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Investigating Pattern in Design Performance of Interdisciplinary Undergraduate Engineering Student Teams

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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] and resulted in many prominent calls to reduce the distance between engineering education and engineering practice. The most notable call is perhaps from the National Academy of Engineering's Engineer of 2020 project [5], [6] which calls for the inclusion of interdisciplinary knowledge and teamwork skills into engineering curricula. As a result, engineering education is starting to change.

One major area of change in engineering education is in design. 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. Now, as the engineering curriculum has progressed, first year design courses, known as the cornerstone engineering courses, and fourth year design courses, referred to as capstone courses, have seen increased development as well [1]. However, these capstone courses serve as the only standard opportunity across engineering education for undergraduate engineering students to showcase their engineering education. This traditional way of approaching engineering education does not compare to modern engineering practice in which interdisciplinary teamwork and design are centrally important. 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 [7], James Madison [8], Purdue's EPICS [9] and Multidisciplinary Engineering programs [9], [10] and the Technology Leaders Program at the University of Virginia [11].

The interdisciplinary undergraduate engineering program at the University of Virginia, the Technology Leaders Program, provided the case study for this research. This interdisciplinary program consists of collaboration between the Electrical and Computer Engineering (ECE) and Systems Engineering (SIE) departments. It is comprised of a three year curriculum that fosters a learning environment in which electrical, computer and systems engineering students collaborate to engage in the designing, prototyping and testing of engineering systems. The value added of a TLP student is grounded in their ability to engage both systems integration and domain-specific engineering work. At the end of the curriculum, graduates should be more able to "design systems requiring the integration of knowledge and skills from" electrical, computer and systems engineering and "collaborate on interdisciplinary teams" [11].

Therefore the goal of this paper was to present findings on how undergraduate engineering students from traditional engineering curriculum and the Technology Leaders Program engage in an interdisciplinary engineering design team activity. Specifically, the research interest was in how these student teams distribute their time with respect to different stages of engineering design, seeking answers to the following questions:

1) What patterns of behavior with respect to design stage do interdisciplinary teams exhibit during an engineering design activity?
2) What patterns of behavior with respect to team structure do interdisciplinary teams exhibit during an engineering design activity?
3) For what reasons do interdisciplinary teams split into subgroup structures during an engineering design activity?

MOTIVATION & LITERATURE REVIEW

The motivation for this study was in part due to the literature regarding the evaluation of interdisciplinary work, interdisciplinary design and the absence of research in how to best educate students in interdisciplinary design. Several notable studies in engineering design and interdisciplinary education were used as motivation in modeling this research study. This section highlights some of those notable studies and their relation to this study.

Atman has conducted several studies using Verbal Protocol Analysis (VPA) to observe and compare the design process of undergraduate students, specifically first and fourth year students [12]–[15]. In her studies, participants individually worked through open-ended design questions with limited information provided upfront. However, participants were not selected based on major and did not commence in any physical implementation of their designs. Results from her studies show there are noticeable differences between first and fourth year student's design processes, particularly in the amount of information gathered, transition behavior and their progression through design steps. These studies give valuable insight to design as it relates to teamwork but did not include the implementation of design into a prototype. These studies also did not give insight into design as it relates to interdisciplinarity in engineering.

The Delft Protocol Workshop [16] included two significant workshops aimed at studying engineering design activities and knowledge. The Delft Protocol Workshop [16] brought together a group of researchers all versed in protocol analysis to analyze a standard set of data collected by Cross et al [16]. The data was a recorded collection of both individual designers and a three-person team of designers designing a fastening device for a backpack to go on a mountain bike. The experimental setup was similar to the setup of this study with information being distributed upon request and participants completing a short follow-up interview after the activity. However, in Cross' study only individual participants were instructed to think aloud and complete a short initial think aloud exercise. The groups in this study were not instructed in the same manner to do the same but instead expected to talk aloud in communication with other members of the group. Also, participants of Cross' study were all professionals with varying years of engineering design experience. Examples of what researchers did with the data include formulating comparisons and dissimilarities between team and individual performance in design [17], [18], characterizing aspects of a team [19] and looking at the relationship between the ways design ideas mutate and evolve within a group [20], [21].

Richter explored and uncovered mixed results about the learning barriers students face in interdisciplinary contexts within engineering. One study looked at a student's ability to recognize relationships between the student's major and interdisciplinary topics as well as identify connections between their own field and other's fields in terms of contributions, viewpoints and expertise [22]. Results from this study show students exhibit a disciplinary egocentrism, the inability to think beyond their discipline, and this is a cognitive barrier faced when interacting in the interdisciplinary setting. In another study, Richter used a scenario-based instrument to measure a student's ability to identify and value contributions of multiple disciplines and measure a student's understanding of the need for broad based interdisciplinary collaboration [23]. Results from this study show students do exhibit awareness for the need of interdisciplinary collaboration and the ability to value the contributions of multiple disciplines. These results do potentially conflict with the findings of Richter's other study about student learning barriers. However neither set of results give insight into how students of differing disciplines contribute in a team setting.

Lattuca and Borrego also conducted research on barriers to interdisciplinary learning in students, Lattuca from a pedagogical view and Borrego through literature analysis. Lattuca explored the various theories and definitions used by scholars to define interdisciplinarity. Results from her study revealed varying and conflicting definitions of interdisciplinarity used by engineering administrators and faculty across engineering education. These conflicting definitions potentially hamper the development of a student's interdisciplinary competence [24]. Borrego explored and identified five categories of learning outcomes for interdisciplinary graduate education by comparing literature of interdisciplinary studies with content analysis of successful National Science Foundation proposals [25].

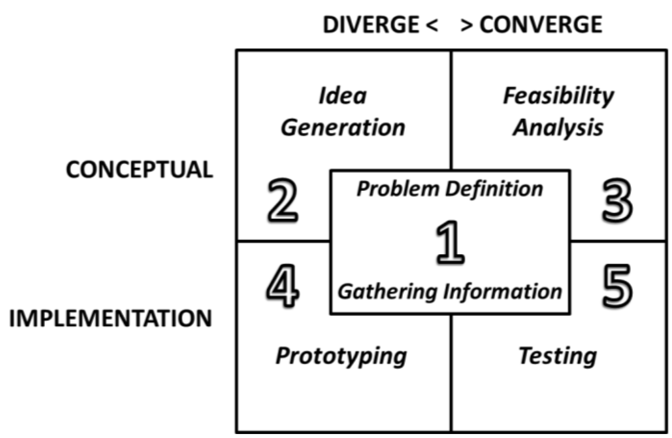
In summary, research in interdisciplinary collaboration and engineering design are two important areas in the understanding of how students become proficient at interdisciplinary design. Although studies conducted on design teams resulted in significant findings, the studies presented did not include implementation of design solutions in their methods. Also, the participants in these studies were not determined based on discipline.

In addition, there exists prior work in the humanities on students navigating interdisciplinary situations; however, in the field of engineering this work is limited. Out of the work that does exist it primarily has been conducted through the use of interviews, "critical incident interviews" [26], scenario-based cases and surveys. This study instead used the method of video analysis to investigate those interdisciplinary team interactions between students. Moreover, prior video analysis of engineering design teams has not focused on interdisciplinary teams. Therefore, the purpose of this study was to build on the research presented on the role of interdisciplinarity and design in engineering through video analysis of interdisciplinary design teams.

ENGINEERING FRAMEWORK

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 [15]. 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 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) [27]. 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. The shape in figure 1 was created to represent and show this framework as an iterative process versus a linear one. 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.

STUDY SETUP & PARTICIPANTS

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 [12]–[15] and Cross, Christaans and Dorst [16]. Following the activity, students also participated in a focus group and completed a post-activity survey. Participants completed the study in two sets, with the first set participating in spring of 2012 and the second in spring of 2013. Both sets of this study were approved by the Institutional Review Board.

The engineering design activity was a three-hour activity in which students worked as a team to develop and model a prototype for a newspaper counter for the college newspaper, the Cavalier Daily. The students were presented with information about the Cavalier Daily Newspaper, a list of requirements for the desired prototype, a Cavalier Daily newspaper distribution box, various construction materials (tape, cardboard, scissors, paper, etc.) and several electronic sensors manufactured by Phidgets and SunSPOT. Students were also provided with four laptop computers outfitted with Microsoft Office and Integrated Development Environments to configure the electrical sensors. The researcher acted as a representative of Cavalier Daily answering questions and providing any information requested of the client by the students throughout the duration of the activity.

All students were recruited using electronic surveys, were asked to consent to participation in the study and received $100 for successful completion of the entire study. Students were then divided into groups of four, each group having two SIE students and two ECE students. The number of TLP students on each team was determined based on the availability of students for the study. Table 2 shows the breakdown of all study participants by curriculum, gender, and major.

Table 2 Breakdown of Study Participants

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

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 complete prototyping within the given three-hour time frame. The entire activity was recorded using multiple video cameras and tape recorders.

DATA PREPARATION

To make data preparation easier, all video recordings were first edited using VSDC Free Video Editor [28] to include audio from tape recorders and a timer.

A transcript of summarized paragraphs detailing the events of each team throughout the activity was created for each video. Segment breaks were inserted when the design stage the team was functioning in changed or when there was a change in team structure (working as a single group versus in subgroups). To check the validity of the summaries written, each transcript was reviewed by a second reviewer for 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 review of the videos and transcripts was completed by the principle researcher to incorporate feedback from the second reviewer.

As a final step to transcript preparation, before applying the coding scheme, a sample amount of segments were selected at random to be jointly coded by the principle researcher and a second coder. After discussing the challenges identified from the second coder review, the principal researcher completed another review of all transcripts. Therefore, after three iterations of review for each video transcript, 11 video transcripts totaling 583 segments were created. These segments were then combined into one transcript and decontextualized through order randomization before applying the coding scheme.

CODING SCHEMES

To prepare for analysis of the video data, each transcript segment was randomized and assigned two codes. The first code was representative of the engineering design stage the team was working in at that time, and the second code was representative of the team structure the team was working in at that time. However, after conducting the first round of coding, it was found that teams sometimes rapidly oscillated 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 the transcript segments. Table 3.1 explains how the codes for design stages presented in the engineering design framework were assigned.

Table 3.1 Coding Notation Used for Design Stages

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

In the same manner, team structure was observed to determine if a particular structure a group chose to work in correlated with the selected tasks done during that time period. Codes for team structure were applied in the following way:

Table 3.2 Coding Notation Used for Team Structure

<table>
<tr><th>Code</th><th colspan="4">Explanation of Team Structure</th></tr>
<tr><td>4s</td><td colspan="4">All 4 students in a single group.</td></tr>
<tr><td>31e</td><td colspan="3">2 SIE and 1 ECE students in a subgroup.</td><td>1 ECE student alone.</td></tr>
<tr><td>31s</td><td colspan="3">1 SIE and 2 ECE students in a subgroup.</td><td>1 SIE student alone.</td></tr>
<tr><td>22m</td><td colspan="2">1 SIE and 1 ECE students in a subgroup.</td><td colspan="2">1 SIE and 1 ECE students in a subgroup.</td></tr>
<tr><td>22s</td><td colspan="2">2 SIE students in a subgroup.</td><td colspan="2">2 ECE students in a subgroup.</td></tr>
<tr><td>211e</td><td colspan="2">2 ECE students in a subgroup.</td><td>1 SIE student alone.</td><td>1 SIE student alone.</td></tr>
<tr><td>211m</td><td colspan="2">1 SIE and 1 ECE students in a subgroup.</td><td>1 SIE student alone.</td><td>1 ECE student alone.</td></tr>
<tr><td>211s</td><td colspan="2">2 SIE students in a subgroup.</td><td>1 ECE student alone.</td><td>1 ECE student alone.</td></tr>
<tr><td>1111s</td><td>1 SIE student alone.</td><td>1 SIE student alone.</td><td>1 ECE student alone.</td><td>1 ECE student alone.</td></tr>
</table>

After application of the codes for design stage and team structure to all transcript segments, the final result was one transcript with 583 coded segments representative of all 11 videos.

VALIDITY

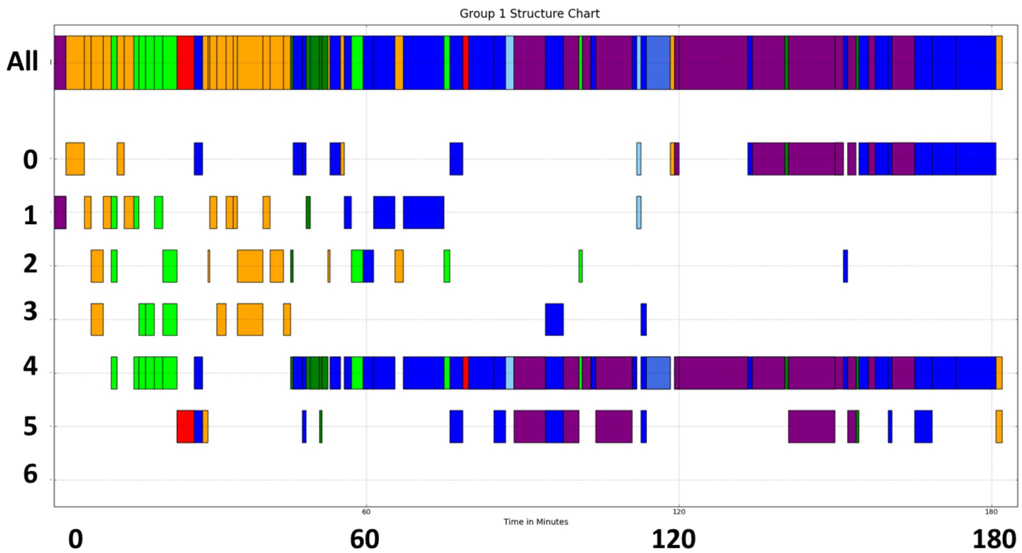
Inter-rater reliability for design stage coding was established by having 20% of the overall number of segments coded by second coder. Three percent of those statements were coded jointly with the second coder as described before. The remaining 17% were coded independently and inter-rater agreement measured by computing Cohen's kappa coefficient, a commonly accepted method of assessing inter-coder reliability [29]–[31]. 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 C shows inter-rater agreement of coded segments. Team structure was easily identifiable from video and therefore was only rated by one person.

RESULTS

There were different ways the data from this study was analyzed to uncover research findings. To answer the research questions posed in this paper, this section will show the analysis used to determine how each group navigated the design stages of this activity and in what ways they utilized team structure. This was accomplished by creating a team activity map for each team based off the coded segments for that team.

These maps were created using Python. The following figure is an example of the team activity map created for Group #1.

Figure 4.1 Group #1 Team Activity Map



These charts show the activity of each team by design stage (y-axis) across the three hour time span allotted for the activity (x-axis). Each box represents a segment from the team transcript. The segments that consisted of multiple activities representative of multiple design stages are represented as stage 6 on the chart above. The color of the box denotes which structure the team was working in during that segment. Table 4 explains the color scheme used to represent team structure in the activity maps.

Table 4 Team Structure Color Scheme for Activity Maps

<table>
<tr><th>Code</th><th>Code</th><th colspan="4">Explanation of Team Structure</th></tr>
<tr><td>Orange</td><td>4s</td><td colspan="4">All 4 students in a single group.</td></tr>
<tr><td>Lime</td><td>31e</td><td colspan="3">2 SIE and 1 ECE students in a subgroup.</td><td>1 ECE student alone.</td></tr>
<tr><td>Dark Green</td><td>31s</td><td colspan="3">1 SIE and 2 ECE students in a subgroup.</td><td>1 SIE student alone.</td></tr>
<tr><td>Red</td><td>22m</td><td colspan="2">1 SIE and 1 ECE students in a subgroup.</td><td colspan="2">1 SIE and 1 ECE students in a subgroup.</td></tr>
<tr><td>Maroon</td><td>22s</td><td colspan="2">2 SIE students in a subgroup.</td><td colspan="2">2 ECE students in a subgroup.</td></tr>
<tr><td>Royal Blue</td><td>211e</td><td colspan="2">2 ECE students in a subgroup.</td><td>1 SIE student alone.</td><td>1 SIE student alone.</td></tr>
<tr><td>Blue</td><td>211m</td><td colspan="2">1 SIE and 1 ECE students in a subgroup.</td><td>1 SIE student alone.</td><td>1 ECE student alone.</td></tr>
<tr><td>Light Sky Blue</td><td>211s</td><td colspan="2">2 SIE students in a subgroup.</td><td>1 ECE student alone.</td><td>1 ECE student alone.</td></tr>
<tr><td>Purple</td><td>1111s</td><td>1 SIE student alone.</td><td>1 SIE student alone.</td><td>1 ECE student alone.</td><td>1 ECE student alone.</td></tr>
</table>

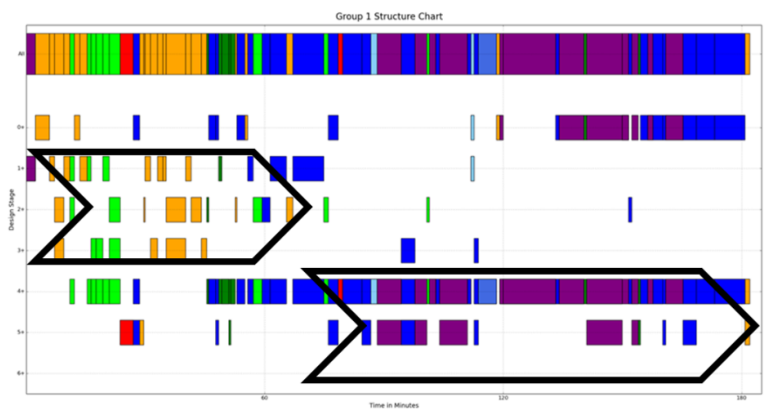
After reviewing all 11 activity maps, the findings discovered produced the following responses to the research questions of interest for this paper.

1) ***What patterns of behavior with respect to design stage do interdisciplinary teams exhibit during an engineering design activity?***

There were four patterns of movement through team structure that emerged from analysis of the team activity maps.

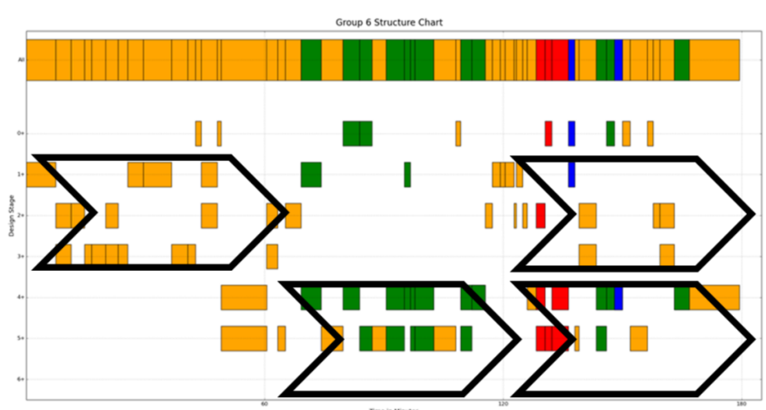
(DSP-1) The first pattern and most popular that emerged was the pattern of conducting work in the gathering information and conceptual stages early in the activity then spending the remaining amount of time focusing on work in the implementation stages. The team activity map from group #1 is an example of this pattern.

Figure 4.1 DSP-1 from Group #1 Team Activity Map



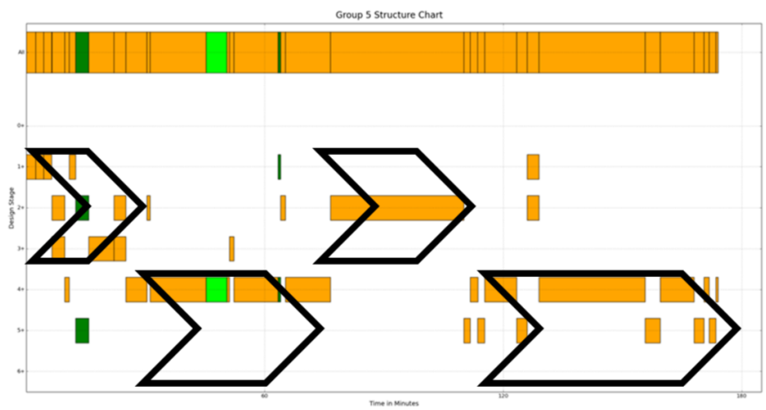
(DSP-2) The second pattern, similar to the first, consisted of conducting work in the gathering information and conceptual stages upfront, moving into work focusing on the implementation stages, but then conducting work across all five stages to conclude the activity. The team activity map from group #6 is an example of this pattern.

Figure 4.2 DSP-2 from Group #6 Team Activity Map



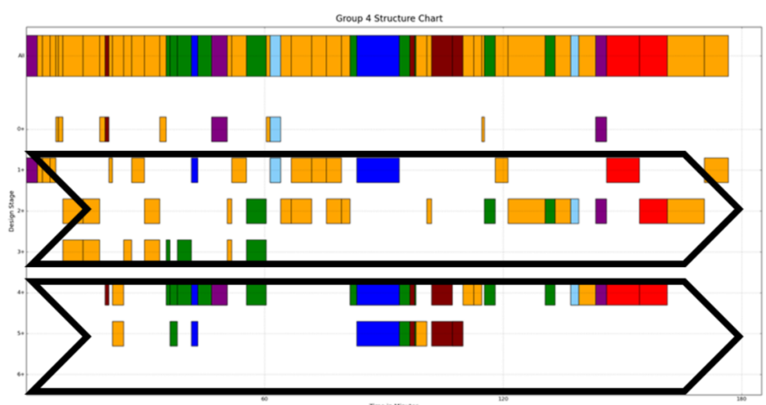
(DSP-3) The third pattern consisted of switching back and forth between the conceptual stages and implementation stages repeatedly throughout the activity. The team activity map from group #5 is an example of this pattern.

Figure 4.3 DSP-3 from Group #5 Team Activity Map



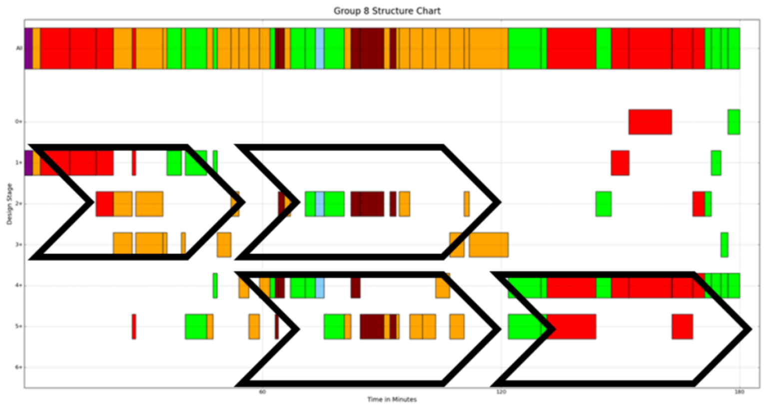
(DSP-4) The fourth pattern consisted of working concurrently through both the conceptual and implementation stages throughout the activity. This means a group primarily split into subgroups for the majority of the activity with each subgroup working in a different design stage. The team activity map from group #4 is an example of this pattern.

Figure 4.4 DSP-4 from Group #4 Team Activity Map



(DSP-5) The fifth pattern consisted of beginning work in the conceptual stages, then moving to working concurrently in the conceptual and implementation stages, to finally just working in the implementation stages. This pattern was more of a gradual move from conceptual to implementation whereas the first pattern was quick move. The team activity map from group #8 is an example of this pattern.

Figure 4.5 DSP-5 from Group #8 Team Activity Map



The following table shows the design stage pattern utilized by each team in this study. The most popular pattern shown among the groups was design stage pattern #1. For those teams exhibiting this pattern there was a noticeable point in each of their activities at which the team decided they had spent enough time generating and critiquing ideas. At this point is when the team began working in the implementation stages, constructing and testing their prototype in as effort to meet the activity deliverable of a physical working prototype. Since coding was the task teams spent the most time on, teams of design stage pattern #1 committed their time coding, and as a result not leaving time to revisit the brainstorming or critiquing stages during the activity.

Design Stage Pattern by Group Number

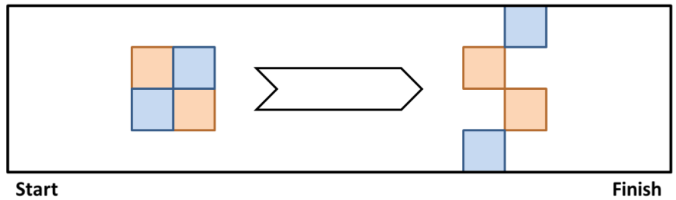
Design Stage Pattern	Group Number										
	1	2	3	4	5	6	7	8	9	10	11
1	X	X	X						X	X	X
2						X	X				
3					X						
4				X							
5								X			

2) ***What patterns of behavior with respect to team structure do interdisciplinary teams exhibit during an engineering design activity?***

There were four patterns of movement through team structure that emerged from analysis of the team activity maps.

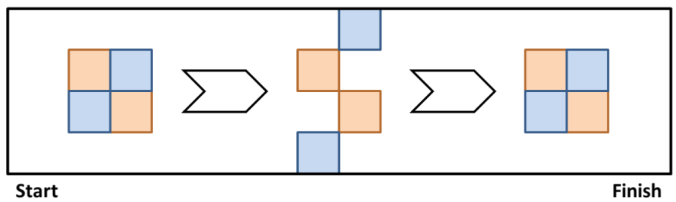
(TSP-1) The first pattern consisted of starting the activity working as a group, usually in the gathering information and conceptual stages, then splitting into subgroups to work in the implementation stages. The groups that operated in this manner were G1 and G7.

Team Structure Pattern #1



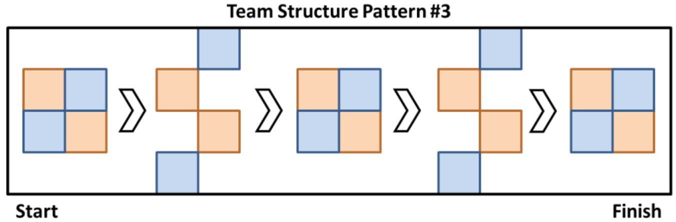
(TSP-2) The second pattern consisted of starting the activity working as a group, moving to a period of working as a subgroup, and then ending the activity working as a single group again. Similar to the first pattern, the period where groups split into subgroups was also the period where work in the implementation stages began. The groups that operated in this manner were G2, G9, and G11.

Team Structure Pattern #2



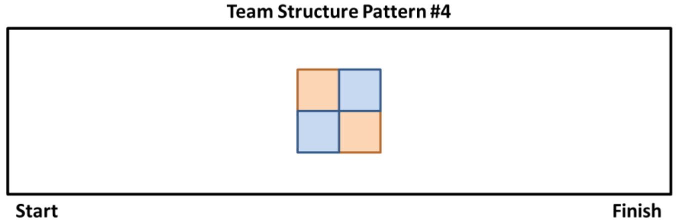
(TSP-3) The third pattern, similar to the second, consisted of constant switching back and forth between working as a single group and working as a subgroup. This pattern is different from the second pattern as it involves multiple switches of single group to subgroups whereas the second pattern only consisted of one switch. The groups that operated in this manner were G3, G4, G6 and G8.

Team Structure Pattern #3



(TSP-4) The fourth pattern consisted of working through most of the activity as a group, with little to no time spent working as a subgroup. The groups that operated in this pattern were G5 and G10.

Team Structure Pattern #4



The following table shows the team structure pattern of each team in this study. The patterns most utilized were team structure patterns #2 and #3, the patterns which included some level of iteration between single group and subgroup structures. Groups who utilized these patterns often used the subgroup structures to work across multiple design stages and mitigate the large amount of time needed for coding.

Team Structure Pattern by Group Number

Team Structure Pattern	Group Number										
	1	2	3	4	5	6	7	8	9	10	11
1	X						X				
2		X							X		X
3			X	X		X		X			
4					X					X	

3) ***For what reasons do interdisciplinary teams split into subgroup structures during an engineering design activity?***

To answer this question all the segments in which teams transitioned from the single group structure into some combination of a subgroup were analyzed to develop a list of reasons as to what caused this transition.

The two most apparent reasons leading to a team transition from a group to a subgroup structure were related to the methods teams used to handle design issues and software coding. There were many instances where, as a group, students talked through an issue related to the prototype (i.e. design features, testing results, construction challenges, etc.) and then used a "divide and conquer" method to address the issue. Often following a group decision on how to address the issue, a path forward consisting of multiple tasks was laid out to which the team split to execute the various tasks. This method was also used early in the activity by some teams to gather information and brainstorm ideas for solutions. Instead of going through each sensor one by one as a group, the team decided to split the sensors up among their subgroups to brainstorm ideas. Therefore the reason why teams split were to execute as planned the tasks they had determined as a group.

The other most apparent reason why teams split was attributed to the writing of software code. This was also confirmed in other findings from the study which compared the time working in a single group to various subgroup structures across the design stages. Results of that comparison, presented in a prior paper [32], showed nearly 80% of the total time spent working in stage 4 was in a subgroup structure and 56% of the total time for stage 5. During these instances most often one or two students took on the task of coding due to their prior experience or confidence in their coding ability.

Other reasons why teams transitioned from a group structure to a subgroup were due to

a) Single member influences such as…
   - **One student's decision to work alone –** One student in the group decides to work on a task alone, most often coding of the prototype, but it is not apparent why the student does this. It does not occur as the result of a suggestion by this student or decision of the team.
   - **A suggestion made by a team member –** One student in the group makes a suggestion to split into subgroups to carry out various tasks and the group agrees.

b) External influences such as…

- **A new data set being provided to the team –** The client provided a new set of data to the group, which after reading through this data caused the team to change direction in some sort of way.
- **The researcher interjecting into the study –** Occasionally the researcher conducted a team check-in to determine what the students were working on at any particular time in the study. Sometimes after the conclusion of this check-in, the team split into subgroups to work on different tasks.
- **One or more students working on unrelated activities –** Segment was recorded as a subgroup structure due to one or more students engaging in tasks or actions unrelated to the study while the remaining team members continue working on task.

c) Intermediate team actions such as…

- **Short group interactions while working in subgroups –** They were instances where a team was working in a subgroup structure but occasionally came together to answer questions or confirm decisions before returning to their same subgroup structure. Therefore the reason why the team split in this case was to continue working on the same tasks they worked on prior to the group coming together.

Each of these categories could be further subdivided to seek out a specific action or statement that led to the transition of team structure. However due to limited number of groups who completed this study, driving that level of detail for this study would not prove beneficial to answering this research question. Also, to sufficiently further pinpoint the root cause of each transition the researcher would need to know the internal thought process of each student at the time the transition happened. It can be inferred from the video data what each student might have been thinking but that inference can only be made from what was said and done by each student at that particular time in the study.

CONCLUSIONS

The overall aim of this 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 student on interdisciplinary teams, specifically patterns of team behavior in relation to team structure and engineering design. This paper's findings show there were four distinct patterns for team structure and 5 patterns for design stage activity that emerged from analysis of results. Key findings also show there were varying reasons why teams transitioned from a single group to a subgroup structure but the two most prevalent reasons related to software coding and teams using a "divide and conquer" method to trouble shoot issues and challenges. If more teams were included in this study, or if the researcher had more access to the students' thought process during the study, further analysis of the data could yield more defined reasons for why teams split into subgroups structures. Future work to be conducted for this study includes analysis of the individual contributions (both verbal and physical) of students to each team to understand how individual students might have influenced the patterns of team behavior presented.

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