student expected grade is the dependent variable. By constructing a binary logistic regression, we are testing a null hypothesis for each independent variable (STA, PRO,
PDR and Holland’s classification) to see whether adding a specific independent variable into the model changes the fit of the model any more than expected by chance. Results of the logistic regression are reported in Table 3. According to the Hosmer-Lemeshow test, goodness of fit measure is calculated as \( \chi^2 (8) = 11.199 \), p-value= 0.19 > \( \alpha =0.05 \). This indicates a good model fit.

Results from the logistic regression model shows that PGO negatively affects student expected grade (odds ratio=0.60; p-value<0.05), which means the increase of project gender orientation decreases the probability of expecting to receive a higher grade. One level increase on the project gender orientation decreases the odds of students expecting to receive a higher grade by 60%. In other words, when students feel that the project is skewed to one gender, the probability of expectation to receive a high grade decreases. However, STA, PDR, and Holland’s classification do not have a statistically significant effect on students’ expected grades (all p-value>0.05).

RQ2: Which combination of the predictors STA, PGO, PDR, gender, student confidence of expected grades, and student expected grades best predicts SCE? A linear regression model was built to examine the significant independent variables (STA, PGO, PDR, expected grade, gender and student confidence of expected grades) to predict SCE in Table 4. An independent variable, student confidence on expected grade is statistically significant to predict SCE (p-value=0.03). Other independent variables PGO, STA, PDR, expected grade and gender are not statistically significant to predict SCE.

RQ3: Does tolerance to ambiguity of different occupation and gender groups vary by PGO? Before observing the potential effect of PGO, we examined whether there
was a group difference in STA among Holland’s classification groups or between genders. Thus, a two-way ANOVA was performed. According to the results reported in Table 5, STA does not significantly differ based on student gender or Holland’s classification (p values are 0.61 and 0.21, respectively). However, because there are gender differences (e.g., enrollment numbers) in engineering disciplines [37, 38], it is reasonable to believe that PGO may also influence the effect of Holland’s classification and gender on STA. Moreover, there is a significant correlation between STA and PGO (Pearson correlation in Table 2, ρ = -0.181; p-value<0.05) which indicates that PGO is an appropriate covariate. Therefore, we included the PGO as a covariate and ran an ANCOVA model. According to the results reported in Table 6, STA significantly changes based on PGO, p=0.03. However, STA does not significantly differ based on student gender or Holland’s classification (p values are 0.64 and 0.20, respectively).

DISCUSSION AND CONCLUSION

Our goal in this study is to assist educators in selecting and implementing design projects in order to increase student performance and motivation. Since the effects of STA, PGO and PDR are known, instructors should pay attention to selection of design projects to avoid negative impacts of gender bias or make adjustments to project description to mitigate the potential negative effects. Three potentially problematic issues are considered as barriers to effective design courses in the literature [14, 28, 29], and an extensive study examining the effects of these issues on student self- and collective efficacy in an engineering design project context is reported herein.
From a comprehensive literature review and the feedback of engineering education experts, we developed an instrument to assess student perception of tolerance to ambiguity (STA), student perception of project gender orientation (PGO) and student perception of project domain relatedness (PDR). There are 8 items for the STA scale, 6 items for the PGO scale, 7 items for the PDR scale and 1 item for PAL, resulting in 46 items on the revised version of the survey. The overall Cronbach alpha reliability coefficient of the instrument is 0.899.

With regard to the developed instrument, we performed statistical analyses. In the first analysis, a binary logistic regression model results showed that project gender orientation has a negative effect on a student’s expected grade. An increase on the project gender orientation decreases the probability of a student’s expectation on getting a higher grade. Similar to the studies in the literature [12, 15, 45], student self-efficacy decreases when the project has gender bias as perceived by students. In the second statistical analysis, a linear regression model showed that student confidence on their expected grade has a statistically significant positive effect on SCE. Moreover, PGO may have impact on SCE due to the p-value (p-value=0.09) in the regression model. Impact of PGO on SCE should be examined in future studies for projects with stronger gender overtones.

In the third statistical analysis, the ANCOVA model shows that PGO significantly changes STA. Additionally, there is a negative correlation between PGO and STA, which means that when students feel the project is skewed to one gender their tolerance to ambiguity decreases. As a consequence, all three analyses show that an increase in
project gender orientation negatively influences student self-efficacy and collective-efficacy. Moreover, it diminishes student tolerance to cope with ambiguous situations.

This study contributes to engineering design research by demonstrating how ambiguity, gender orientation and domain relatedness impact a design project. These findings articulate how specific factors effect student performance in a design course in terms of self-efficacy and collective efficacy. No research is immune to some limitations; some of these limitations for the shared work are:

(i) A comparison analysis between clearly defined design projects and more abstract ones may be performed to investigate how self-efficacy and collective-efficacy of the students change. Since there was only one design project in the term, no comparison was done in this study.

(ii) The survey can be conducted in a timely fashion so that student self-efficacy can be compared at the beginning and at the end of the design course. This approach gives an opportunity to investigate how a student’s belief and abilities change throughout a specific design course.

(iii) In the regression model, PGO has a marginal significant negative effect (p-value=0.09) on SCE. Therefore, increasing the number of the participants may give an opportunity to better understand the impacts of PGO on SCE.

(iv) An individual’s dominant Holland type is determined based on their anticipated major. However, we readily acknowledge that any person will have characteristics corresponding to more than one type. Further investigations will be conducted to capture and study different interest types of the individuals.
Overall, this paper articulates the negative effect of gender relatedness of the design project on student self- and collective-efficacy. Due to the correlation between self-efficacy and pursuing a career in engineering [12, 33], our study should contribute to retention of students in engineering fields. Moreover, findings of the study will support instructors to choose appropriate design projects neutralizing significant gendered-language to limit their negative impacts.

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REFERENCES

[1] King, A., 1993, "From Sage on the Stage to Guide on the Side," College Teaching, 41(1), pp. 30-35.

[2] Piaget, J., 1965, The Moral Judgement of the Child, New York: Free Press.

[3] Telenko, C., Wood, K., Otto, K., Elara, M. R., Foong, S., Pey, K. L., Tan, U.-X., Camburn, B., Moreno, D., and Frey, D., 2016, "Designettes: An Approach to Multidisciplinary Engineering Design Education," Journal of Mechanical Design, 138(2), pp. 022001.

[4] Soman, R., Gupta, N., and Shih, C., 2016, "A Coordinated Design Course Sequence to Integrate Mechanical Engineering Capstone Design Experience," 123rd ASEE Annual Conference & Exposition, New Orleans, Louisiana, ASME Paper No. 15200, https://peer.asee.org/26299.

[5] Alpay, E., 2013, "Student Attraction to Engineering through Flexibility and Breadth in the Curriculum," European Journal of Engineering Education, 38(1), pp. 58-69.

[6] Lattuca, L. R., Knight, D., Seifert, T. A., Reason, R. D., and Liu, Q., 2017, "Examining the Impact of Interdisciplinary Programs on Student Learning," Innovative Higher Education, 42(4), pp. 337-353.

[7] Richter, D. M., and Paretti, M. C., 2009, "Identifying Barriers to and Outcomes of Interdisciplinarity in the Engineering Classroom," European Journal of Engineering Education, 34(1), pp. 29-45.

[8] Mills, J. E., and Treagust, D. F., 2003, "Engineering Education—Is Problem-based or Project-based Learning the Answer?" Australasian Journal of Engineering Education, 3(2), pp. 2-16.

[9] Knight, D. W., Carlson, L. E., and Sullivan, J. F., 2007, "Improving Engineering Student Retention Through Hands-on, Team Based, First-year Design Projects," Proceedings of the 31st International Conference on Research in Engineering Education, Honolulu, HI, pp.1-13. DOI: 10.18260/p.26299

[10] Bairaktarova, D., Graziano, W., and Cox, M., 2017, "Enhancing Engineering Students' Performance on Design Task: The Box of Parts," Journal of Mechanical Design, 139(5), p. 052001.

[11] Jones, B. D., Paretti, M. C., Hein, S. F., and Knott, T. W., 2010, "An Analysis of Motivation Constructs with First-year Engineering Students: Relationships among Expectancies, Values, Achievement, and Career Plans," Journal of Engineering Education, 99(4), pp. 319-336.
[12] Marra, R. M., Rodgers, K. A., Shen, D., and Bogue, B., 2009, "Women Engineering Students and Self-efficacy: A Multi-year, Multi-institution Study of Women Engineering Student Self-efficacy," Journal of Engineering Education, 98(1), pp. 27-38.

[13] Chen, X., 2013, "STEM Attrition: College Students' Paths into and out of STEM Fields. Statistical Analysis Report. Report No. NCES 2014-001, U.S. Department of Education, National Center for Education Statistics."

[14] Okudan, G. E., Mohammed, S., and Ogot, M., 2006, "An Investigation on Industry-sponsored Design Projects' Effectiveness at the First-year Level: Potential Issues and Preliminary Results," European Journal of Engineering Education, 31(6), pp. 693-704.

[15] Okudan, G. E., and Mohammed, S., 2006, "Task Gender Orientation Perceptions by Novice Designers: Implications for Engineering Design Research, Teaching and Practice," Design Studies, 27(6), pp. 723-740.

[16] Male, S. A., Bush, M. B., and Murray, K., 2009, "Think Engineer, Think Male?," European Journal of Engineering Education, 34(5), pp. 455-464.

[17] Holland, J. L., 1997, Making Vocational Choices: A Theory of Vocational Personalities and Work Environments (3rd ed.), Psychological Assessment Resources, Odessa, FL, US.

[18] Smart, J. C., Feldman, K. A., and Ethington, C. A., 2000, Academic Disciplines: Holland’s Theory and the Study of College Students and Faculty, Vanderbilt University Press.

[19] Mourtos, N. J., DeJong-Okamoto, N., and Rhee, J., 2004, "Open-ended Problem-solving Skills in Thermal-fluids Engineering," Global Journal of Engineering Education, 8(2), pp. 189-200.

[20] Mourtos, N. J., 2010, "Challenges Students Face when Solving Open-ended Problems," International Journal of Engineering Education, 26(4), pp. 846-859.

[21] Kahn, B. E., and Sarin, R. K., 1988, "Modeling Ambiguity in Decisions under Uncertainty," Journal of Consumer Research, 15(2), pp. 265-272.

[22] Dringenberg, E. A., 2015, "A Phenomenographic Analysis of First-year Engineering Students' Experiences with Problems Involving Multiple Possible Solutions," Ph.D. thesis, Purdue University, https://search.proquest.com/docview/1734375899?pq-origsite=gscholar
[23] Hullsiek, B., 2011, "The Effects of Tolerance for Ambiguity and Ambiguous Instructions on Creativity", Master thesis, University of Nebraska at Omaha, https://search.proquest.com/docview/858609047?pq-origsite=gscholar.

[24] Tauritz, R., 2012, "How to Handle Knowledge Uncertainty: Learning and Teaching in Times of Accelerating Change," In A. Wals & P. Corcoran (Eds.), Learning for Sustainability in Times of Accelerating Change, pp. 299-316. Wageningen, The Netherlands: Wageningen Academic Pub.

[25] Zheng, X., Ritter, S. C., and Miller, S. R., 2018, "How Concept Selection Tools Impact the Development of Creative Ideas in Engineering Design Education," Journal of Mechanical Design, 140(5), p. 052002.

[26] Kazerounian, K., and Foley, S., 2007, "Barriers to Creativity in Engineering Education: A Study of Instructors and Students Perceptions," Journal of Mechanical Design, 129(7), pp. 761-768.

[27] Richter, D. M., and Paretti, M. C., 2009,"A Cognitive Framework for Understanding the Role of Students’ Expectations and Motivations in Interdisciplinary Design Collaboration," Proc. Proceedings of the Research in Engineering Education Symposium, REES.

[28] Mohammed, S., Okudan, G. E., and Ogot, M., 2006, "Tolerance for Ambiguity: An Investigation on Its Effect on Student Design Performance?," American Society of Engineering Education, age 11, p.1-8.

[29] Dringenberg, E., and Wertz, R., 2016, "How Do First-year Engineering Students Experience Ambiguity in Engineering Design Problems: The Development of a Self-report Instrument, " 123rd ASEE Annual Conference & Exposition, New Orleans, Louisiana, Paper No. 15094, 10.18260/p.25474.

[30] Okudan, G. E., Bilén, S. G., and Wu, X., 2003, "Gender Orientation of the Design Task: Product Domain and Familiarity Issues," Proc. DS 31: Proceedings of ICED 03, the 14th International Conference on Engineering Design, August 19-22, Stockholm.

[31] Moskal, B. M., 2000, "Looking to the Future: Women in Science and Engineering," Proc. Frontiers in Education Conference, 2000. FIE 2000, 30th Annual, IEEE, 11, pp. F1B/19-F11B/24, 11.

[32] Moskal, B. M., Knecht, R., and Lasich, D., "Engineering Design: Using a Scoring Rubric to Compare the Products of Teams that Differ in Gender Composition," Proc. American Society of Engineering Education Annual Conference &Exposition, p. 1-12.
[33] Amelink, C. T., and Meszaros, P. S., 2011, "A Comparison of Educational Factors Promoting or Discouraging the Intent to Remain in Engineering by Gender," European Journal of Engineering Education, 36(1), pp. 47-62.

[34] Hill, C., Corbett, C., and St Rose, A., 2010, Why so few? Women in Science, Technology, Engineering, and Mathematics, ERIC, Amer Assoc Univ Women, Washington, DC.

[35] Baker, D. R., 2016, "An Intervention to Address Gender Issues in a Course on Design, Engineering, and Technology for Science Educators," Understanding Girls, Springer, pp. 161-196, Sense Publishers, Rotterdam.

[36] Nicholls, G. M., Wolfe, H., Besterfield-Sacre, M., Shuman, L. J., and Larpkiattaworn, S., 2007, "A Method for Identifying Variables for Predicting STEM Enrollment," Journal of Engineering Education, 96(1), pp. 33-44.

[37] Bucak, S., and Kadirgan, N., 2011, "Influence of Gender in Choosing a Career amongst Engineering Fields: A Survey Study from Turkey," European Journal of Engineering Education, 36(5), pp. 449-460.

[38] Knight, D. B., Lattuca, L. R., Yin, A., Kremer, G., York, T., and Ro, H. K., 2012, "An Exploration of Gender Diversity in Engineering Programs: A Curriculum and Instruction-based Perspective," Journal of Women and Minorities in Science and Engineering, 18(1).

[39] Bandura, A., 1977, "Self-efficacy: Toward a Unifying Theory of Behavioral Change," Psychological Review, 84(2), pp. 191-215.

[40] Bandura, A., 2000, "Exercise of Human Agency through Collective Efficacy," Current Directions in Psychological Science, 9(3), pp. 75-78.

[41] Chachra, D., Dillon, A., Spingola, E., and Saul, B., 2014, "Self-efficacy and Task Orientation in First-year Engineering Design Courses," Proc. IEEE Frontiers in Education Conference (FIE), Madrid, Spain, pp. 1-4.

[42] McLain, D. L., 1993, "The MSTAT-I: A New Measure of an Individual's Tolerance for Ambiguity," Educational and Psychological Measurement, 53(1), pp. 183-189.

[43] Jex, S. M., and Bliese, P. D., 1999, "Efficacy Beliefs as A Moderator of the Impact of Work-related Stressors: A Multilevel Study," Journal of Applied Psychology, 84(3), p. 349.

[44] Zimmerman, B. J., Bandura, A., and Martinez-Pons, M., 1992, "Self-motivation for Academic Attainment: The Role of Self-efficacy Beliefs and Personal Goal Setting," American Educational Research Journal, 29(3), pp. 663-676.
[45] Hutchison, M. A., Follman, D. K., Sumpter, M., and Bodner, G. M., 2006, "Factors Influencing the Self-efficacy Beliefs of First-year Engineering Students," Journal of Engineering Education, 95(1), pp. 39-47.
Figure Captions List

Fig. 1  Percentage of 2003-04 beginning bachelor’s degree students who left STEM and selected non-STEM fields after their entrance into these fields, by major field entered: 2003-2009 [13]
Table Captions List

Table 1  Descriptive statistics for all survey scales by gender

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Table 5  Summary of ANOVA model for investigating the effects of gender and major on STA

Table 6  Summary of ANCOVA model for investigating the effects of PGO, gender, Holland’s classification on STA
Figure 1. Percentage of 2003-04 beginning bachelor’s degree students who left STEM and selected non-STEM fields after their entrance into these fields, by major field entered: 2003-2009 [13]
Table 1. Descriptive statistics for all survey scales by gender

|                          | Minimum | Maximum | Median | Mean  | StDev |
|--------------------------|---------|---------|--------|-------|-------|
| **Female students (n=41)** |         |         |        |       |       |
| Student tolerance to ambiguity (STA) | 1.75    | 4.88    | 3.50   | 3.46  | 0.65  |
| Student collective efficacy (SCE)     | 1.25    | 4.92    | 3.88   | 3.77  | 0.94  |
| Student perception on project gender orientation (PGO) | 1.00    | 4.33    | 2.67   | 2.38  | 1.07  |
| Student perception on project domain relatedness (PDR) | 1.00    | 4.86    | 2.86   | 2.79  | 0.97  |
| Project ambiguity level (PAL)         | 1.00    | 5.00    | 4.00   | 3.64  | 1.11  |
| **Male students (n=89)** |         |         |        |       |       |
| Student tolerance to ambiguity (STA) | 1.13    | 5.00    | 3.50   | 3.52  | 0.65  |
| Students’ collective efficacy (SCE)     | 1.83    | 4.96    | 4.00   | 3.85  | 0.82  |
| Student perception on project gender orientation (PGO) | 1.00    | 5.00    | 2.17   | 2.35  | 1.16  |
| Student perception on project domain relatedness (PDR) | 1.00    | 5.00    | 3.14   | 3.11  | 0.94  |
| Project ambiguity level (PAL)         | 1.00    | 5.00    | 4.00   | 3.51  | 1.15  |
Table 2. Correlation among variables in the survey

|                                      | STA  | SCE  | PGO  | PDR  | PAL  | Student confidence to achieve expected grade |
|--------------------------------------|------|------|------|------|------|---------------------------------------------|
| Student tolerance to ambiguity (STA)| 1    |      |      |      |      |                                             |
| Students' collective efficacy (SCE)  |      | -0.002|      |      |      |                                             |
| Student perception on project gender orientation (PGO) |      |      | -0.128|      |      |                                             |
| Student perception on project domain relatedness (PDR) |      | 0.077| 0.139| 0.022|      |                                             |
| Project ambiguity level (PAL)       |      |      |      |      |      |                                             |
| Student confidence to achieve expected grade |      |      |      |      | 0.081| -0.256**                                   |

Note. * = p < .05; ** = p < .01
Table 3. Logistic regression analysis results

| Predictor                                      | Coef(β) | S.E. Coef | Wald’s | df | p value | e^β (odds ratio) |
|------------------------------------------------|---------|-----------|--------|----|---------|-----------------|
| Student tolerance to ambiguity (STA)           | 0.49    | 0.39      | 1.56   | 1.00 | 0.21    | 1.63            |
| Student perception on project gender orientation (PGO) | -0.51   | 0.23      | 4.86   | 1.00 | 0.03*   | 0.60            |
| Student perception on project domain relatedness (PDR) | 0.33    | 0.28      | 1.41   | 1.00 | 0.24    | 1.39            |
| Holland’s classification                       |         |           |        |     |         |                 |
| Holland’s classification (1)                   | -20.26  | 28014.49  | 0.00   | 1.00 | 0.99    | 0.00            |
| Holland’s classification (2)                   | -19.88  | 28014.49  | 0.00   | 1.00 | 0.99    | 0.00            |
| Holland’s classification (3)                   | -19.53  | 28014.49  | 0.00   | 1.00 | 0.99    | 0.00            |
| Constant                                       | 20.08   | 28014.49  | 0.00   | 1.00 | 0.99    | 524981915.52    |

Goodness-of-Fit Test

| Test                | χ²      | df | p value   |
|---------------------|---------|----|-----------|
| Hosmer-Lemeshow     | 11.199  | 8  | 0.19      |

Cox & Snell R² = 0.088; Nagelkerke R² = 0.142
Table 4. Summary of linear regression analysis for variables predicting SCE

| Independent variables                                      | Coef. | SE Coef | T-value | p-value |
|------------------------------------------------------------|-------|---------|---------|---------|
| Constant                                                   | 3.71  | 0.63    | 5.90    | 0.00    |
| Student tolerance to ambiguity (STA)                       | -0.17 | 0.13    | -1.27   | 0.20    |
| Student perception on project gender orientation (PGO)     | -0.12 | 0.07    | -1.71   | 0.09    |
| Student perception on project domain relatedness (PDR)     | 0.03  | 0.09    | 0.30    | 0.76    |
| Expected grade                                             | 0.00  | 0.20    | 0.01    | 0.99    |
| Gender                                                     | -0.22 | 0.17    | -1.31   | 0.19    |
| Student confidence on expected grade                       | 1.21  | 0.55    | 2.19    | 0.03    |
Table 5. Summary of ANOVA model for investigating the effects of gender and major on STA.

| Independent variables      | df | Seq. SS | Adj SS | Adj MS | F   | p value |
|----------------------------|----|---------|--------|--------|-----|---------|
| Gender                    | 1  | 0.07    | 0.11   | 0.26   | 0.61|         |
| Holland’s classification   | 3  | 1.95    | 1.95   | 0.65   | 1.54| 0.21    |
| Error                     | 113| 47.90   | 47.90  | 0.42   |     |         |
| Total                     | 117| 49.92   |        |        |     |         |

R-Sq = 4.05%  R-Sq(adj) = 0.66%
Table 6. Summary of ANCOVA model for investigating the effects of PGO, gender, Holland’s classification on STA.

| Independent variables                      | df | Seq. SS | Adj SS | Adj MS | F     | p value |
|--------------------------------------------|----|---------|--------|--------|-------|---------|
| Student perception on project gender orientation (PGO) | 1   | 2.12    | 2.08   | 2.08   | 5.08  | 0.03    |
| Gender                                     | 1   | 0.09    | 0.09   | 0.09   | 0.23  | 0.64    |
| Holland’s classification                    | 3   | 1.89    | 1.93   | 0.64   | 1.57  | 0.20    |
| Error                                      | 112 | 45.82   | 45.82  | 0.41   |       |         |
| Total                                      | 117 | 49.92   |        |        |       |         |

R-Sq = 8.22%   R-Sq(adj) = 4.12%
Appendix A

The survey to assess design project appropriateness for first year students in terms of STA, SCE, PDR, PGO, and PAL

**Student Tolerance to Ambiguity (STA)**
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.
12. I enjoy tackling problems, which are complex enough to be ambiguous.
13. I try to avoid problems, which don’t seem to have only one “best” solution.
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.
17. Some problems are so complex that just trying to understand them is fun.
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”
20. I find it hard to make a choice when the outcome is uncertain.
21. I enjoy an occasional surprise.
22. I prefer a situation in which there is some ambiguity.

**Students’ Collective Efficacy (SCE)**
1. I am satisfied with the way my team worked together.
2. Team members have worked better together now than when the team was formed.
3. Team members are more aware of group dynamics now than when they joined the team.
4. Being a part of this team has helped members appreciate different types of people.
5. Overall, I am satisfied with team performance on projects.
6. If we have had another engineering project, this team should continue to function as a team.
7. If I could have left this team and worked with another team, I would have.
8. I would not hesitate to participate on another project with the same team members.
9. This team is not capable of working together as a unit.
10. I am satisfied with this team compared to teams I have been on in the past.
11. Our team has tackled difficult work assignments enthusiastically.
12. Team members have adapted their schedules to meet one another’s demands.
13. Our team have supported and encouraged team members with problems.
14. Team members have helped each other with their tasks.
15. Team members have respected one another and show understanding.
16. Team members have given their opinion when it concerned important issues.
17. Members have maintained a positive attitude about the team.
18. We have effectively talked through disagreements about ideas/opinions in my group.
19. We have effectively talked through disagreements about procedures (the way we get work done) in my group.
20. We have effectively dealt with interpersonal friction/personality clashes in my group.
21. The members of this group have excellent skills in team-working and communication.
22. I have real confidence in my group’s ability to perform well on projects.
23. This group did not do as well as other groups in my class.
24. Some members in this group did not do their jobs well.
25. I have had to work closely with my teammates to do my work properly.

**Project Domain Relatedness (PDR)**
1. The industrial sponsored project this semester relates to my major/anticipated major.
2. The industrial sponsored project has motivated/inspired me to learn.
3. The skills I learned through this industrial sponsored project have helped me easily decide/choose/or stay with my
major.
4. The satisfaction I have felt throughout this industrial sponsored project has helped me easily decide/choose or stay with my major.
5. This industrial sponsored project will positively impact the way I evaluate the course at the end of the semester when the SRTE (Student Rating of Teaching Effectiveness) is conducted.
6. The industrial sponsored project this semester has positively impacted me to stay with my major/anticipated major.
7. 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.
8. I found certain aspects of the design projects to be related to my chosen discipline

Project Gender Orientation (PGO)
1. 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).
2. The project my group worked on was associated with a masculine or feminine experience (e.g., cooking makes me think of females).
3. The project my group worked on was associated with a masculine or feminine institution (e.g., the military makes me think of males).
4. The project my group worked on was associated with a masculine or feminine action related (e.g., teaching makes me think of females).
5. 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).
6. 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).
7. 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).
8. The project my group worked on was associated with a masculine or feminine composition (e.g., the group was all male).

Project Ambiguity Level (PAL)

Project Ambiguity Level
Appendix B

Brief explanations on the EDSGN 100 course, its learning goals, and the description of the design project are provided below. Course relevant information was provided by Xinli Wu.

Design project description is minimally modified from a version prepared and used by Engineering Design Program faculty at Penn State.

Course Overview

EDSGN 100, Introduction to Engineering Design, provides students with a foundation for engineering design through hands-on team projects that address specified design opportunities. Through this course, students will recognize the role that engineering and design have in improving the health, safety, and welfare of the global community, as well as identifying when a solution is technically feasible, economically viable, and desirable. Students will use a range of design tools and techniques to carry out and communicate their design processes as applied to their projects. Additionally, students will develop and practice professional skills, such as communication, teamwork, and ethical decision-making.

Course Learning Goals

1. Apply engineering design to address design opportunities.
2. Use systems thinking and apply it to engineering design.
3. Develop professional skills necessary for becoming a successful engineer.
4. Communicate engineering concepts and designs.
5. Gain experience in hands-on fabrication while developing a “maker” mindset.

Project Description

“In 2012, a large rare-earth element ore deposit, which is rich in the elements Neodymium (Nd), Europium (Eu), Terbium (Tb), Dysprosium (Dy), and Yttrium (Y), was
discovered deep beneath the Pocono Mountains in Pennsylvania. The ore is located
approximately 10,000 meters beneath the Earth’s surface. However, 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
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 an 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/regulated/environmental requirements,
• Safety,
• Costs (e.g., fuel, infrastructure),
• Public opinion, and
• Productivity.

**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**

• A technical report containing the following elements: 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, and economic viability of the system.
• computer-aided drafting drawings, and
• model or prototype of a component of the overall system.”
Appendix C

Developed instrument to assess design project appropriateness for first year students in terms of STA, SCE, PDR, PGO and PAL.

| Factor | 1 | 2 | 3 | 4 | 5 |
|--------|---|---|---|---|---|
| **Student Tolerance to Ambiguity (STA)** |   |   |   |   |   |
| 1. I don’t tolerate ambiguous situation well. | -.196 | -.059 | .223 | .643 | -.026 |
| 2. I would rather avoid solving a problem that must be viewed from several different perspectives | -.043 | -.204 | .054 | .494 | .020 |
| 3. I try to avoid situations, which are ambiguous. | -.058 | -.079 | .311 | .734 | -.014 |
| 4. I avoid situations, which are too complicated for me to easily understand. | .161 | -.131 | .104 | .440 | .130 |
| 5. I am tolerant of ambiguous situations. | -.037 | .024 | -.006 | .729 | .050 |
| 6. I enjoy tackling problems, which are complex enough to be ambiguous. | .151 | -.102 | .246 | .587 | .078 |
| 7. I dislike ambiguous situations. | -.126 | -.069 | .059 | .740 | -.069 |
| 8. I prefer a situation in which there is some ambiguity. | -.023 | -.102 | .090 | .616 | -.026 |
| **Students’ Collective Efficacy (SCE)** |   |   |   |   |   |
| 1. I am satisfied with the way my team worked together. | .896 | -.025 | .016 | .023 | -.001 |
| 2. Team members have worked better together now than when the team was formed. | .771 | .046 | .052 | -.024 | -.104 |
| 3. Team members are more aware of group dynamics now than when they joined the team. | .840 | .020 | .068 | .063 | -.107 |
| 4. Being a part of this team has helped members appreciate different types of people. | .673 | .001 | .052 | .090 | -.055 |
| 5. Overall, I am satisfied with team performance on projects. | .915 | -.042 | .082 | -.020 | -.039 |
| 6. If we have had another engineering project, this team should not continue to function as a team. | .749 | .013 | -.042 | -.032 | .040 |
| 7. If I could have left this team and worked with another team, I would have. | .828 | -.054 | -.070 | -.066 | .066 |
| 8. I would not hesitate to participate on another project with the same team members. | .783 | -.038 | -.012 | -.094 | .033 |
| 9. This team is not capable of working together as a unit. | .716 | -.137 | -.071 | .072 | .102 |
| 10. I am satisfied with this team compared to teams I have been on in the past. | .704 | .030 | -.054 | -.149 | .139 |
| 11. Our team has tackled difficult work assignments enthusiastically. | .747 | -.005 | -.202 | -.013 | .178 |
| 12. Team members have adapted their schedules to meet one another’s demands. | .708 | .010 | -.187 | -.056 | .237 |
| 13. Our team have supported and encouraged team members with problems. | .744 | -.023 | .109 | -.029 | .287 |
| 14. Team members have helped each other with their tasks. | .844 | -.086 | .071 | -.066 | -.004 |
| 15. Team members have respected one another and show understanding. | .699 | -.035 | .040 | -.036 | .364 |
| 16. Team members have given their opinion when it concerned important issues. | .540 | .069 | .053 | .091 | .452 |
| 17. Members have maintained a positive attitude about the team. | .703 | .000 | .055 | .130 | .448 |
| 18. We have effectively talked through disagreements about ideas/opinions in my group. | .716 | -.004 | .077 | .136 | .577 |
| 19. We have effectively talked through disagreements about procedures (the way we get work done) in my group. | .610 | .085 | .141 | .014 | .569 |
| 20. We have effectively dealt with interpersonal friction/personality clashes in my group. | .314 | .087 | .170 | .039 | .421 |
| **Project Domain Relatedness (PDR)** |   |   |   |   |   |
| 1. The industrial sponsored project this semester relates to my major/anticipated major. | -.079 | .853 | -.130 | -.060 | .117 |
| 2. The industrial sponsored project has motivated/inspired me to learn. | -.011 | .815 | -.051 | -.128 | .002 |
| 3. The skills I learned through this industrial sponsored project has helped me easily decide/choose/or stay with my major. | -.078 | .878 | -.180 | -.110 | -.011 |
| 4. The satisfaction I have felt throughout this industrial sponsored project has helped me easily decide/choose or stay with my major. | -.095 | .820 | .004 | -.156 | -.018 |
| 5. This industrial sponsored project will positively impact the way I evaluate the course at the end of the semester when the SRTE (Student Rating of Teaching Effectiveness) is conducted. | -.044 | .838 | -.013 | -.196 | .026 |
6. 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.

7. The industrial sponsored project this semester has positively impacted me to stay with my major/anticipated major.

**Project Gender Orientation (PGO)**
1. The project my group worked on was associated with a masculine or feminine experience (e.g., cooking makes me think of females).

2. The project my group worked on was associated with a masculine or feminine institution (e.g., the military makes me think of males).

3. The project my group worked on was associated with a masculine or feminine action related (e.g., teaching makes me think of females).

4. 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).

5. 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).

6. 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).

**Project Ambiguity Level (PAL)**
1. Project Ambiguity level

|   |   |   |   |
|---|---|---|---|
| .020 | .039 | .116 | .014 |
| .077 | .005 | .057 | -.007 |
| .125 | .013 | .810 | .084 | .013 |
| -.088 | -.076 | .777 | .053 | .050 |
| -.017 | -.045 | .841 | -.020 | .082 |
| .137 | .017 | .785 | .133 | .051 |
| .064 | .006 | .734 | .095 | .016 |
| .150 | -.113 | .745 | .042 | -.062 |
| -.012 | .079 | -.333 | .075 | -.064 |