AC 2010-1741: EXAMINING STUDENTS' PERCEPTIONS OF INTERDISCIPLINARITY BASED ON GENDER AND DISCIPLINARY AFFILIATION

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Examining Students' Perceptions of Interdisciplinarity Based on Gender and Disciplinary Affiliation

Abstract

The aim of the research proposed here is to contribute to theories about the development of undergraduate engineering students as interdisciplinary engineers, by examining engineering students' perceptions of interdisciplinarity based on gender and disciplinary affiliation. The motivation for this study is due to the gap in the literature regarding the evaluation of interdisciplinary work and the increase in the number of interdisciplinary undergraduate engineering programs and courses. In addition, research indicates female students give greater attention to context in a design problem than their male counterparts, and therefore, could have different experiences in interdisciplinary programs, which are context-focused. Literature has also indicated potential barriers to a student's interdisciplinary understanding exist due to the student's affiliation with a particular engineering discipline.

An open-ended questionnaire was used to gain an understanding of the characteristics of engineering students from two majors at the start of the second year, which is the first semester of major coursework at the university in this study. Of the one hundred students in the study, twelve had elected to participate in an interdisciplinary program between the two majors. The questionnaire itself asks students to think about interdisciplinary and non-interdisciplinary engineering projects. Students' responses to the questionnaire were analyzed using the open coding method of grounded theory to identify emerging themes or categories within the responses. The final coding scheme recognizes students' differing perceptions of what constitutes an interdisciplinary collaboration, the purpose of using an interdisciplinary approach, and the process for establishing disciplinary grounding. The importance of team dynamics in engineering projects emerged from the responses, specifically in the discussion of communication, task delegation, and recruitment of team members. Additionally, while disciplinary affiliation appeared to influence students' understanding of the purpose behind using an interdisciplinary approach, gender affected students' examples of interdisciplinary collaborations. Participation in the interdisciplinary engineering program also was associated with providing the program as an example of an interdisciplinary collaboration. Beyond these areas, there were no significant differences in students' responses based on gender or disciplinary affiliation. The small sample size of students could have contributed to the small number of significant differences between the independent variables. Overall, due to the open-ended nature of questions, it was not possible to indicate whether all of the students agreed or disagreed with the different perceptions. Therefore, these results were utilized within a larger mixed-methods study, designed to further explore these research questions.

Introduction

In the 2009-2010 academic year, undergraduate engineering students from across the country will specialize in green engineering, nanobiotechnology, and pharmaceutical engineering or enter majors such as nanosystems engineering and energy engineering.[1,2] The objectives of these programs focus on imparting graduates with the abilities to apply tools and skills from multiple departments and become leaders in industry and academia.[3] However, presently it is unknown how graduates of these programs differ from graduates of the more classical engineering disciplines, such as mechanical engineering and civil engineering. Additionally, forms of interdisciplinary assessment and evaluation as well as studies of student development in these programs are limited.[4] Therefore, reliable methods of assessment and evaluation are necessary to determine what students are learning and how they are developing as interdisciplinary engineers.[4, 5]

This research builds upon a rubric and framework for the assessment of interdisciplinary work at the collegiate level, which was originally created to assess the performance of liberal arts students participating in interdisicplinary projects.[4,6] The framework and rubric were developed using a comprehensive definition of what constitutes a student's interdisicplinary understanding based upon faculty assessment of student interdisicplinary research. The definition consists of four dimensions of interdisicplinary understanding presented in the rubric and framework: (1) *purposefulness,* (2) *disciplinary grounding,* (3) *integration,* and (4) *critical awareness*.[4]

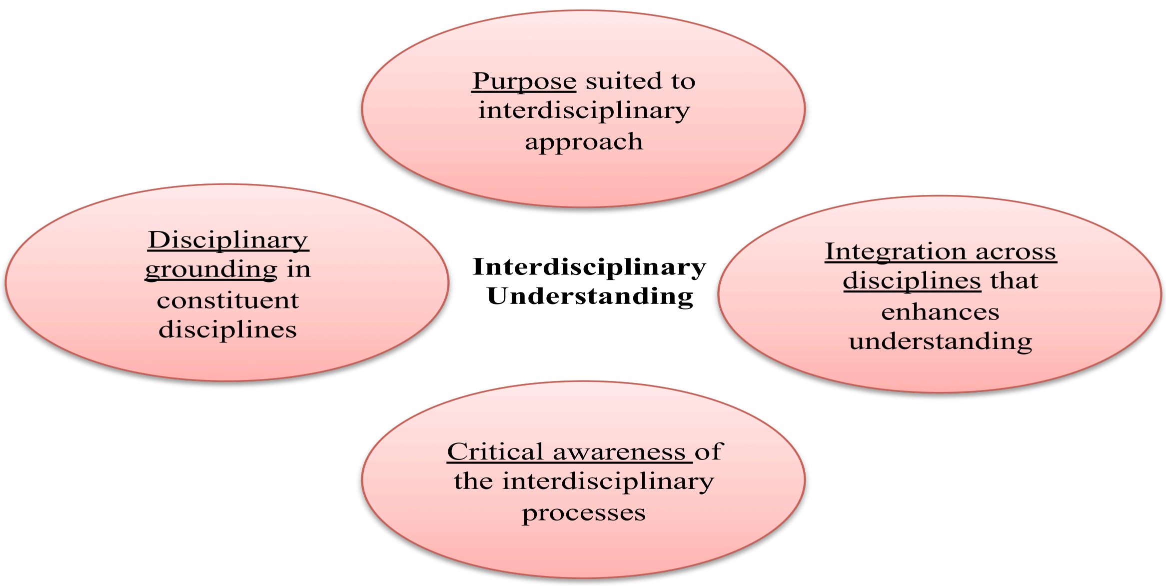

Figure 1: The four dimensions with which to assess interdisciplinary understanding[4,6]

In the original studies used to develop these dimensions, students' projects were only examined within the humanities and the sciences, not engineering. While disciplinary borders and interdisciplinary programs in the humanities and the sciences have been examined for decades, this is not the case for engineering disciplines and programs.[7] In other cases, the core elements of an interdisciplinary curriculum were discussed theoretically[8], yet these discussions lacked an explanation of how such a curriculum could be implemented. Other studies focused on only one or two of the dimensions of interdisciplinary understanding. In a green engineering program, for instance, concept maps were used to assess the students' ability to integrate the different concepts.[9] Another assessment of interdisciplinary collaborative efforts measured students' awareness of the need for these efforts and their willingness to participate in a project which required contributions from multiple disciplines.[10] Fruchter and Lewis[11] developed a metric and assessment method to monitor student development in a cross-disciplinary learning environment and describe how students evolve in this environment (see Table 1). The resulting framework parallels the dimensions of interdisciplinary understanding presented in Boix Mansilla and Duraisingh[6] yet differs in its focus on students' evolution from one dimension to another.In addition, this framework assumes an individual first has grounding in one discipline and then develops an awareness of, an appreciation for, and an understanding of a second discipline. In contrast, the four dimensions of interdisciplinary understanding indicate that a single individual can have disciplinary grounding in multiple disciplines, without necessarily mastering one before developing grounding in another. Overall, the prior studies illustrate the importance of examining student development in undergraduate engineering curricula, yet there still exist many variables which have not been considered, including undergraduate engineering students' interdisciplinary understanding in their first two years of college.

Table 1: Student Development with Cross-Disciplinary Learning[11]

Islands of Knowledge	The student masters his/her discipline, but does not have experience in other disciplines.
Awareness	The student is aware of the other discipline's goals and constraints.
Appreciation	The student begins to build a conceptual framework of the other discipline, is interested to understand and support the other discipline's goals and concepts, and knows what questions to ask.
Understanding	The student develops a conceptual understanding of the other disciplines, can negotiate, is proactive in discussions with participants from the other disciplines, provides input before input is requested, and begins to use the language of the other disciplines.

Gender and Disciplinary Affiliation

National studies indicate that women currently earn about 20% of the engineering degrees awarded each year.[12] Recent findings also suggest retention problems are not the main reason universities graduate such a small percentage of women engineers, inferring a need to refocus on the recruitment of female students to engineering.[13] Considering the significance of the gender differences in the number of female engineering graduates and the findings regarding recruitment, could interdisciplinary undergraduate engineering (IUE) programs be used to attract more women to engineering?

In addition, research findings suggest women and men define engineering and frame engineering problems differently.[14] According to the study, when given an engineering design problem, female undergraduate engineering students were found to give significantly greater attention to the context of the design than their male counterparts.[14] The research also suggests these differences could be used to restructure engineering programs with a greater focus on context than traditional practice.[14] The focus of many IUEs on engineering in context strengthens the need to investigate potential gender differences in students' interdisciplinary understanding.

The use of a disciplinary affiliation lens for this project was grounded in several studies. A study at the University of California – Berkeley, for instance, revealed that undergraduate engineering students have a strong belief system surrounding the nature of disciplines, which negatively affected the integration of these disciplines within the curriculum.[15] Another study analyzed students' perceptions of a lab course in communication systems.[15,16] The results indicated the students viewed electrical engineers as technicians, focusing on the practical aspects of the labs, rather than the theoretical concepts, which served as the basis of the labs.[15,16] Both of these studies are indicate students' perceptions of disciplines, specifically their own discipline, can affect students' learning outcomes.[10]

A 2009 study, which aimed to identify the barriers to interdisciplinarity, found, in many cases, students struggled to think beyond their own discipline.[17] The researchers coined "disciplinary egocentrism" to describe this phenomenon.[17] This finding, along with the previous examples, indicates a strong need to examine how disciplinary affiliation will affect students in an IUE program and whether a disciplinary affiliation will affect engineering students' perceptions as early as the first semester of major coursework.

Research Objectives and Methods

The purpose of this research is to begin to investigate a student's development as an interdisciplinary engineer within an interdisciplinary undergraduate engineering program. To facilitate this investigation, this study utilized a questionnaire to examine engineering students within the first semester of their major coursework with two main objectives. The first objective is to explore students' perceptions and understanding of engineering and interdisciplinary engineering projects and programs, utilizing the framework by Boix Mansilla and Duraisingh[4] as a guide. The second is to determine if students' perceptions of interdisciplinarity vary by gender or disciplinary affliation.

Site and Participant Information

The Leaders in Engineering Program (LEP) at Southeastern University is an interdisciplinary undergraduate engineering program, which combines concepts and methodologies from Systems Engineering (SE) as well as Electrical and Computer Engineering (ECE). One of the main objectives of this program is to enable students to work on interdisciplinary engineering projects requiring an understanding of electrical and computer design as well as systems analysis. Over the course of three years in the program, students will be required to complete coursework in both the SE and ECE departments, including two joint laboratory courses in the third year and a team-based, interdisciplinary capstone project in the fourth year.

In fall of 2009, 15 students became the first cohort to begin this program. In the first semester of the program, these students are required to take an introduction to systems engineering course (SE 101) as well as an introduction to circuits course (ECE 101). SE 101 is composed of, beyond the LEP students, only systems engineering majors, while ECE 101 includes students from a few engineering departments, such as electrical engineering, computer engineering, and mechanical engineering majors. The opportunity to study the first group to enter in the program, along with the design of the program's requirements, make this site ideal to examine the early stages of student development as interdisciplinary engineers.

The 100 participants for this study were students enrolled in SE 101 and/or ECE 101. Twenty-six are electrical and computer engineering majors, while the other seventy-four are students in the systems engineering department. Of the participants, 31 are female engineering students, which is similar to the undergraduate engineering demographics (approximately 28% are women).[18] In the LEP, 5 of the 12 students who participated are women, while 4 are SE students, and 8 are ECE students.

Data Collection

To elicit information from all the students in ECE 101 and SE 101, an eleven-item questionnaire was developed. The questionnaire provided the students with the opportunity to answer each question in their own words.[19] By not limiting responses, the possibility for "unusual" answers or answers that could demonstrate students' understanding of interdisciplinarity was introduced.[19] Furthermore, gaps in the literature demonstrated a lack of clarity in students' interdisciplinary understanding at the different stages of their education; therefore, this instrument attempted to capture these unknown viewpoints.

Engineering students and faculty piloted the questionnaire, and existing literature was consulted to assess the clarity of, and reduce potential bias in, the questions.[20] The questions themselves were developed using the dimensions of interdisciplinary understanding in Figure **1** as a guide, specifically:

(1) students' understanding of the need and purpose for interdisciplinary work,
(2) students' awareness of the different disciplines involved in interdisciplinary projects,
(3) students' recognitionof the integration involved in interdisciplinary work, and
(4) students' awareness of the process and its similarities or differences to the process taken in other projects.

The questionnaire contains 6 main questions, which ask the student to think about interdisciplinary and non-interdisciplinary engineering projects. Questions 2 and 3 focused on students' definition of an interdisciplinary project. Question 4 was designed to specifically examine the dimension of purpose, as explained in item 1 above, while question 6 focused on critical awareness, as defined in item 4. The fifth question inquired about the approach to an interdisciplinary problem, which was included to explore students' general perceptions about this issue as well as whether students would discuss disciplinary grounding (item 2) or integration (item 3). The last questions ask about the respondent's gender, disciplinary affiliation, career plans, and previous involvement in engineering projects. A copy of the survey is included in Appendix A.

The questionnaire, approved by the university's Institutional Review Board (Project # 2009-0308-00), was distributed to both SE 101 and ECE 101 during the first half of the semester. Students in SE 101 were required to complete the assignmentin order to receive points towards their class participation grade. Students in ECE 101, on the other hand, were solicited through a class announcement and email. The questionnaire was posted on *SurveyMonkey*, an online platform for survey design and data collection, and a link was provided to all of the students via email. Of the 194 students in the two classes, 100 consented to participate in the study.

Data Analysis and Results

A grounded theory approach was used to examine emerging themes within the responses. The initial coding scheme was influenced by the survey questions themselves as well as the assessment framework developed by Boix Mansilla and Duraisingh[4], but was flexible in the event that other categories emerged.[19, 21] Through this method, responses for each question were read and reread to begin to gain a general idea of the breadth of perceptions. Student responses were first coded based on descriptive codes, regarding whether the student was talking about example projects, how to approach an engineering problem, or challenges of engineering problems.

Once all the responses were coded based on this descriptive scheme, the data was reread and recoded to determine which codes most appropriately described the data. A second researcher used this to code the data and then the coding was checked against the coding of the first researcher for interrater reliability purposes. Inter-rater reliability was calculated using the formula recommended by Miles & Huberman[22]. The agreements refer to the codes assigned to segments of the transcripts. Since the reliability was greater than the inter-rater reliability goal of 80 percent, disagreements were discussed between the raters to achieve consensus.

Defining Dimensions

The next step in the analysis process was to identify categories,which connect the descriptive codes used in the preliminary coding schemes. The first fourcategories incorporated the four dimensions of interdisciplinary understanding (*purpose, disciplinary grounding, integration, critical awareness).* A final category was developed to describe the different definitions of interdisciplinary projects that students provided (*definitions of interdisciplinarity).* Each category was then divided into a hierarchical tree structure used to display the different themes, which emerged from the responses. A table discussing the percentages of students who responded in a certain category or subcategory is included in Appendix B.

Definitions of Interdisciplinarity

Within *Definitions of Interdisciplinary,* the codes describe the different definitions students used to describe interdisciplinary and non-interdisciplinary collaborations (see Table 2). The percentage of sample (n=100) column indicates the percentage of students whose responses were coded in that particular category.

The five Tier 1 categories are the primary groupings of student responses about the definition of interdisciplinarity. Within three of these tiers, sub-groupings (referred to as Tier 2) were also present.

The first Tier 1 category was derived from students' examples of interdisciplinary collaborations between engineering disciplines (with the Leaders in Engineering Program being a commonly cited example). Students also provided examples of using engineering and non-engineering disciplines when defining interdisciplinarity, as indicated by the second Tier 1 category. Within this tier, a sub-category was created to capture the responses of some students who felt engineering represented a single discipline. Thus for a collaboration to be considered interdisciplinary, it needed to be between engineering and a non-engineering discipline. One student explained, "The interdisciplinary approach was used, because there were more than just engineering aspects of the project. The non interdisciplinary approach was used, because only engineering was sufficient in its development."

Table 2: Coding Scheme for *Definitions of Interdisciplinarity*

Tier 1	**Tier 2**	**Description**	**% of Sample (n=100)**
Engineering + Engineering Collaborations	*General Engineering + Engineering Collaborations*	Interdisciplinary collaborations between engineering disciplines	20%
	Leaders in Engineering Program	The IUE program which is the focus of this research	16%
Engineering + Non-Engineering Collaborations	*General Engineering + Non-Engineering Collaborations*	Interdisciplinary collaborations between engineering and non-engineering disciplines	39%
	Engineering as One Discipline	It is necessary for a non-engineering discipline to be involved with an engineering project for the project to be considered interdisciplinary.	5%
It's All Interdisciplinary		All projects or programs could be considered interdisciplinary.	4%
No Clear Specification		No specific type of collaboration was specified.	34%
Discussion of Disciplines	*Interdisciplinary Engineering Disciplines*	Certain engineering disciplines are interdisciplinary.	6%
	Non-Interdisciplinary Engineering Disciplines	Disciplines or programs students explicitly state are not interdisciplinary.	11%

Other students who gave examples of *engineering + engineering collaborations* indicated, "Almost any project can be considered an interdisciplinary project", which led to the development of the third Tier 1 category (*It's All Interdisciplinary*). The fourth Tier 1 category (*No Clear Specification*) was utilized to classify those examples of interdisciplinary projects or programs, which did not include a description of the type of collaboration, "solar car", for instance. In regards to engineering programs, there was disagreement regarding whether disciplines, such as systems engineering and biomedical engineering, were considered interdisciplinary or non-interdisciplinary. These disagreements were sorted into the final Tier 1 category, *Discussions of Disciplines.* Within the category, students' responses were separated into the two Tier 2 categories to distinguish a student's description of systems engineering as "inherently interdisciplinary cause often times the projects span a couple engineering types" from students who describe systems engineering as non-interdisciplinary. The idea that there are distinct differences in how individuals define of "interdisciplinary" is not unique to these students, as researchers have previously shown that the definitions vary not only by industry and field, but also by country.[7]

Within the *Definitions of Interdisciplinarity* category, chi-square tests were used to determine whether there were any statistically significant associations between gender or disciplinary affiliation and the students' responses. It was found that an association exists between the subcategory of *General Engineering + Engineering Contributions* and gender (Pearson's Chi Square Value = 5.154, $p = 0.023$). Of the twenty responses included in this category, eighteen were written by male students. Also within the Tier 1 Category *Engineering + Engineering Contributions* the relationship between students who cited the Leaders in Engineering Program as an example of an interdisciplinary collaboration and whether or not the students were participants of the program was significant (Pearson's Chi Square Value = 35.319, $p < 0.001$, Fisher's exact test $p < 0.001$).

Beyond these two results, there were no other significant differences (no p value less than 0.05), and thus no other associations with gender or disciplinary affiliation. The lack of significance could be attributed to the small sample sizes. The probability of a Type II error is increased, since a very large difference is necessary for a result to be considered significant. In the case of the relationship found between gender and *General Engineering + Engineering Contributions*, for example, the achieved power is 0.723. Yet, for this same sub-category and major, the achieved power is 0.4927. To obtain a power of 0.8 due to major, the required sample size is 133 SE students and 47 ECE students, as compared with the actual sample of 74 SE students and 26 ECE students. It is also possible that differences could have emerged if the researchers had been able to classify the examples within the Tier 1 category *No Clear Specification*, as over one third of the students provided examples without specifying the type of collaboration.

Purpose and Need for Interdisciplinarity

Boix Mansilla and Duraisingh[6] discuss the dimension of *purposefulness* as clear reasons for utilizing an interdisciplinary approach. Overall, the students' responses encompassed many potential reasons for selecting an interdisciplinary approach (see Table 3). The responses were grouped into five main Tier 1 categories.

More than half of the students (67%) indicated an interdisciplinary approach should be used when there is a *Need for Multiple Disciplines*, the first Tier 1 category. This category was divided into three Tier 2 categories used to capture trends within the Tier 1 category. The first describes the many responses regarding the need for multiple perspectives. Since almost 40% focused on the specific need for expertise in more than one discipline, a second Tier 2 category was developed. For this category*, Need for Multiple Specializations or Expertise,* whether a student indicated this purpose or not was dependent on their disciplinary affiliation (Pearson's Chi-Square Value = 5.613, $p = 0.018$). Twenty-three of the 74 SE students indicated that when there is a need for multiple specializations or expertise an interdisciplinary approach should be utilized, while only 2 of the 26 ECE students mentioned this purpose. The third sub-category captured all the remaining responses, which discussed a need for multiple disciplines but did not specifically mention perspectives or expertise. Within this category, two significant relationships were found. Sixteen of the 26 ECE students noted a need for multiple disciplines, while only 18 of the 74 SE discussed this purpose (Pearson's Chi-Square Value = 11.874, p = 0.001). Of the 12 students in the LEP program, eight mentioned a need for multiple disciplines, and 26 of the 88 non-LEP students had responses in this sub-category (Pearson's Chi-Square Value = 6.485, p = 0.011, Fisher's exact test *p=0.02)*.

Table 3: Coding Scheme for *Purpose Suited to an Interdisciplinary Approach*

Tier 1	**Tier 2**	**Description**	**% of Sample (n=100)**
Need for Multiple Disciplines	*Need for Multiple Perspectives*	When there is a need for multiple perspectives or viewpoints.	8%
	Need for Multiple Specializations or Expertise	When there is need for multiple specializations or expertise	25%
	General/Unspecified Need for Multiple Disciplines	When there is a need for multiple disciplines	34%
Need for Integration		When there is a need to integrate the knowledge from multiple disciplines.	8%
Real World Problems		In the case of real-world scenarios or projects	5%
Scope & Complexity	*Broad Topics*	When a project looks at broad topics	9%
	Complexity	When a project is considered complex	10%
	Project Scale	When a project is large in scale	8%
Unique Reason		A distinct purpose	5%

The second Tier 1 category originated from students' descriptions of the importance of integration as an indicator for when an interdisciplinary approach is necessary. In describing a "green" playground project, a student explained the project "is interdisciplinary because it reaches into fields such as interactive education and synthesizes it with education". A quarter of the students mentioned the scope and complexity of the project as factors in determining whether to use an interdisciplinary approach. The fourth Tier 1 category and its three Tier 2 categories focus on these students' explanations for using an interdisciplinary approach. For instance, one student wrote, "An interdisciplinary approach was used for more complex projects that have many aspects because they need specialization on more levels". This response was coded in the Tier 2 category of *Complexity*.

Disciplinary Grounding

In the interdisciplinary studies projects examined by Boix Mansilla and Duraisingh[4], *disciplinary grounding* describes the selection of disciplines for the project and the appropriateness in the use of knowledge from the different disciplines. For these engineering students, the dimension of *disciplinary grounding* was realized due to the number of different ways students indicated they would approach an interdisciplinary project as the project manager (see Table 4). The focus of their responses was on the challenges caused by all the knowledge necessary to develop solutions to the project (the first Tier 1 category) and the different options for how to acquire that knowledge (the second Tier 1 category). Over a quarter of the students indicated a challenge of an interdisciplinary project was the lack of knowledge the project manager and/or the team members have of each of the disciplines involved in the project. From one student's perspective, "each member or group of related discipline members don't necessarily grasp what the other groups are working on, because it might be way out of the realm of their own field."

Table 4: Coding Scheme for *Disciplinary Grounding*

Tier 1	**Tier 2**	**Description**	**% of Sample (n=100)**
Challenges	*Amount of Information to Gather*	It is necessary to gather a large amount of information in order to develop solutions	7%
	Lack of Knowledge in Each of the Disciplines Involved	The project manager and team members lack of knowledge in the different disciplines	27%
How to Develop Disciplinary Grounding	*Consider Multiple Perspectives*	It is important to consider multiple perspectives.	22%,
	Project Manager needs knowledgein each discipline	As project manager, they need to develop some background or knowledge about every discipline that is included in the project.	20%
	Recruit a Diverse Team	A diverse team, with a wide variety of backgrounds, needs to be recruited.	4%
	Recruit Experts	Experts should be recruited to work on the interdisciplinary project.	7%
	Team Members need knowledge in each discipline	As project manager, they would like the team members to develop some knowledge, background or skills from each of the disciplines involved in the project.	3%

As students' considered how they would approach an interdisciplinary project in the role of the project manager, Tier 2 categories emerged regarding who on the team needed to acquire a background in each discipline. The responses for the role of project manager ranged from "managing an inter-disciplinary project requires a little knowledge in all the fields related to the project" to "you must have working knowledge of multiple disciplines in order to create the best final product possible." In the case of team members, one student indicated, "Before even tackling the problem, I would make sure that all of the team members had at least a bare minimum understanding about the other fields of work that would be actively contributing to the problem solution." Some students, on the other hand, concentrated on the types of team members they would recruit for the project, leading to the development of two other Tier 2 categories. While a few discussed the recruiting team members with a wide variety of backgrounds, others stated, "Simply put, I would look to hire experts from different fields".

Of the six questions on the questionnaire, no one question asked students to directly consider disciplinary grounding. Thus, while further analysis of this category did not result in any statistically significant associations due to gender or disciplinary affiliation, these results indicate that students are indeed aware of the need for disciplinary grounding on an interdisciplinary project.

Integration

The team aspect of many interdisciplinary engineering projects contributed a new element to the concept of *integration across disciplines* (see Table 5). Instead of focusing on just how to integrate the knowledge and methods of each discipline, the students reflected on the importance of determining how tasks would be delegated. The *Division of Labor* Tier 1 category was derived from these reflections, and the three Tier 2 categories describe the differences of opinion among the students. Some students preferred to "have subgroups working within their specialty and then collaborating and communicating with other subgroups of different specialties", while others would "generalize tasks more so that everyone in the group would be able to work with each [sic] other".

Table 5: Coding Scheme for *Integration Across Disciplines*

Tier 1	**Tier 2**	**Description**	**% of Sample (n=100)**
Division of Labor	*Disciplinary Boundaries*	Tasks are delegated according to the disciplinary affiliation of team members	9%
	Functional Groups	The team is divided based on functional groups or subsystems, instead of by discipline	3%
	No Clear Specification	Need to divide tasks, but no clear explanation of how	7%
Challenges	*How to Integrate*	The challenge of integrating knowledge, components, or subsystems across different disciplines.	18%
	Limitations due to Disciplines	Certain fundamentals of a discipline could limit potential integration solutions.	6%
Process of Integration	*Balance the Different Disciplines*	The need to balance the disciplines	4%
	Decide How Disciplines Fit Together	The need to integrate the disciplines	11%
	Determine How Disciplines Relate or Impact One Another	The need to determine how disciplines relate, interact, and impact one another	4%
	Weigh the Importance of Disciplines	The need to weigh the importance of the disciplines	5%

Challenges of integration were also among the topics discussed by the students (another Tier 1 category). The Tier 2 category *How to Integrate* stemmed from students' discussions of how the procedure for integrating the disciplines is a challenge. A few students acknowledged that the characteristics of certain disciplines could negatively impact the integration process. This guided the development of the second Tier 2 category. One student provided the following example "something that may be acceptable in a Systems Engineering point of view may not be a good view in economics, if the two fields are coupled together".

A sampling of potential methods for integration also emerged from students' responses, along with a third Tier 1 category. Some students discussed the need to balance the different disciplines, while others focused on fitting the disciplines together. A small number of students mentioned the importance of determining how the disciplines interacted or impacted one another. For instance, one student explained the need to "know how the fields interact, and be aware that the different fields may have different requirements that may restrict each other". Another small group of students focused on examining "both the strength and weaknesses of the different disciplines involved in the project".

As with *Disciplinary Grounding*, the responses did not indicate any statistically significant associations between the independent variables. Still, within the questionnaire, no one question was explicitly written to inquire about students' perceptions of *integration across disciplines*. Therefore, the breadth and depth of students' discussions about the challenges and the process of integration demonstrate a high level of understanding by these second-year students.

Critical Awareness

The dimension of *critical awareness* is centered around an individual's reflectiveness on the interdisciplinary process. Does the individual recognize and acknowledge the limitations of the process as a whole? Did the individual reflect on the aspects of the process, which could affect the project's overall success or failure? Through responses to the questions regarding how the students would approach an interdisciplinary project and the challenges of the project, the students only reflected on a few general limitations of the process (the first Tier 1 category). These included discussions of the duration of the project, the amount of work necessary, and, for the case of one student, the limited number of possible solutions. As with integration, the focus of many of the limitations discussed related to the operation of an interdisciplinary team (see Table 6). This led to the development of the second Tier 1 category and its subsequent Tier 2 categories. Students concentrated on the characteristics of these teams that could pose a challenge, such as the differences between the goals of one discipline and another. The simple fact that the team may be composed of members with different disciplinary affiliations could create conflict or misunderstandings on the team. The final two Tier 1 categories, the importance of communication and trust, weighed heavily on the students as potential factors, which could affect the success of the project. "The project manager would have to open communication much more so that nothing is missed." In addition, a challenge is "finding a universal language that allows people to research in depth while still communicating effectively". However, while there was an abundance of reflections included in this category, no statistically significant associations were found.

Table 6: Coding Scheme for *Critical Awareness*

Tier 1	Tier 2	Description	% of Sample (n=100)
Limitations of the Process		General Limitations of an Interdisciplinary Process	1%
Limitations/Challenges of Interdisciplinary Teams	*Approaches, Methods, and Thought Processes*	Different disciplines have different approaches, different methods, and ways of thinking.	11%
	Philosophies and Goals	Different disciplines have distinct philosophies and goals	6%
	Team Members from Different Disciplines	Team Members could come from different disciplines	11%
Importance of Communication		Importance of communication and how it can be a challenge	19%
Importance of Trust		Importance of trust and how it can be a challenge	3%

Discussion

While the second year students in this study may have already selected a major, this may be their first class in that department. For the limited experiences of these students, their perceptions of the interdisciplinary process, its challenges and limitations illustrate a breadth of understanding. Students' discussions ranged from the knowledge a team member would need to work on an interdisciplinary project to the different methods of dividing tasks among the team members. Even though the questionnaire did not directly address the dimensions of *disciplinary grounding* or *integration*, students also made mention of recruiting experts and the challenges involved with how to integrate the different aspects or disciplines of the project. Additionally, a few students mentioned very specific challenges of interdisciplinary projects, including the possibility that an interdisciplinary approach could reduce the number of potential solutions. Another student mentioned, "If I was the project manager of one of the interdisciplinary projects, I would be more careful of the differing schools of thought on the problem, coming from the fact that I would be working with different types of engineers."

The importance of the team dynamic in engineering problems was also apparent in each of the dimensions as communication, task delegation, and need for multiple specializations were discussed. In addition, these responses were not only from one or two of the students in the study. Sixty-seven percent of the students mentioned the use of an interdisciplinary approach is necessary when there is the *Need for Multiple Disciplines* (Tier 1 Category). Different methods of task delegation were discussed by 19% of the sample, and 19% also mentioned the importance of communication in their responses. With the team composition and dynamics, it was interesting to note the disagreements among some students' responses. There were some students (7%) who wanted to recruit experts for their interdisciplinary engineering team, while others wanted the project manager to be an expert in all of the disciplines. When considering how to divide the team into sub-teams, a group of students (9%) mentioned dividing the team based on the different disciplines involved (for instance, all the electrical engineers in one group). A few students did not necessarily want to divide the team by discipline. One student wrote, "I would approach the problem thinking about which individuals working for me would best be suited for each aspect of the project." Contrasting opinions were also found regarding how to integrate the different disciplines. One student wanted to "ensure each discipline gets the proper share of the project," while another stated that "different members will be able to contribute different amounts to the project, rather than all being on the same playing field as far as what they can help with." These different viewpoints, while not being statistically significant in relation to an independent variable, highlight different aspects of the four dimensions of interdisciplinary understanding, which could be worth investigating further in future work.

In regards to disciplinary affiliation, a few associations arose from the results, yet it was particularly interesting that they were all in the *purpose suited to an interdisciplinary approach* dimension. The SE students focused their responses more on the need for multiple specializations and expertise, while the ECE students, as well as the LEP students, discussed the need for multiple disciplines. In some cases, this may have just been due to a student's choice of words, but it is still important to note. Gender only played a role in the question regarding examples of interdisciplinary collaborations, where the male students discussed collaborations between two or more engineering disciplines more often than the female students. However, 45% of the women in the study provided examples of interdisciplinary collaborations in which they did not specify the disciplines involved, therefore, it is possible that this could have affected the findings. The two most common categories discussed by the female students were *Engineering + Non-Engineering Collaborations*, which is also affected by the previous statistic, and *Lack of Knowledge in each of the Disciplines Involved.* For the male students, it was *Engineering + Non-Engineering Collaborations* and *General/Unspecified Need for Multiple Disciplines.* Yet, none of the differences between the two groups were significant in these cases. For students in the interdisciplinary program, it was not surprising that a significant difference was found for the sub-category *Leaders in Engineering Program*. It was interesting though that the seven students not in LEP who gave this example were a mix of SE and ECE students as well as males and females.

Future Work

This research study sought to investigate a student's development as an interdisciplinary engineer within an interdisciplinary undergraduate engineering program. One hundred second year engineering students in SE and ECE departments completed an eleven-item questionnaire about interdisciplinary and non-interdisciplinary engineering projects. Of those students, twelve had self-selected to participate in the Leaders in Engineering program, a new interdisciplinary engineering program, at their university. The focus of the questionnaire was to explore students' perceptions and understanding of engineering and interdisciplinary engineering projects and programs and determine if students' perceptions of interdisciplinarity vary by gender or disciplinary affliation. Four dimensions of interdisciplinary understanding, based on the research of Boix Mansilla and Duraisingh, were examined by either directly asking about a particular dimension or evaluating students' responses based on the dimension during data analysis. Overall, students' responses to the questionnaire revealed an awareness of the importance of disciplinary grounding and integration on an interdisciplinary engineering project and also demonstrated an understanding of the need and purpose for interdisciplinary work. The team component that is characteristic of many interdisciplinary engineering projects was included in the responses through discussions of team dymanics and challenges.

Additionally, while disciplinary affiliation appeared to influence students' understanding of the purpose behind using an interdisciplinary approach, gender affected students' examples of interdisciplinary collaborations. Participation in the interdisciplinary engineering program also was associated with providing the program as an example of an interdisciplinary collaboration. Beyond these areas, there were no significant differences in students' responses based on gender or disciplinary affiliation. The small sample size of students could have contributed to the small number of significant differences between the independent variables. Furthermore, another contributing factor could have been the open-ended nature of questions, which did not permit students to agree or disagree with the existence of each dimension and sub-category.

Due in part to this characteristic of questionnaires, a mixed methods research project was designed to examine students' perceptions of interdisciplinary understanding. The results discussed here were utilized in the development of a quantitative survey instrument. The purpose of the instrument is to further explore the dimensions of interdisciplinary understanding and the themes, which emerged from the questionnaire. In addition, the research design was used to continue to study the potential effects of IUE programs on female participants and barriers to interdisciplinary understanding caused by disciplinary affiliation.

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Appendix A

Engineering and Interdisciplinary Engineering Projects: A Survey
Direction: Please answer these questions in your own words. There are no right or wronganswers to these questions.

1. What do you think the goal or purpose of engineering is?

2. Describe one or two interdisciplinary undergraduate engineering programs orinterdisciplinary engineering projects. These could be projects or programs you haveparticipated in, projects you have heard about or simply fictitious examples.

3. Describe one or two non-interdisciplinary undergraduate engineering programs ornon-disciplinary engineering projects.

4. Consider your examples of projects from questions (2) and (3).Why do you think an interdisciplinary approach was used for the projects in (2),while a non-interdisciplinary approach was used for the projects in (3)?

5. Consider your examples of projects from question (2).Imagine you are the project manager of one of the interdisciplinary projects. Howwould you approach the problem differently than a project manager for one of thenon-interdisciplinary projects from question (3)?

6. What do you think are the challenges of managing or working on an interdisciplinaryproject, as compared to a non-interdisciplinary project?

7. Gender: Male Female

8. What is your major?

9. Would you be interested in participating in follow-up interviews?

10. What are your career plans for after you've completed your engineering degree? (Optional)

11. Have you been involved with an engineering project outside of the classroom (e.g. aninternship, summer job, extracurricular activities? If yes, please describe theengineering project(s) in which you participated. (Optional)

Appendix B

% of Sample (n = 100) To be Coded in a Given Category
*(An * indicates a statistically significant (p ≤ 0.05) association)*

Definitions of Interdisciplinarity		Total Sample	Gender		Major		LEP	
			Male	Female	SE	ECE	LEP	Not LEP
Tier 1	**Tier 2**	%	%	%	%	%	%	%
Engineering + Engineering Collaborations	General Engineering + Engineering Collaborations	20%, n=100	26.1%*, n=69	6.5%*, n=31	24.3%, n=74	7.7%, n=26	0.0%, n=12	22.7%, n=88
	Leaders in Engineering Program	16%, n=100	15.9%, n=69	16.1%, n=31	12.2%, n=74	26.9%, n=26	75%,* n=12	8.0%,* n=88
Engineering + Non-Engineering Collaborations	General Engineering + Non-Engineering Collaborations	39%, n=100	42%, n=69	32.3%, n=31	35.1%, n=74	50%, n=26	25%, n=12	40.9%, n=88
	Engineering as One Discipline	5.0%, n=100	2.9%, n=69	9.7%, n=31	5.4%, n=74	3.8%, n=26	8.3%, n=12	4.5%, n=88
It's All Interdisciplinary		4.0%, n=100	4.3%, n=69	3.2%, n=31	4.1%, n=74	3.8%, n=26	8.3%, n=12	3.4%, n=88
No Clear Specification		34%, n=100	29%, n=69	45.2%, n=31	40.5%, n=74	15.4%, n=26	8.3% n=12	37.5%, n=88
Discussion of Disciplines	Interdisciplinary Engineering Disciplines	6.0%, n=100	5.8%, n=69	6.5%, n=31	6.8%, n=74	3.8%, n=26	0.0%, n=12	6.9%, n=88
	Non-Interdisciplinary Engineering Disciplines	11%, n=100	8.7%, n=69	16.1%, n=31	10.8%, n=74	11.5%, n=26	0.0%, n=12	12.5%, n=88

% of Sample (n = 100) To be Coded in a Given Category
*(An * indicates a statistically significant (p ≤ 0.05) association)*

Purpose Suited to an Interdisciplinary Approach		Total Sample	Gender		Major		LEP	
			Male	Female	SE	ECE	LEP	Not LEP
Tier 1	**Tier 2**	%	%	%	%	%	%	%
Need for Multiple Disciplines	Need for Multiple Perspectives	8.0%, n=100	10.1%, n=69	3.2%, n=31	10.8%, n=74	0.0%, n=26	0.0%, n=12	9.1%, n=88
	Need for Multiple Specializations or Expertise	25%, n=100	24.6%, n=69	25.8%, n=31	31.1%,* n=74	7.7%,* n=26	8.3%, n=12	27.3%, n=88
	General/Unspecified Need for Multiple Disciplines	34%, n=100	36.2%, n=69	29%, n=31	24.3%,* n=74	61.5%,* n=26	66.7%,* n=12	29.5%,* n=88
Need for Integration		8.0%, n=100	5.8%, n=69	12.9%, n=31	5.4%, n=74	15.4%, n=26	8.3%, n=12	8.0%, n=88
Real World Problems		5.0%, n=100	5.8%, n=69	3.2%, n=31	5.4%, n=74	3.8%, n=26	0.0%, n=12	5.7%, n=88
Scope & Complexity	Broad Topics	9.0%, n=100	7.2%, n=69	12.9%, n=31	12.2%, n=74	0.0%, n=26	0.0%, n=12	10.2%, n=88
	Complexity	10%, n=100	13.0%, n=69	3.2%, n=31	10.8%, n=74	7.7%, n=26	8.3%, n=12	10.2%, n=88
	Project Scale	8.0%, n=100	8.7%, n=69	6.5%, n=31	6.8%, n=74	11.5%, n=26	16.7%, n=12	6.8%, n=88
Unique Reason		5.0%, n=100	5.8%, n=69	3.2%, n=31	6.8%, n=74	0.0%, n=26	0.0%, n=12	5.7%, n=88

% of Sample (n = 100) To be Coded in a Given Category
*(An * indicates a statistically significant (p ≤ 0.05) association)*

Disciplinary Grounding		Total Sample	Gender		Major		LEP	
			Male	Female	SE	ECE	LEP	Not LEP
Tier 1	**Tier 2**	%	%	%	%	%	%	%
Challenges	Amount of Information to Gather	7.0%, n=100	5.8%, n=69	9.7%, n=31	8.1%, n=74	3.8%, n=26	0.0%, n=12	8.0%, n=88
	Lack of Knowledge in Each of the Disciplines Involved	27%, n=100	24.6%, n=69	32.3%, n=31	27.0%, n=74	26.9%, n=26	8.3%, n=12	29.5%, n=88
How to Develop Disciplinary Grounding	Consider Multiple Perspectives	22%, n=100	20.3%, n=69	25.8%, n=31	21.6%, n=74	35.1%, n=26	33.3%, n=12	20.5%, n=88
	Project Manager needs knowledge in each discipline	20%, n=100	23.2%, n=69	12.9%, n=31	17.6%, n=74	26.9%, n=26	41.7%, n=12	17.0%, n=88
	Recruit a Diverse Team	4.0%, n=100	5.8%, n=69	0.0%, n=31	5.4%, n=74	0.0%, n=26	0.0%, n=12	4.5%, n=88
	Recruit Experts	7.0%, n=100	8.7%, n=69	3.2%, n=31	6.8%, n=74	7.7%, n=26	0.0%, n=12	8.0%, n=88
	Team Members need knowledge in each discipline	3.0%, n=100	2.9%, n=69	3.2%, n=31	2.7%, n=74	3.8%, n=26	0.0%, n=12	3.4%, n=88

% of Sample (n = 100) To be Coded in a Given Category
*(An * indicates a statistically significant (p ≤ 0.05) association)*

Integration		Total Sample	Gender		Major		LEP	
			Male	Female	SE	ECE	LEP	Not LEP
Tier 1	**Tier 2**	%	%	%	%	%	%	%
Division of Labor	Disciplinary Boundaries	9.0%, n=100	8.7%, n=69	9.7%, n=31	10.8%, n=74	3.8%, n=26	0.0%, n=12	10.2%, n=88
	Functional Groups	3.0%, n=100	2.9%, n=69	3.2%, n=31	4.1%, n=74	0.0%, n=26	0.0%, n=12	3.4%, n=88
	No Clear Specification	7.0%, n=100	8.7%, n=69	3.2%, n=31	6.8%, n=74	7.7%, n=26	8.3%, n=12	6.8%, n=88
Challenges	How to Integrate	18%, n=100	17.4%, n=69	19.4%, n=31	20.3%, n=74	11.5%, n=26	16.7%, n=12	18.2%, n=88
	Limitations due to Disciplines	6.0%, n=100	2.9%, n=69	12.9%, n=31	4.1%, n=74	11.5%, n=26	16.7%, n=12	4.5%, n=88
Process of Integration	Balance the Different Disciplines	4.0%, n=100	5.8%, n=69	0.0%, n=31	4.1%, n=74	3.8%, n=26	0.0%, n=12	4.5%, n=88
	Decide How Disciplines Fit Together	11%, n=100	10.1%, n=69	12.9%, n=31	8.1%, n=74	19.2%, n=26	16.7%, n=12	10.2%, n=88
	Determine How Disciplines Relate or Impact One Another	4.0%, n=100	4.3%, n=69	3.2%, n=31	4.1%, n=74	3.8%, n=26	8.3%, n=12	3.4%, n=88
	Weigh the Importance of Disciplines	5.0%, n=100	4.3%, n=69	6.5%, n=31	5.4%, n=74	3.8%, n=26	0.0%, n=12	5.7%, n=88

% of Sample (n = 100) To be Coded in a Given Category
*(An * indicates a statistically significant (p ≤ 0.05) association)*

Critical Awareness		Total Sample	Gender		Major		LEP	
			Male	Female	SE	ECE	LEP	Not LEP
Tier 1	**Tier 2**	%	%	%	%	%	%	%
Limitations of the Process		1.0%, n=100	0.0%, n=69	3.2%, n=31	1.4%, n=74	0.0%, n=26	0.0%, n=12	1.1%, n=88
Limitations/Challenges of Interdisciplinary Teams	Approaches, Methods, and Thought Processes	11%, n=100	13%, n=69	6.5%, n=31	13.5%, n=74	3.8%, n=26	8.3%, n=12	11.3%, n=88
	Philosophies and Goals	6.0%, n=100	7.2%, n=69	3.2%, n=31	6.8%, n=74	3.8%, n=26	0.0%, n=12	6.8%, n=88
	Team Members from Different Disciplines	11%, n=100	8.7%, n=69	16.1%, n=31	12.2%, n=74	7.7%, n=26	16.7%, n=12	10.2%, n=88
Importance of Communication		19%, n=100	20.3%, n=69	16.1%, n=31	18.9%, n=74	19.2%, n=26	0.0%, n=12	21.6%, n=88
Importance of Trust		3.0%, n=100	4.3%, n=69	0.0%, n=31	1.4%, n=74	7.7%, n=26	8.3%, n=12	2.3%, n=88