121st ASEE Annual Conference & Exposition
Indianapolis, IN
June 15-18, 2014

Paper ID #10273

Investigating Team Structure of Interdisciplinary Undergraduate Engineering Student Teams during Design Performance

Matthew E McFarland, University of Virginia

3rd Year Master's Student in Systems Engineering

Prof. Reid Bailey, University of Virginia

Investigating Team Structure of Interdisciplinary Undergraduate Engineering Student Teams during Design Performance

Matthew E. McFarland, UVA; Dr. Robert R. Bailey, UVA

INTRODUCTION

Over the last 5 decades, the average engineering curriculum has largely been based on an "engineering science" model in which the analytical and mathematical elements of engineering are strictly of focus [1]. This implies that all challenges faced in engineering can be condensed and modeled as solvable math equations. This model, however, poses a threat to the current methods of engineering practice by giving the notion that all serious engineering is done in the language of mathematics [2]. While the engineering science model approach has a clear role in a design process, the model neglects to show that engineering also involves "working between technical and non-technical considerations … and managing trade-offs where solutions are judged by interdisciplinary criteria" [3]. Therefore, in instituting this model in engineering curricula, those factors that make engineering design as much of a social activity as a mathematical process are neglected [2]. Neglected factors include the "systems methodology" and "engineering design" related processes such as need identification, problem formulation, development of alternatives, and analysis and decision-making using prototypes and judgment. Also neglected are social aspects such as cultural and environmental influences and processes such as working with a group of individuals. All of these factors, plus many more, are what drive the demands of technology and product innovation today. These demands have evolved the current practice of engineering in such a way that there now exists disconnect between engineering education and engineering practice. This disconnect has resulted in today's engineering students lacking the key skills needed to be successful engineers [4].

There have been many prominent calls to reduce the distance between engineering education and engineering practice, with perhaps the most notable being from the National Academy of Engineering's Engineer of 2020 project [5], [6]. As a result, engineering education is starting to change.

One key area of change in engineering education is the inclusion of interdisciplinary knowledge and teamwork skills into engineering curricula. According to the National Academy of Engineering, the need to experience interdisciplinary collaborations is growing due to the increasing complexity and scale of systems-based engineering problems. As a result the future of engineering education must emphasize preparing engineers who can deal with complexity, innovate on demand and bridge disciplinary boundaries [6]. "Where disciplinary approaches to design are situated in specific bodies of knowledge, cross-disciplinary approaches focus on the nature of the problem, integrating several perspectives to synthesize a collective whole." [3]. Therefore the ability to exhibit interdisciplinary knowledge is vital to the development of the modern engineer. In the context of this study, interdisciplinary knowledge will refer to the common understanding among engineers which centers around teamwork and the dynamics of completing team projects with individuals from other disciplines [7], [8].

Another major area of recent change in engineering education is design. As articulated by Dym and Levitt, engineering design is "the systematic, intelligent generation and evaluation of specifications for artifacts whose form and function achieve stated objectives and satisfy specified constraints" [9]. Although design is widely considered as the most distinguishing and fundamental activity of engineering [1], most curricula have it either isolated in the senior year or sometimes also in the first year. It was once thought that first year students did not have the capacity to comprehend engineering design before completing the fundamental coursework of engineering. Now, as the engineering curriculum has progressed, first year design courses, known as the cornerstone engineering courses, have become staple courses across engineering programs in the United States [1]. Similarly, fourth year design courses, referred to as capstone courses, have seen significant development over time through integration of industry-sponsored projects with real world applications into the coursework. However, these capstone courses serve as the only standard opportunity across engineering education for undergraduate engineering students to showcase their engineering education.

In summary, while interdisciplinary teamwork and design are centrally important to modern engineering practice, many traditional engineering programs do not have interdisciplinary design collaboration built into their engineering curriculum; instead their programs are mainly analytical and theoretical, leaving little room for students to develop professional practices. Many programs also approach engineering design from an engineering science model; focusing on analytical approaches to design within single engineering disciplines. This disconnect between engineering education and engineering practice has been recognized and a growing number of curricula are being created to address it; included in such programs are those at Harvey Mudd [10], James Madison [11], and Purdue's EPIC and Multidisciplinary Engineering programs [12], [13].

RESEARCH QUESTIONS

Included among those universities implementing engineering curricula change is University of Virginia, where an interdisciplinary engineering program exists in the form of the Technology Leadership Program (TLP). This program's curriculum focuses on developing a student's knowledge and skills that address both component level design and systems integration. This interdisciplinary program is a cross collaboration between the Electrical and Computer Engineering (ECE), Systems Engineering (SIE) and Mechanical Engineering (MAE) departments. Its three year curriculum fosters a learning environment in which electrical, computer, systems and mechanical engineering students collaborate to engage in interdisciplinary engineering design.

Unfortunately, there is a lack of research available into how to best educate students in interdisciplinary design around which such a program can be built. Therefore, during the spring semesters of 2012 and 2013, a study was conducted at the University of Virginia to assess the impact of the Technology Leadership Program. This study only included electrical, computer and systems engineering students since mechanical engineering students were just recently added to the Technology Leadership Program this past academic year. Its aim was to uncover insights into interdisciplinary collaboration and engineering design by developing a strategy to evaluate the interdisciplinary design skills of undergraduate students.

This paper investigates the behavior of undergraduate engineering students, both TLP students and their peers, on interdisciplinary teams engaged in an engineering design project. The specific behavior of interest is when student teams split into subgroups to conduct work. To facilitate this goal this paper seeks to offer insight into the following research questions:

1) For what engineering design tasks do undergraduate engineering interdisciplinary teams split into subgroups?

2) When undergraduate engineering interdisciplinary teams split into subgroups, is the split by major, curricular program or other factors?

METHODS

Students in this study participated in a design activity in interdisciplinary teams of four. During the design activity students were asked to follow the Verbal Protocol Analysis method of thinking aloud while working through the activity. This method was used in a way similar to how design has been studied by many others including Atman [14]–[17], and Cross, Christaans and Dorst [18]. Following the activity, students also participated in a focus group and completed a post-activity survey. The pilot study was conducted in spring of 2012. A second set of participants completed the protocol in spring of 2013. Both studies were approved by the Institutional Review Board.

Engineering Design Activity

Participants completed a three-hour activity in which they worked as a team to develop and model a prototype for a newspaper counter for the college newspaper, the Sunapee Daily. The newspaper counter must be designed using the materials provided and constructed as an addition to the current Sunapee Daily newspaper distribution boxes. The students were presented with information about the Sunapee Daily Newspaper and a list of requirements for the desired prototype established by Sunapee Daily. The students were then instructed to act as engineering consultants and develop a solution based on those requirements. In addition to a Sunapee Daily newspaper distribution box, the students were provided with several electronic sensors manufactured by Phidgets and SunSPOT as well as various construction materials (tape, cardboard, scissors, paper, etc.) to construct the desired prototype. Students were also provided with four laptop computers outfitted with Microsoft Office and Integrated Development Environments to configure the electrical sensors. During the three-hour activity, the researcher acted as a representative of Sunapee Daily answering questions and providing any information requested of the client by the students. The problem chosen for this Engineering Design Activity required skills related to the Electrical Engineering, Computer Engineering, and Systems Engineering majors. This engineering problem was complex enough to allow students to fully engage in the engineering design process and simple enough to conduct prototyping within the given three-hour time frame. The entire activity was recorded using multiple video cameras and digital audio recorders.

Recruitment of Participants

All students were recruited using two electronic surveys. The first survey was distributed to all 4th year engineering students in Systems Engineering and Electrical and Computer Engineering departments to collect the major and year of interested participants. Only second semester 4th year students were accepted for the study. The second survey was administered to eligible students who respond to the first survey and used to identify their availability for participation in the research study. A separate survey was administered to 4th year TLP students to identify their availability to participate in the research study as well. All students were asked to consent to participation in the study and get $100 for successful completion of the entire study.

Overall, the study included eleven teams totaling forty-two fourth year undergraduate engineering students as participants. The following Table 2.2 shows a breakdown of all participants by curriculum, gender, and major.

Curriculum	Male	Female	ECE	SIE	CS
Traditional	13	8	10	11	
TLP	14	7	9	11	1

Table 2.2 Breakdown of Study Participants

Group Compositions

Students were divided into groups of four. Each group had two SIE students, two ECE students and make up one of five group structures depending on the number of TLP students available to participate in the study. The five group structures are as follows:

GC1 – Four TLP students (two SIE, two ECE)
GC2 – Two traditional students (one SIE, one ECE), two TLP students (one SIE, one ECE),
GC3 – Two traditional students (both ECE), two TLP students (both SIE)
GC4 – Two traditional students (both SIE), two TLP students (both ECE)
GC5 – Four traditional students (two SIE, two ECE)

The word “traditional” is used to refer to students who are enrolled in single discipline majors only, not also enrolled in the TLP. Table 2.3 shows the breakdown of groups in the study by composition. One GC4 group and one GC5 group only had three students to complete the study (noted by the *).

Composition	GC1	GC2	GC3	GC4	GC5
# of Groups	2	3	2	2*	2*

Table 2.3 Breakdown of Study Groups by Composition

Group Formation

Since the TLP students participating are predetermined for the design activity, those students are placed in groups first before placing non-TLP students. The TLP students are paired into groups based on major and capstone team advisor. The intent is to separate those students who worked on the same capstone team to minimize the amount of prior experience each student had working together. Once availability was obtained from the paired TLP students, non-TLP students who matched in availability and were on different capstone teams from each other were selected to complete the design activity groups.

DATA PREPARATION

The first step in data preparation was to merge the audio and video data together. The audio recording for each group was overlaid on its respective video recording using VSDC Free Video Editor [19]. To make analysis of video easier, a timer was also added to each video using the same software.

To create a transcript of the events occurring in each design activity, summarized paragraphs detailing events of each team, such as actions taken or statements made, were recorded and separated while watching each video. Section breaks were inserted between paragraphs based on when a design stage a team was functioning in changed or when there was a change in team structure (working as a single group versus in subgroups). At each section break, time was also recorded to make referencing of segments easier in analysis. This resulted in the creation of a transcript which included, for each segment, a video identification number, a start time, a stop time, time elapsed and a summary of events. The following table 3.1 shows an example of a summarized video transcript.

Video	Start	Stop	Elapsed	Summary	
7.1	0:00:00	0:03:23	0:03:23	[Bradley], [Carla], [Olivia] and [Patricia] starts off reading the prompt individually and writing notes on their sheets.	
7.2	0:03:23	0:07:04	0:03:41	[Bradley] begins to re-read aloud the requirements from the activity prompt to the group, each group member contributes pointing out different requirements. Determine the creation of the optimal distribution plan and power is out of scope. [Carla] begins to rank aloud the requirements for the project. The group begins reading through specs to determine what sensors are provided.	
---	---	---	---	---	
7.23	0:53:51	0:54:36	0:00:45	[Patricia] updates [Carla] on the issues of sensitivity faced with the thin force sensor. [Patricia] and [Carla] begin brainstorming ways to use the remaining sensors to count individual newspapers.	[Bradley] and [Olivia] are testing the RFID sensor (and I believe distance sensor) inside the distribution box.
---	---	---	---	---	
7.47	2:36:06	2:37:01	0:01:05	[Bradley] and [Carla] look up pricing for an Arduino board and other materials used.	[Olivia] and [Patricia] continue to work on finalizing the code for the prototype.
7.48	2:37:01	2:37:11	0:00:10	The group informs the client they have finished with their prototype.	

Table 3.1 Summarized Video Transcript

To check the validity of the summaries written, each transcript was reviewed by a second reviewer. The reviewer was tasked to read each transcript in conjunction with watching its respective video and to offer feedback on the following areas: the accuracy of the summary (i.e. what happened, who said it, is there context missing, etc), the accuracy of the time recorded (within a few seconds), and the length of the segments (i.e. if subsequent statements should be combined or if long segments should be split). Following this review, a second iteration was done by the principle researcher in conjunction with watching the videos to incorporate feedback from the second reviewer.

To evaluate whether the transcripts were ready to be coded and to begin refining the selected coding scheme, a sample of approximately 30 segments were selected at random to be jointly coded by the principle researcher and a second coder. From doing so, challenges to coding emerged that required the researcher to do a third iteration over the transcripts. The challenges discovered were summaries either (1) containing certain key words that were very general and representative of multiple design stage processes without further context added or (2) describing team activities representative of multiple design stage processes. The following #.1 and #.2 are examples of those challenges.

Figure 3.1: A segment containing general key words.

Before 3rd Iteration:

6.47	[Josh] begins to write the **results** up on the board. [Josh] asks [Herman] if it can work in java. [Herman] explains the **situation** with the software, suggests to try and translate visual studio into java but doesn't think will be too successful. [Herman] suggests writing out code instead.

After 3rd Iteration:

6.47	[Josh] begins to write the results up on the board **from testing of the two force sensors**. [Josh] asks [Herman] if it can work in java. [Herman] explains **he cannot find code sample in Java and is waiting for visual studio to download**. [Herman] suggests trying translating visual studio into Java but doesn't think he will be too successful. [Herman] suggests writing out how the **pseudo** code would work instead.

In the "before" segment the words "results", "situation" and "code" are all general terms. After completing the 3rd iteration, the resulting "after" segment included context added (text in bold and underlined) to further describe the previously highlighted general terms.

Figure 3.2: A segment describing activities representative of multiple design stages.

Before 3rd Iteration:

4.14	[Vivian] looks for the maximum number of papers. The client points out to take note of the different types of distribution points. [Eric] confirms that the distribution box points are the ones that only matter. [Vivian] determines the max based on the data provided and points out its more than the sensors can handle. [Eric] wonders if the weighted would be divided in two or if both would max out. [Dennis] clarifies with [Vivian] that the force sensor isn't good to use of weight measurement, instead supposed to be used as a button. [Dennis] thinks could use the RFID to see if someone is reaching inside the box. [William] suggests using the distance sensor to measure the distance of the stack from the top of the box. [Vivian] reads the specs on the distance sensor, says it's not enough of a range (but doesn't actually measure). [Dennis] physically shows what he suggests to [Vivian]. [Dennis] suggests putting contraption inside that measures the right height.

After 3rd Iteration:

4.14	[Vivian] looks for the maximum number of papers. The client points out to take note of the different types of distribution points. [Eric] confirms that the distribution box points are the ones that only matter. [Vivian] determines the max based on the data provided and points out its more than the sensors can handle. [Eric] wonders if the weighted would be divided in two or if both would max out.
4.15	[Dennis] clarifies with [Vivian] that the force sensor isn't good to use of weight measurement, instead supposed to be used as a button. [Dennis] thinks could use the RFID to see if someone is reaching inside the box. [William] suggests using the distance sensor to measure the distance of the stack from the top of the box. [Vivian] reads the specs on the distance sensor, says its not enough of a range (but doesn't actually measure). [Dennis] physically shows what he suggests to [Vivian]. [Dennis] suggests putting contraption inside that measures the right height.

The “before” segment describes the student team functioning in two different design stage processes, gathering information about the product and generating ideas for a solution. After iteration, the “before” segment was split into two segments, each summarizing one of the two design stage processes.

After completing three iterations of review for each video transcript, 11 video transcripts totaling 583 segments were created. These segments were combined into one transcript and decontextualized through order randomization before applying a coding scheme.

CODING

In order to answer the research questions of interest, the coding framework selected for this study needed to map all conversations and activities observed in segments back to stages of engineering design process. The framework selected was based on a coding scheme developed by Atman of the University of Washington [18]. However, it was adapted to account for prototyping and testing of a physical product (the Atman scheme ended with conceptual designs), and to aggregate several categories from the Atman scheme into a less granular, more generalized stages of design. The following figure shows the adapted coding scheme:

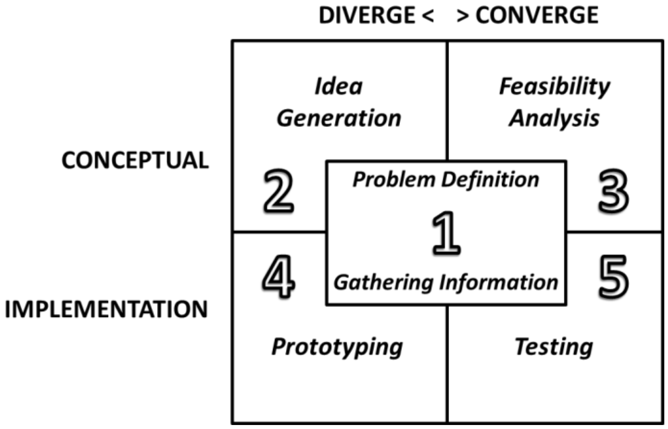

Figure 5.1 Engineering Design Stages Coding Scheme

This framework is divided into two dimensions – conceptual versus implementation and diverge versus converge – which determine the location of the stages in the diagram. First, each stage is characterized by whether the actions and conversations that occur within it are either abstract/generalized thinking of the mind (conceptual) or as practical implementation of thoughts and ideas (implementation) [20]. Each stage is also characterized as either an expansion from a small to a broad view of an idea or topic (diverge) or moving from a broad viewpoint to a specific focus (converge). Divergence is associated with activities like brainstorming, ideation, building, and prototyping. Convergence is associated with activities such as analysis, selection, evaluation, and testing.

Altogether, five stages comprise this framework. Stage 1 focuses on conversations or actions pertaining to defining requirements, project scoping, and gathering information about a particular project or the needs of stakeholders. Stage 2 focuses on conceptual conversations about new ideas for solutions or designs that pertain to the prototype, including brainstorming and other forms of idea generation (which could be applied prior to any implementation or in response to testing or implementation problems). Stage 3 focuses on conceptual conversations about the feasibility of a proposed solution, including analysis, evaluation, simulations, and multi-attribute selection of a concept. Stage 4 focuses on actions and conversations associated with the constructing of a prototype including building and software coding. Stage 5 focuses on actions or conversations associated with the testing of an implemented system or prototype.

After conducting the first round of coding, we found that teams would sometimes rapidly oscillate between two different design stages. For example, while brainstorming potential solutions for a prototype, a group would often critique whether or not the proposed idea was feasible before moving on to the next idea. In this particular case, separating the segment into multiple segments to represent stage 2 and stage 3 exclusively was avoided. Instead the segment was coded as oscillating between both stage 2 and stage 3. Cases with segments such as this one existed in pairs of any combination of design stages and emerged from coding of all transcript segments.

All segments were randomized and assigned two codes, one signifying the design stage it represented and the other to describe the structure of the team during that segment. Table 4.1 shows how the Codes for design stages from the previously described framework were assigned.

Segment Condition	**Example Code**
If a segment consisted of one or multiple activities primarily representative of a single design stage, coded as the number of its respective stage.	2
If a segment consisted of oscillations between two activities representative of two different design stages, coded as two numbers respective of the design stages	2 $ 3
If a segment consisted of multiple activities representative of multiple design stages, coded as a six.	6
If a segment consisted of one or multiple activities unrelated to any design stages, coded as a zero.	0
Subgroup segments were coded in the same manner, but with two codes separated.	2 | 3

Table 4.1: Coding Notation Used for Design Stages

Codes for team structure were applied in the following way:

Code	Explanation of Team Structure			
4s	All four students working in a single group.			
31e	Three students (two SIE, one ECE) working in a subgroup.			One ECE student working alone.
31s	Three students (two ECE, one SIE) working in a subgroup.			One SIE student working alone.
22m	Two students (one SIE, one ECE) working in a subgroup.		Two students (one SIE, one ECE) working in a subgroup.	
22s	Two students (two SIE) working in a subgroup.		Two students (two ECE) working in a subgroup.	
211e	Two students (two ECE) working in a subgroup.		One SIE student working alone.	One SIE student working alone.
211m	Two students (one SIE, one ECE) working in a subgroup.		One ECE student working alone.	One SIE student working alone.
211s	Two students (two SIE) working in a subgroup.		One ECE student working alone.	One ECE student working alone.
1111s	One SIE student working alone.	One SIE student working alone.	One ECE student working alone.	One ECE student working alone.

Table 4.2: Coding Notation Used for Team Structure

Applying codes for both design stage and team structure to all transcript segments resulted in one transcript with 583 coded segments like the ones shown in the following table:

Video	Design Stage	Team Structure	Summary	
9.03	2	4s	[Tasha] suggests going through the function of each sensor. [Vince] talks about the interface kit and its functionality. [Vince] suggests a way for using the RFID, [Calvin] also suggests an idea for the RFID. [Tasha] suggests to place one of the sensors inside the door. [Calvin] starts checking the box to see how to place the sensor inside the box.	
6.02	2$3	4s	[Herman] questions if more than one sensor should be used in the prototype. [Josh] suggests the thin force sensor would work. [Herman] questions its limitations and if it would work. [Zach] suggests to measure one newspaper but [Xavier] doesn't think it would be accurate enough and would leave large amount of error. [Herman] suggests using a sensor to just count the door opening each day. [Josh] talks through the usage of force sensors over time, reading the limitations of both the thin and the large force sensor, rule out the large force sensor. [Herman] then suggests the RFID. [Xavier] confirms will need to use more than one sensor to measure, then asks about accelerometer. [Josh] explains the accelerometer and its functionality. [Xavier] doesn't think the accelerometer will work because it would be damaged by users.	
7.41	4|5	22s	[Bradley] and [Carla] test the sensors inside the distribution box with newspapers.	[Olivia] and [Patricia] work on writing code for the sensors.
1.42	2|4$5	31e	[Connor] talks through how time stamps will needed and how the data would be displayed and analysis conducted with [Fiona] and [Susan].	[Paul] continues to write code and occasionally test to see if code is working.

Table 4.3: Example of Coding Notation Applied to Segments

VALIDITY

Validity for the method of verbal protocol analysis used in this study was established in a previous study conducted by Ericsson and Simon. The study demonstrated that procedures requiring participants to “think aloud” do not influence the thought process of the participant, specifically the sequence of the process [21].

Inter-rater and intra-rater reliability for design stage coding was established by having 20% of the overall number of segments coded by second coder. Three percent of those statements were coded jointly with the second coder as described before. The remaining 17% were coded independently and inter-rater agreement measured by computing Cohen’s kappa coefficient, a commonly accepted method of assessing inter-coder reliability [22]–[24]. An agreement was defined as both coders assigning the same code to a transcript segment. The Cohen’s kappa coefficient measured after independently coding the remaining 17% was 0.81. Appendix A shows inter-rater agreement of coded segments. Team structure was easily identifiable from video and therefore was only rated by one person.

RESULTS

The data collected in this study totals 1905.97 minutes. In order to code the activity of subgroups independently, segments representing subgroups were separated. For example, a segment coded as “2|4” was separated into two segments, one coded as “2” and the other as “4”. This resulted in the final data being represented as 930 total transcript segments. However, in this paper data from two 3-person groups was excluded in order to compare team structure fairly. Therefore, the tables and figures presented in this paper are representative of data comprised of 1570.86 total minutes and 786 transcript segments from the nine 4-person groups. The following Figure 6.1 shows the total amount of time (1570.86 minutes) spent in each of the team structures.

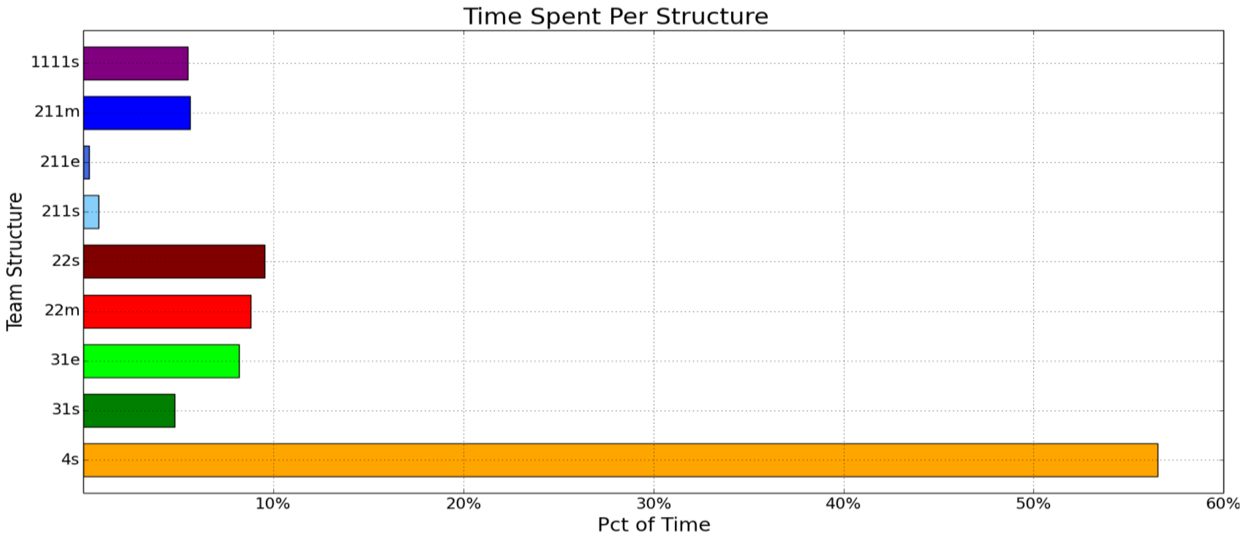

Figure 6.1: Percent of Time in Each Team Structure

Figure 6.1 shows the majority of time (56.5%) was spent working in a single group versus some sort of sub-group combination. Among the time spent working in sub-groups, the three most popular sub-group combinations were 22s, 22m, and 31e which accounted for 26.5% of the total time. In comparison to time spent in each structure, Figure 6.2 shows the percentage of total time spent working in each of the design stages.

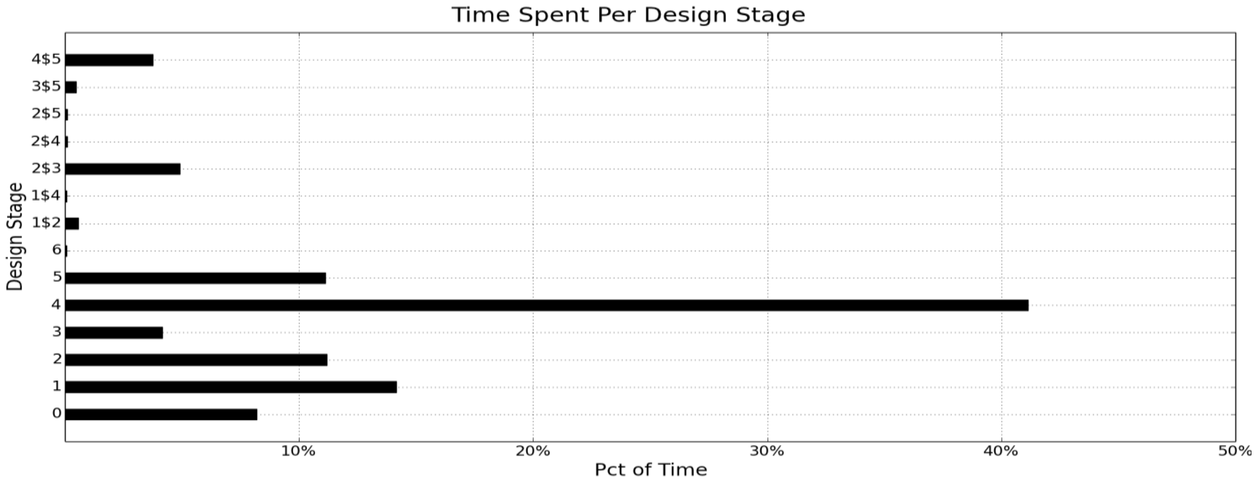

Figure 6.2: Percent of Time in Each Design Stage

Figure 6.2 shows the majority of activity time was spent working within stage 4 – prototyping (41%). The time spent working in the conceptual realm (stages 2 and 3) totaled roughly 20% while time spent working in the implementation realm (stages 4 and 5) totaled 56% overall. The following Table 6.1 shows the total percentage of time for each stage as well as a breakdown of the percentage of overall time spent in each stage. The first row represents the design stages and design stage combinations gathered from the data. The first column represents the possible team structures.

Tab.1	0	1	2	3	4	5	6	1$2	1$4	2$3	2$4	2$5	3$5	4$5
1111s	1.87	2.62	0.96	-	7.07	0.12	-	-	-	-	-	-	-	1.06
211e	-	-	-	-	0.55	-	-	-	-	-	-	-	-	-
211m	1.43	1.28	0.11	0.04	6.23	0.42	-	-	-	-	-	-	0.14	0.82
211s	0.27	0.27	0.17	-	0.66	0.13	-	-	-	-	-	-	-	-
22m	0.56	1.95	2.26	0.04	3.90	1.90	0.07	-	-	0.05	-	-	-	0.25
22s	0.73	0.72	1.48	0.32	7.14	1.52	-	-	-	-	-	-	-	-
31e	1.47	1.04	1.09	0.32	4.54	1.00	-	0.05	-	0.51	-	-	0.18	-
31s	0.50	0.29	0.35	0.18	3.48	0.99	-	-	-	0.20	-	-	-	-
4s	1.43	6.00	4.79	3.26	7.69	5.38	-	0.51	0.09	4.17	0.11	0.09	0.15	1.63
% Time	**8.26**	**14.18**	**11.21**	**4.16**	**41.24**	**11.46**	**0.07**	**0.56**	**0.09**	**4.92**	**0.11**	**0.09**	**0.46**	**3.76**

Table 6.1: Total Percentage of Time in Each Design Stage

Table 6.2 shows the allocation of time within each stage / team structure combination normalized by total time per design stage. For example, from Table 6.1, 2.62% of the total time was spent in stage 1 as structure 1111s. From Table 6.2, this same design stage/team structure combination is shown to represent 18.5% of time spent in design stage 1 From Table 6.2 it can be easily observed how often a group used specific team structure for each stage. The first row represents the design stages and design stage combinations gathered from the data. The first column represents the possible team structures.

Tab.2	0	1	2	3	4	5	6	1$2	1$4	2$3	2$4	2$5	3$5	4$5
1111s	22.63	18.52	8.56	-	17.15	1.04	-	-	-	-	-	-	-	28.07
211e	-	-	-	-	1.34	-	-	-	-	-	-	-	-	-
211m	17.32	9.06	1.00	0.96	15.10	3.66	-	-	-	-	-	-	29.31	21.91
211s	3.29	1.94	1.48	-	1.59	1.17	-	-	-	-	-	-	-	-
22m	6.75	13.73	20.17	1.07	9.45	16.57	100.00	-	-	0.93	-	-	-	6.60
22s	8.84	5.07	13.22	7.62	17.31	13.23	-	-	-	-	-	-	-	-
31e	17.76	7.32	9.71	7.66	11.00	8.76	-	8.50	-	10.38	-	-	39.25	-
31s	6.08	2.07	3.12	4.30	8.43	8.65	-	-	-	4.02	-	-	-	-
4s	17.33	42.30	42.74	78.39	18.64	46.93	-	91.50	100.00	84.67	100.00	100.00	31.45	43.41
% SUM	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Table 6.2: Total Allocation of Time in Each Design Stage

DISCUSSION

The research questions of interest in this paper are: 1) For what engineering design tasks do undergraduate engineering interdisciplinary teams split into subgroups?; 2) When undergraduate engineering interdisciplinary teams split into subgroups, is the split by major, curricular program or other factors?

To answer these questions, the first area to investigate is how teams overall spent their time in reference to team structure and design stages. Observations from Figure 6.1 show teams spent roughly the same amount of time split into subgroups as they did in a single group. Figure 6.2 shows teams spent the majority of their time working on tasks related to stage 4, the prototyping and construction stage. To understand the correlation between the findings from these figures, Tables 6.1 and 6.2 were constructed to understand how time was distributed across both factors, structure and design stage.

Observations from these Tables 6.1 and 6.2 show that, when working in stage 4, teams rarely work as a single group (18.6% of the total work done in stage 4). Further analysis of the transcripts showed the most common task associated with stage 4 was programming of the electrical sensors. Also further analysis showed most teams chose to designate one or two people to work on programming due to the significant amount of time they estimated would be needed for that task. Major did not seem to be the determining factor in who was selected to do the programming. In most cases, the student (or students) who felt most comfortable with programming from past experiences volunteered. To reinforce this finding, Tables 6.4 and 6.5 show how students working solo or in two person teams spent their time with reference to the design stages. Table 6.4 compares the 31s and 31e team structures. In this table “1e” represents an ECE student working alone, “1s” a SIE student working alone, and “3m” a mixed subgroup of three students. The first row represents the design stages and design stage combinations gathered from coding of all transcript segments.

Tab.4		0	1	2	3	4	5	6	1$2	1$4	2$3	2$4	2$5	3$5	4$5	SUM
31e	**1e**	23.67	7.80	5.96	-	60.76	1.81	-	-	-	-	-	-	-	-	100
	3m	5.10	12.56	15.39	6.25	28.27	17.89	-	0.94	-	10.03	-	-	3.57	-	100
31s	**1s**	15.83	-	-	-	78.03	6.13	-	-	-	-	-	-	-	-	100
	3m	0.93	9.78	11.68	5.97	38.05	26.97	-	-	-	6.61	-	-	-	-	100

Table 6.4: Time Spent in 31e and 31s

Comparing the single student structures (1s and 1e) it can be seen in both cases the single student spent the majority of their time working in design stage 4, regardless of whether the single student's major. Therefore it can be concluded that, for this particular team structure combination (three student group, one single student), major does not influence time spent working in stage 4. In order to understand if the same applies to a two person subgroup Table 6.5 compares the 22s and 22m team structures. In this table "2e" represents two ECE students working as a subgroup, "2s" represents two SIE students working as a subgroup, and "2m" represents a mixed subgroup of one SIE and one ECE student.

Tab.5		0	1	2	3	4	5	6	1$2	1$4	2$3	2$4	2$5	3$5	4$5	SUM
22m	**2m**	5.08	17.74	20.62	0.41	35.55	17.31	0.60	-	-	0.42	-	-	-	2.26	100
22s	**2e**	-	0.83	7.54	2.12	82.93	6.58	-	-	-	-	-	-	-	-	100
	2s	12.27	11.25	17.37	3.20	37.01	18.89	-	-	-	-	-	-	-	-	100

Table 6.5: Time Spent in 22m and 22s

Observations from Table 6.5 show time is spent much differently between these two structures. When working in the 22m structure, students spent their time working across all the stages more evenly whereas in 22s structure the ECE pair (2e) was concentrated their time working in stage 4. This finding does imply major influenced the work done in stage 4. Another notable observation was the distribution of time by the SIE pair (2s) compared to the distribution of the mixed pair (2m) was similar. What this finding implies that ECE students more often concentrate their time in the technical tasks of stage 4 when not paired with a SIE student. Appendix B shows all of the remaining structures and sub-structures time spent with reference to the design stages.

Other notable observations from Table 6.2 relate to stages 3 and 2$3. Table 6.2 shows these stages were most often conducted in a single group. Stage 3 is the feasibility analysis stage and 2$3 is the oscillation between stage 3 and stage 2, the idea generation stage. It seems as though this type of work is more efficient when done in a group because it involves critiquing ideas and solutions to design challenges that may arise from those ideas. Working as a group is ideal since students are able to approach a critique from different perspectives developed from various experiences the students have had previously. From additional review of the transcripts it also makes sense for the oscillation between stages to occur in a group because one student's critique often prompted another student to come up with a new idea that could eliminate a previously identified issue. Another reason why this oscillation occurred most in a single group is due to the way some teams chose to approach brainstorming. For example, one of the teams chose to brainstorm separately to begin the activity, followed by a period of sharing and critiquing each other's ideas. Further analysis of the pattern each team chose to take during the design activity could yield more insight to why certain structures were used more often than others in certain stages.

CONCLUSION

The aim of this overall study was to uncover insights into interdisciplinary collaboration and engineering design by developing a strategy to evaluate the interdisciplinary design skills of undergraduate students. The purpose of this paper was to investigate the behavior of undergraduate engineering students on interdisciplinary teams, specifically their behavior in relation to team structure. This paper's findings show how interdisciplinary teams spend their time in reference to team structure and work on engineering design tasks. Key findings show the time spent working as a single group is equal to the time split working in subgroups. Teams spent the least amount of time working in stage 4 as a single group (18.6%) and when working in a subgroup in this stage usually one person dedicated the majority of his/her time to doing the stage 4 work. Findings also show that major did not influence work done in stage 4. However, further analysis will show whether or not major influenced work done in other stages. Future work to be conducted for this study includes an analysis of the individual contributions (both verbal and physical) of students to each design stage and investigation into each team's pattern through the stages of engineering design.

REFERENCES

[1] C. Dym, A. Agogino, O. Eris, D. Frey, and L. Leifer, "Engineering design thinking, teaching, and learning," *J. Eng. Educ.*, no. January, pp. 103–120, 2005.

[2] C. Dym, "Design and design centers in engineering education," *AI EDAM*, vol. 12, no. 01, pp. 43–46, 1998.

[3] R. S. Adams, L. Mann, S. Jordan, and S. Daly, "Exploring the Boundaries: Language, Roles and Structures in Cross-Disciplinary Design Teams," in *About: Designing: Analysing Design Meetings*, 2009, pp. 339–361.

[4] M. Lih, "Educating future executives," *ASEE Prism*, 1997.

[5] National Academy of Engineering of the National Academies, *Educating the engineer of 2020 : adapting engineering education to the new century*. Washington, DC, 2005.

[6] National Academy of Engineering of the National Academies, *The engineer of 2020 : visions of engineering in the new century*. Washington, DC: National Academies Press, 2004.

[7] D. M. Richter and M. C. Paretti, "Identifying barriers to and outcomes of interdisciplinarity in the engineering classroom," *Eur. J. Eng. Educ.*, vol. 34, no. 1, pp. 29–45, Mar. 2009.

[8] M. Borrego and S. Cutler, "Constructive alignment of interdisciplinary graduate curriculum in engineering and science: An analysis of successful IGERT proposals," *J. Eng. Educ.*, 2010.

[9] C. Dym, *Engineering design: a synthesis of views*. Press Syndicate of the University of Cambridge, 1994.

[10] C. L. Dym, M. M. Gilkeson, and J. R. Phillips, "Engineering Design at Harvey Mudd College: Innovation Institutionalized, Lessons Learned," *J. Mech. Des.*, vol. 134, no. 8, p. 080202, 2012.

[11] "Department of Engineering at James Madison University: CISE." [Online]. Available: http://www.jmu.edu/engineering/curriculumoverview.html.

[12] "Purdue University: EPICS." [Online]. Available: https://engineering.purdue.edu/EPICS/About.

[13] "Undergraduate Programs: Multidisciplinary Engineering and Interdisciplinary Engineering Studies." [Online]. Available: https://engineering.purdue.edu/ENE/Academics/Undergrad.

[14] C. J. Atman, M. E. Cardella, J. Turns, and R. Adams, "Comparing freshman and senior engineering design processes: an in-depth follow-up study," *Des. Stud.*, vol. 26, no. 4, pp. 325–357, Jul. 2005.

[15] C. J. Atman, R. S. Adams, M. E. Cardella, J. Turns, S. Mosborg, and J. Saleem, "Engineering design processes: A comparison of students and expert practitioners," *J. Eng. Educ.*, no. October, pp. 359–379, 2007.

[16] C. J. Atman, J. R. Chimka, K. M. Bursic, and H. L. Nachtmann, "A comparison of freshman and senior engineering design processes," *Des. Stud.*, vol. 20, no. 2, pp. 131–152, Mar. 1999.

[17] C. Atman, J. Borgford-Parnell, and K. Deibel, "Matters of context in design," in *About: Designing: Analysing Design Meetings*, 2009, pp. 399–416.

[18] N. Cross, H. Christiaans, and K. Dorst, *Analysing design activity*. John Wiley & Sons, 1996.

[19] Flash-Integro, "VSDC Free Video Editor." www.CNET.com.

[20] V. Kumar, *101 Design methods: A structured approach for driving innovation in your organization*. Wiley, 2012.

[21] K. A. Ericsson and H. A. Simon, *Protocol analysis verbal reports as data*. Cambridge, MA: MIT Press, 1993.

[22] D. Kilgore, C. J. Atman, K. Yasuhara, T. J. Barker, and A. Morozov, "Considering Context : A Study of First-Year," *J. Eng. Educ.*, vol. 96, no. 4, pp. 321–334, 2007.

[23] D. H. Jonassen and Y. H. Cho, "Fostering Argumentation While Solving Engineering Ethics Problems," *J. Eng. Educ.*, vol. 100, no. 4, pp. 680–702, Oct. 2011.

[24] N. Genco, K. Holtta-Otto, and C. C. Seepersad, "An Experimental Investigation of the Innovation Capabilities of Undergraduate," *J. Eng. Educ.*, vol. 101, no. 1, pp. 60–81, 2012.

APPENDIX

Appendix A: Inter-rater Reliability using Cohen's Kappa

App.1		Reviewer Codes												
		0	1	2	3	4	5	6	1$2	1$4	2$3	2$5	3$5	4$5
Researcher Codes	0	6	3	1	1	-	-	1	-	-	-	-	-	-
	1	1	18	1	1	1	1	-	-	-	-	-	-	-
	2	-	-	14	-	1	-	1	-	-	-	1	-	-
	3	-	-	-	6	-	-	-	-	-	-	-	-	-
	4	-	-	1	-	58	-	-	-	-	-	-	-	-
	5	-	-	-	1	-	17	-	-	-	-	-	-	1
	6	-	-	-	-	-	-	-	-	-	-	-	-	-
	1$2	-	-	-	-	-	-	-	-	-	1	-	-	-
	1$4	-	-	-	-	1	-	-	-	-	-	-	-	-
	2$3	-	-	1	1	-	-	-	-	-	5	-	-	-
	2$5	-	-	-	-	-	-	-	-	-	-	-	-	-
	3$5	-	-	-	-	-	1	-	-	-	-	-	-	-
	4$5	-	-	-	-	-	-	-	-	-	-	-	-	3

pr-a	0.852
pr-e	0.223
kappa	0.810

Appendix B: Percent of Time Spent in Stages per Sub-Structure

App. B		0	1	2	3	4	5	6	1$2	1$4	2$3	2$4	2$5	3$5	4$5	SUM
1111s	1e	18.7	21.4	7.8	-	36.7	-	-	-	-	-	-	-	-	15.4	100
	1s	8.6	16.9	6.2	-	66.5	1.7	-	-	-	-	-	-	-	-	100
211e	1s	-	-	-	-	100.0	-	-	-	-	-	-	-	-	-	100
	2e	-	-	-	-	100.0	-	-	-	-	-	-	-	-	-	100
211m	1e	38.7	27.6	2.3	-	26.4	-	-	-	-	-	-	-	-	5.0	100
	1s	-	5.8	-	-	92.4	1.8	-	-	-	-	-	-	-	-	100
	2m	2.3	3.4	0.9	1.1	59.6	10.2	-	-	-	-	-	-	3.9	18.6	100
211s	1e	27.1	13.7	16.6	-	42.6	-	-	-	-	-	-	-	-	-	100
	2s	-	27.4	-	-	45.8	26.7	-	-	-	-	-	-	-	-	100
22m	2m	5.1	17.7	20.6	0.4	35.5	17.3	0.6	-	-	0.4	-	-	-	2.3	100
22s	2e	-	0.8	7.5	2.1	82.9	6.6	-	-	-	-	-	-	-	-	100
	2s	12.3	11.2	17.4	3.2	37.0	18.9	-	-	-	-	-	-	-	-	100
31e	1e	23.7	7.8	6.0	-	60.8	1.8	-	-	-	-	-	-	-	-	100
	3m	5.1	12.6	15.4	6.3	28.3	17.9	-	0.9	-	10.0	-	-	3.6	-	100
31s	1s	15.8	-	-	-	78.0	6.1	-	-	-	-	-	-	-	-	100
	3m	0.9	9.8	11.7	6.0	38.1	27.0	-	-	-	6.6	-	-	-	-	100
4s	4s	4.1	17.0	13.6	9.2	21.8	15.2	-	1.5	0.2	11.8	0.3	0.3	0.4	4.6	100