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Engineering Design Activity to Develop Strategy to Evaluate Interdisciplinary Design Skills

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1 INTRODUCTION

At the Sunapee State University engineering majors are similar to those at other schools around the nation. Most students choose a specific major in an area of interest to them and their future career plans. Within the engineering major, these students follow a specific track of courses with little variation in the form of electives taken during the third and fourth years. With the only common courses between majors being rooted in math, physics, chemistry, writing and some social sciences, it is unsurprising to find that graduates from different programs develop and exhibit a completely different set of technical skills. The issue in this model surfaces when those graduates leave the university to begin their professional careers. On the job, engineers are faced with challenges daily that require knowledge spanning across many different engineering fields in order to find a solution. Graduates of the current model are not readily equipped to tackle these challenges without having to seek out the expertise of others. In an effort to develop engineers who can tackle these issues, universities across the nation have turned to creating interdisciplinary engineering programs.

At the Sunapee State University, an interdisciplinary engineering program exists in the form of the Collaborative Engineering Program (CEP). This interdisciplinary program is a cross collaboration between the Electrical and Computer Engineering and Systems Engineering 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 projects. At the end of the curriculum, students of both majors will have developed a unique skillset which allows for them to effectively solve the real world engineering challenges faced in industry. Specifically, fourth year systems engineering graduates will have the ability to work on technology-oriented projects while electrical and computer engineering graduates with have the ability to integrate domain-specific technical designs into larger systems.

During the spring semester of 2012, a pilot study was conducted at the Sunapee State University to assess the impact of the Collaborative Engineering Program on its cohort of students.

1.1 Research Questions

The long-term goal of this research is to improve understanding of how students become proficient at interdisciplinary design for the purpose of creating better curricula to develop graduates with those skills. To facilitate this goal, the primary research method used was to observe engineering students from both the Collaborative Engineering Program and not in the program working on interdisciplinary design teams on an engineering design activity. It uses a mixed-methods approach to address two main objectives, interdisciplinary collaboration and engineering design, by addressing two high level research questions.

Research Question 1 and its sublevel questions of interest pertain to how a student's curriculum relates to how they engage in engineering design.

RQ 1.0 How do undergraduate engineering students of differing curricular programs engage in the engineering design process?
- RQ 1.1 How do interdisciplinary teams with differing student compositions distribute their time with respect to the engineering design stages?
- RQ 1.2 How do individual students from differing curricular programs contribute to the engineering design stages?

Research Question 2 and its sublevel questions of interest pertain to how a student's curriculum relates to how they engage on an interdisciplinary design team.

RQ 2.0 How do undergraduate engineering students of differing curricular programs participate as members of interdisciplinary teams engaging in an engineering design activity?
- RQ 2.1 When interdisciplinary teams of differing student composition split into subgroups, how do those subgroups contribute to the engineering design stages?
- RQ 2.2 When interdisciplinary teams of differing student composition split into subgroups are those groups determined by majors, curriculum or other?
- RQ 2.3 How do individual students from differing curricular programs participate in situations where interdisciplinary "collaboration" occurs?
- RQ 2.4 How do individual students from differing curricular programs perceive each student's contributions to the team and project?
- RQ 2.5 Do individual students from differing curricular programs value each student's contributions to the team and project?

2 LITERATURE REVIEW

The definition of interdisciplinary as defined by Merriam-Webster (2012) is "involving two or more academic, scientific, or artistic disciplines." In relation to engineering the Engineer of 2020 Project at Pennsylvania State University defines interdisciplinarity as, "a perspective, practice or problem-solving approach that utilizes modes of inquiry drawn from one or more disciplinary or nondisciplinary perspectives (i.e. the "real world")"[4]This study is centered on assessing interdisciplinary learning as it relates to engineering.

The need to produce graduates who not only have a solid foundation in a specific engineering discipline but also knowledge across engineering disciplines is recognized by universities across the nation. The necessity to address this need has been recognized in the creation of multiple interdisciplinary engineering programs. According to the University of Alabama at Birmingham School of Engineering, "it is the premise of these interdisciplinary programs that students must be educated in more than one area to remain competitive and have successful careers whether they choose to stay in academia or work in industry."[6]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[2]. An example of an undergraduate program is seen at Purdue University School of Engineering where there exists the Interdisciplinary Engineering Program (IDE) which is "for the student whose interests and abilities lie at the interface between engineering disciplines, or between engineering and other disciplines"[6]. Interdisciplinary programs are also seen in graduate education programs such as at the University of Alabama at Birmingham School of Engineering where there exists a Ph.D in Interdisciplinary Engineering program. This curriculum "fosters interdisciplinary interactions between the School of Engineering and medical and biomedical units and the Schools of Business and Public Health and the College of Arts and Sciences"[8] and serves as an ideal example of how engineering has some element of interaction with every discipline.

One of the primary objectives seen across interdisciplinary programs is being able to apply interdisciplinary knowledge to design. The need for engineering graduates to understand and apply cross discipline knowledge in design is extremely vital to finding a problem solution. "The degree to which a designer or design team is able to competently address both the fine grained details of a design as well as its broader contextual parameters, the greater the likelihood is of a successful outcome"[1]. The value added of a CEP 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 TLP majors" and "collaborate on interdisciplinary teams"[7].

3 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[1] and Cross, Christaans and Dorst[3]. Following the activity, students also participated in a focus group and completed a post-activity survey.

3.1 Research Components

3.1.1 Engineering Design Activity

Participants completed a three hour activity in which students worked as a team to develop and model a prototype for a newspaper counter. The newspaper counter must be designed using the materials provided and constructed as an addition to the current Cavalier Daily newspaper distribution boxes. The students were presented with information about the Cavalier Daily Newspaper and a list of requirements for the desired prototype established by Cavalier Daily. The students were then instructed to act as engineering consultants and develop a solution based on those requirements. In addition to a Cavalier 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 Cavalier 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 complete within the given three hour time frame. The entire activity was recorded using multiple video cameras and tape recorders. See

Appendix for activity prompt, room set-up and additional Cavalier Daily information provided to students.

3.1.2 Focus Group Session

Each team of students participated in a forty-five minute focus group session immediately following the Engineering Design Activity. During this session, teams were asked a series of questions about thoughts behind their actions taken during the activity and thoughts on the overall team interaction. The questions sought to develop an understanding of the general thought process displayed during the activity with specific questions focusing on the team's overall approach toward developing a solution. Other questions asked during this session were centered on the two curriculums involved in this study and how much prior coursework dictated the actions of each team. The entire session is recorded using video cameras and tape recorders. See Appendix for examples of questions asked during the Focus Group Session.

3.1.3 Assessment Survey

Following the Focus Group Session each student was required to complete an electronic Assessment Survey. The purpose of the survey was to capture individual thoughts about the study that were not expressed during the Engineering Design Activity. Questions on the survey asked participants to explain the distribution of work and the level of contribution each participant displayed during the Design Activity. Participants were asked whether or not their individual contributions to the project were valued by the other participants on their team. Participants were also asked to list the individual contributions of each team member. See Appendix for a copy of the Assessment Survey.

3.2 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 responded to the first survey and used to identify their availability for participation in the research study. A separate survey was administered to 4th year CEP students to identify their availability to participate in the research study as well. Final groups were selected based on matching availability of the CEP and other interested students. All students were asked to consent to participation in the study and get $100 for successful completion of the entire study.

This pilot study included twenty-three (23) fourth year undergraduate engineering students as participants from the following majors: twelve (12) Systems and Information Engineering (SIE), ten (10) Electrical and Computer Engineering (ECE), one (1) Computer Science (CS). Eleven (11) of the twenty-three students were a part of the CEP. Eleven (11) students were traditional curriculum students not associated with the CEP. One (1) student was previously a part of the CEP but withdrew after completing the first year. Table 4.2 shows the breakdown of those students by curriculum, gender, and major.

Curriculum	**Male**	**Female**	**ECE**	**SIE**	**CS**
Traditional	8	4	6	6	
CEP	7	4	4	6	1

Table 4.2 Breakdown of Pilot Study Participants

3.3 Group Compositions

Students were divided into six teams based on major and curriculum. Each group was comprised of two electrical and computer engineering students and two systems engineering students with the exception of team five. The following is the structure of the teams in combinations of traditional and CEP students: team #1 – four CEP students, team #2 and #3 - two traditional students (one SIE, one ECE), two CEP students (one SIE, one ECE), team #4 – two traditional ECE students, two CEP SIE students, team #5 – two traditional SIE students, one CEP CS student, team #6 – four traditional students.

3.4 Group Selection

Since the CEP students were predetermined for the design activity those students were placed in groups first before placing non-CEP students. Groups were determined by first separating CEP students who work in the same capstone team from each other. This step was taken to attempt to minimize the factor of prior experience working with another student in the study on a similar team activity. Then CEP students were placed in a group based on major and availability to complete the design activity. Once all CEP students' placement in groups was determined then eligible non-CEP students were selected and placed to complete the groups based on their stated availability for the study.

3.5 Site Selection

This study took place inside a classroom designed for interactive learning. The room setup included three six foot tables, four desk chairs, various arts and craft materials, loose-leaf paper, mechanical pencils, two white boards and one replica of the newspaper distribution box. Two cameras were positioned in adjacent corners of the room to capture the overall and main table view student participants working during the pilot study. A third camera will be added to future studies to add an additional view of students working inside of the replica newspaper distribution box. A tape recorder was positioned on the main table to capture any discussion between the students that were not picked up by the cameras.

3.6 Data Preparation

Before applying coding schemes, all data collected from the engineering design activity was integrated in the following ways. Each angle of video captured during the Engineering Design Activity and the Focus Group Session was combined into one media file with its corresponding recorded audio data during using media editing software. Then all verbal conversations that occurred during the Engineering Design Activity and Focus Group Sessions were transcribed from the combined video and audio media files. The Assessment Survey responses were compiled and stored in one file per group. Preparation for all data collected from this pilot study has not been completed.

Also, to maintain confidentiality in the transcriptions and survey responses each student was assigned a unique identifier relating to their group number, major and program.

4 DATA ANALYSIS

To accomplish the objectives of this study all data collected is analyzed using the following coding schemes:

A. Individual Statement Analysis
B. Time Distribution
C. Team Structure
D. Isolated Conversation Contribution
E. Survey Responses.

Each coding scheme produces a set of data points that are used to draw comparisons across individual students and their group compositions. Each coding scheme is distinct in the data points it produces, however the coding schemes do not work independently of each other. Section 4.2 describes each coding scheme and section 4.3 shows how each coding scheme answers the research questions given the data points it produces. Section 4.1 explains the framework for engineering design from which the coding schemes were developed.

4.1 Engineering Design Stages

Although interactions between students observed during the engineering design activity may be different per group, all actions occurring during the activity regardless of the group relate to engineering design. Therefore this framework is used to map all conversations and activities conducted to steps that make up an engineering design process. All the coding schemes used in this study are based on this framework. This framework is based on a coding scheme developed by Atman of the University of Washington[1]. However, it is 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 model of design. The coding schemes used in this study utilize the Engineering Design Stages work to characterize each observation of interest. Figure 4.1 shows the coding scheme.

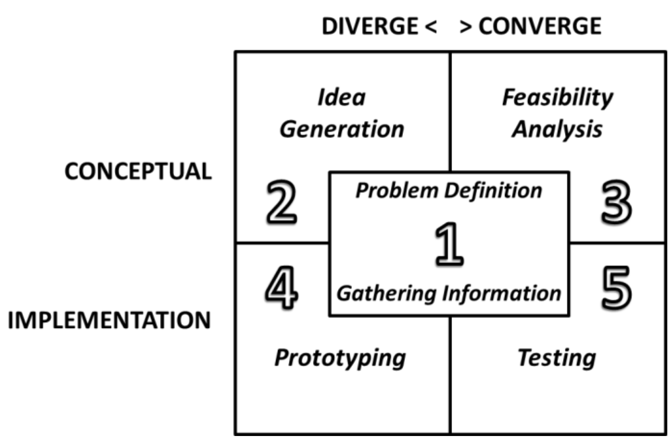

Figure 5.1 Engineering Design Stages Coding Scheme

This framework is divided into two concepts, Conceptual versus Implementation and Divergence versus Convergence, which determines the location of the stages in the diagram. First, each stage is characterized by whether the actions and conversations that occur within it are abstract or generalized thinking of the mind (conceptual) or as practical application of thoughts and ideas (implementation). Then each stage is 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).

There are five stages that comprise this framework. Stage 1 focuses on conversations or actions pertaining to the defining of requirements or project scope and gathering information about a particular project. Stage 2 focuses on conceptual conversations about new ideas for solutions or designs that pertain to the prototype. Stage 3 focuses on conceptual conversations about the feasibility of a proposed solution. Stage 4 focuses on actions and conversations associated with the constructing of a prototype. Stage 5 focuses on actions or conversations associated with the testing of an implemented system. A more detailed description of each stage is in Appendix.

4.2 Coding Schemes

4.2.1 Individual Statement Analysis (A)

All statements recorded during the activity will be transcribed and identified by the speaker. Each statement is assigned a number according to its relation to the engineering design stages. In the same manner, physical actions (non-conversational) undertaken by individual students are also transcribed and assigned a number according to its relation to the engineering design stages. Physical actions observed from the pilot study include writing of code, configuring of electrical hardware, constructing of materials for configuration of electrical hardware, and testing of implemented system. The list of physical actions undertaken by students will be further developed after completion of the spring study using the method of open coding.

In addition, the nature of each statement as it relates to the immediate previous statement is analyzed. The purpose is to determine whether subsequent statements are made in approval or disapproval of the previous statement. The observation of interest is the nature of subsequent statements made by a student of a differing curricular program (i.e. statements made by a SIE student followed by a statement from an ECE student or statements made by a TLP student followed by a statement from a non-TLP student). Each statement transcribed will be coded as a statement of approval or disapproval in addition to the design stage it relates to.

The coding scheme is as follows:

- Numbers one (1) through five (5) are assigned to statements that correspond directly with one of the engineering design stages.
- Zero (0) is assigned to statements that are irrelevant to the study.
- Six (6) is assigned to statements of confirmation or approval.
- Seven (7) is assigned to statements of rejection or disapproval.
- Nine (9) is assigned to statements that are relevant to the study but do not fit one of the other categories.

4.2.2 Time Distribution (B)

Time is observed to determine how long each group spends in each engineering design stage. Time distribution is coded on a numerical scale of 1 through 5, which corresponds to the five stages of the engineering design process. Segments where the activities of the group are irrelevant to the study or are unclear to the researcher are assigned a 0. Segments where the group is multitasking or conducting activities in more than one stage concurrently are assigned a 9. Comparisons in time distribution are made between groups to determine if group composition has any impact on the distribution of time in engineering design stages.

4.2.3 Team Structure (C)

Team structure and composition is observed to determine if either correlates to the distribution of specific tasks throughout the activity. Composition corresponds to group composition noted previously (section 4.3). Team structure is coded on a letter scale of W, X, Y, and Z which corresponds to one of the following structures: all four students working together on one task (W), sub group of three students with one student working alone (X), sub group pairs of two students working on separate tasks (Y), or all four students working alone on individual tasks (Z). Each statement and action transcribed during the Engineering Design Activity is coded as one of the structures.

4.2.4 Isolated Conversation Contribution (D)

Instances where one of three specific topics of conversation occurs are isolated and captured in short video segments. The first discussion topic of interest is any ECE-related or other technical topic such as power distribution, accuracy of electronic equipment, or configuration of electrical hardware. The second discussion topic of interest includes systems methodology related activities such as defining of requirements, needs or objectives associated with the prototype or its stakeholders. The third discussion topic of interest is the debate of prototype features or performance from both a technical and requirements perspective. The purpose of isolating these events is to understand the contributions of individual students to these discussions (i.e. how SIE students contribute to technical topics or how ECE students contribute to requirements based discussions). In addition to coding using the Individual Statement Analysis coding scheme, these sections of video are also open coded to look for emergent themes. Comparisons between individual students are drawn to determine if students contribute differently given their curricular program.

4.2.5 Survey Response (E)

Any data pertaining to responses to questions by individual students from the assessment surveys is coded as Survey Response.

4.3 Data Synthesis

In this study there are several independent and dependent factors of interest observed in the data to help answer the study research questions. Table 4.3.1 lists the factors of interest with a brief description of each as it relates to the study.

FACTORS	DESCRIPTION
Composition	the composition of the group, possible types are noted in section 4.3
Contribution	the student self-reported list of contributions by each team member including themselves.
Major	the major of student, either SIE or ECE
Program	the curriculum of the student, either TLP or non-TLP
Stages	the 5 design stages described in coding scheme A
Statement	the individual statement or phrase spoken by each student
Structure	the structure of the group or subgroups formed during the design activity
Time	the time spent doing a particular activity.
Topic	the topic of the isolated discussion as described in coding scheme C
Value	the student self-reported answer of whether or not a student felt their contributions were valued by each team member, either yes or no response.

Table 4.3.1 – Description of Factors

Each coding scheme has an independent factor that is the observation of interest for one of the research questions. Each coding scheme also has a dependent factor that is used to explain the occurrence of the dependent factor and answer the research questions. Table 4.3.2 shows the relationship between the factors, coding schemes and research questions.

	QUESTION	CODE	DEPENDENT FACTOR	INDEPENDENT FACTOR
1.0	**How do undergraduate engineering students of differing curricular programs engage in the engineering design process?**			
1.1	How do interdisciplinary teams with differing student compositions distribute their time with respect to the engineering design stages?	B	Time	Composition
1.2	How do individual students from differing curricular programs contribute to the engineering design stages?	A	Stages	Major, Program
2.0	**How do undergraduate engineering students of differing curricular programs participate as members of interdisciplinary teams engaging in an engineering design activity?**			
2.1	When interdisciplinary teams of differing student composition split into subgroups, how do those subgroups contribute to the engineering design stages?	C	Structure	Composition
2.2	When interdisciplinary teams of differing student composition split into subgroups are those groups determined by majors, curriculum or other?	C	Structure	Major, Program
2.3	How do individual students from differing curricular programs participate in situations where interdisciplinary "collaboration" occurs?	A/D	Stages, Topic	Major, Program
2.4	How do individual students from differing curricular programs perceive each student's contributions to the team and project?	E	Contribution, Value	Major, Program
2.5	Do individual students from differing curricular programs value each student's contributions to the team and project?	E	Contribution, Value	Major, Program

Table 4.3.2 – Research Questions and Coding Scheme Comparison

5 Examples of Analysis Application

This section presents examples of coding scheme application to data collected from the engineering design activity of the pilot study. The focus group responses and assessments survey results from the pilot study have not been analyzed. The complete analysis will be completed after a second study is conducted in the spring of 2013.

5.1 Coding Scheme A

The first 40 minutes of statements made by team #1 during the design activity was transcribed and coded using coding scheme A described in section 4.2.1. The results of coding are displayed in Table 5.1.1. It can be seen the majority of statements made during this segment fall under design stage 1 as the students spent a significant amount of time defining requirements and gathering information about the project scope. The significance in this analysis lies in the comparison of the number of statements made based on major. For example, it is significant that Everett, an ECE student, made just as many statements as Scott, an SIE student, in design stage 1. Design stage 1predominantly represents systems-oriented actions and thinking therefore it is significant an ECE student displays the same level of thinking as a SIE student. When all statements made for all six groups have been analyzed the sample size of statements made will be large enough to make significant comparisons between students based on both major and program. For example, a significant observation that could surface is of all the number of statements made in design stage 1, the majority came from SIE students, which would be expected. However, when comparing by program an observation that the majority of the statements were made by CEP students would show there is a difference in CEP and non-CEP students as it relates to systems-oriented conversations.

Pseudo	Major	Program	1	2	3	4	5
Scott	SIE	CEP	23	11	21	11	2
Susan	SIE	CEP	8	10	12	1	0
Eve	ECE	CEP	13	0	4	3	1
Everett	ECE	CEP	26	5	15	1	3
		TOTAL	70	26	52	16	6

Table 5.1.1 Breakdown of Statements per Design Stage per Student

5.2 Coding Scheme B

Team #1 spent the majority of their time working in design stage 4, primarily because of the amount of coding needed to successfully configure the electrical sensors. However, team #1 didn't start spending significant time in stage 4 until after an hour into the activity. The majority of the first hour was spent in stage 1 defining requirements and gaining an understanding of the project scope. Table 5.2.1 shows a breakdown of the percentage of time spent by team #1, the all four CEP student team, in the various design stages. The data presented in this section will help to answer research question 1.1 after completion of a similar analysis on the other five teams.

Time Segment	1	2	3	4	5	9	0
0:00:00 - 0:30:00	0.56	0.13	0.04	0.02	0.15	0.07	0.03
0:30:00 - 1:00:00	0.18	0.02	0.33	0.08	0.00	0.38	0.01
1:00:00 - 1:30:00	0.00	0.00	0.16	0.77	0.07	0.00	0.01
1:30:00 - 2:00:00	0.00	0.00	0.06	0.76	0.16	0.00	0.03
2:00:00 - 2:30:00	0.00	0.00	0.12	0.78	0.10	0.00	0.00
2:30:00 - 3:00:00	0.00	0.00	0.03	0.78	0.19	0.00	0.00
Overall	0.13	0.03	0.12	0.53	0.11	0.08	0.01

Table 5.2.1 Percentage Time Spent per Design Stage per Time Bin

5.4 Example Analysis from Coding Scheme C

Preliminary analysis of team structure shows each team operated differently in terms of how to structure their team during the Design Activity. All teams started in the 4-0 structure for the initial phases of problem definition / gathering information and generating ideas. The difference in team structures emerged when teams moved out of their initial generating ideas phase into the modeling / prototyping phase. Further analysis will be conducted to see whether or not individual majors played a part in how the team structures and tasks decided while split into subgroups. The noticeable team structures that emerged are as follows:

- 1-1-1-1, structure in which each person worked separately
- 2-2, structure in which overall group split into two subgroups
- 4-0, structure in which all four students worked together

5.4 Example Analysis from Coding Scheme D

The following excerpts and analyses provided are from two short video clips of conversations relating to the topics described in section 4.2.4. The discussion topic of the first conversation is ECE-related. The discussion topic of the second conversation relates to systems methodology and the defining of requirements.

The first segment is from a three minute video clip of team 1, the four CEP student team consisting of SIE students Sue and Scott, and ECE students Eve and Everett. This segment is an example a team functioning in engineering design stage 3 and a discussion centered on needs or objectives of the stakeholders associated with the prototype.

SIE, CEP, Susan

So, how are we going to distinguish between the door being opened for some people to add in papers or take them out?

SIE, CEP, Susan

Can we put a touch sensor on the inside in a silly location that no one that no one will think to hit otherwise to say this is to signal being put in?

ECE, CEP, Everett

Well another thing, you can train a person to say press this button when it's filled.

SIE, CEP, Susan

Exactly.

ECE, CEP, Eve

Yeah.

SIE, CEP, Scott

We're detecting papers that are added but are we also worried about the person who takes a paper out then puts it back in the box at the end of the day. Are we concerned with that or only if they took the paper?

ECE, CEP, Everett

My intuition tells me that is not a common problem. I don't think many people put back newspapers.

SIE, CEP, Susan

Well it's interesting that they only want to know how many are taken… however, if they are going to use the information like they say they would they would actually know how many they have when they start… I guess we can assume that they have that information.

ECE, CEP, Everett

Do you have any information; did you say you have studies about, on average, how many papers people take out?

The discussion begins with the team talking about the daily operation of restocking newspapers to the distribution box and how to identify when that happens which leads to Susan's first comment. Susan's follow-up suggestion to incorporate a feature into the design that will signal when staff is restocking the distribution box prompts the comment from Everett about training staff to use the prototype. This instance shows how the team is addressing the perspectives of different stakeholders. Susan is thinking about the staff and how to incorporate staff needs into the design. Everett is thinking one step further, beyond the prototype function into how the design will impact other external client operations such as staff training. Scott's thinking is similar but instead from the perspective of how the customer's actions can influence inaccuracy in data collected by the prototype. The discussion shifts slightly with Susan's last comment which ultimately prompts Everett to ask about the information presented in data set B, information observed on how many papers are disbursed when the distribution box is opened. While Eve is not as verbally active during this segment as the other students, the video suggests she is clearly engaged and understanding of the topic being discussed. The statements made during this segment by Susan, Everett and Scott, in which the needs of multiple stakeholders are considered and the system boundary extended well beyond the physical system, directly relate to content taught in systems engineering curriculum. However, it is seen the ECE students are engaged in this systems-oriented discussion. The significance of this segment is in the collaborative interactions seen between both the SIE and ECE students during this discussion most closely related to a single discipline.

The second segment is from a four minute video clip of team 2, consisting of SIE students Seth and Sidney, and ECE students Ervin and Erin. This segment is also an example a team functioning in engineering design stage 3 but their discussion is centered on the accuracy of the electronic equipment used for the prototype.

ECE, NON, Erin	
	Do you think we can use the accelerometer, not for opening and closing of the door but to figure out how many papers are in the box? Because when someone puts in the papers initially they know how many they put in, or they should know. We should find out. And our information that we need to figure out is when and how many.
ECE, CEP, Ervin	
	How precise of data do you need, so you want to know at what time how many newspapers get taken, do you need data that says most of the papers were taken in the morning or 53 papers were taken in the morning?
Sunapee Client	
	Be as precise as you can, I'm leaving it up to you and your professional opinion but be as precise as possible.
ECE, NON, Erin	
	Do you have any information on how any newspapers are taken per open?
Sunapee Client	
	Yes.
ECE, NON, Erin	
	That's what we need, we can use this for our assumption and then just go with the touch sensor.
Sunapee Client	
	(Provides data set B to team.)
ECE, NON, Erin	
	So we might want to assume one is taken at a time because its an 87% percent chance and maybe if they want to further analyze whether it's a child or how many papers are getting taken then they

	can conduct another study. Ours is only to figure out how many newspapers.
ECE, CEP, Ervin	
	So my thought is, the question is do we actually need to know exactly how many papers are being taken, because if we don't…
ECE, NON, Erin	
	We can always find out when the maximum frequency is happening because all we need is a time and when the amount of newspapers…
ECE, CEP, Ervin	
	So what is this data going to be used for?

Erin's comments suggest her thought process is centered on solving the given problem where Ervin's comments suggest he is trying to develop the root cause of the problem. This difference is notable in the way both students ask questions of the client. Ervin's question about what the data will be used for suggest he is trying to flush out the problem by using the inherent knowledge of the client whereas Erin's questions are focused on documented information. Ervin's comments also suggest he has decided precision is an important component of the prototype design as his initial comments relate to precision. Ervin's display of actions and thoughts are representative of a systems engineering approach, using client knowledge to better determine what the root problem is not just to solve the problems given to them.

The significance in this segment is the engagement of both ECE students in this technical-oriented discussion. However, the major difference is in Ervin's thought process and ability to approach the problem from a systems-oriented approach. This type of behavior is not expected from a traditional ECE student but expected in CEP ECE students such as Ervin. Although both students ultimately reached the same conclusion, they worked in parallel as opposed to collaboratively as seen in the first segment.

6 STUDY LIMITATIONS

The pilot study experienced several limitations that may have influenced the outcome of the data. Each limitation was mitigated as much as possible for the pilot study. Additional changes will be made to future studies to decrease the influence of those limitations.

6.0.1 Thinking Aloud

The act of participants thinking aloud can influence the work of each individual. This act is abnormal for participants not used to working on a team. From pilot study observations, abnormality can be inferred in the number of times where extended periods of silence occur and participants are reminded to continue thinking aloud. Validity for the verbal protocol analysis used in the engineering design activity was established in a previous study conducted by Ericsson and Simon[4]. 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. Also, when one participant thinks aloud it can hinder another participant from doing the same since two people generally do not talk at the same time in a group. This can also deter a participant who has a similar thought from expressing it or cause another participant to change their thoughts before expressing them.

6.0.2 Assignment

The assignment presented in the Design Activity was selected because it best mirrored similar group assignments conducted in the Technology Leaders Program. A tradeoff between time allotted, reality of problem and material suitable to majors involved was considered when selecting an assignment. The assignment selected is simple, does not require specialist knowledge and is solvable in the given timeframe. A more complex assignment could uncover further differences between participants by fostering more collaboration and requiring the use of specialist knowledge by participants.

6.0.3 Environment

The environment in which participants work in is a classroom. Although a classroom is not uncommon to participants, it may be an atypical environment for participants to conduct this nature of work. Participants are also limited to the materials provided to them for the study. Participants do not have the opportunity to observe the object of the assignment in its natural environment which can limit their thought process.

6.0.4 Subjects

Although all participants are from one of two majors, each participant's curriculum and educational training varies slightly. Some participants are more familiar with the materials provided than others which may lead those individuals to take on certain roles and tasks during the activity. The wide range of participant Grade Point Averages (only known to the researcher) can influence individual actions of participants. Table 6.0.4 shows the breakdown of GPAs by group.

GPA Range	**G1**	**G2**	**G3**	**G4**	**G5**	**G6**
0.00-2.49		1	1			1
2.50-2.99	1	1			2	1
3.00-3.49	1	2	3	3	1	2
3.50-4.00	2			1		

Table 6.0.4 Breakdown of student GPAs by Group.

Participants from the Technology Leaders Program may have prior coursework experience working together in groups. The TLP students also are also self-selected into the program meaning each student chose to participate in the program. In addition, the TLP students of the pilot study had experience using the same hardware and software in prior coursework. The TLP students of the upcoming spring study will not have used the software or hardware in their prior coursework. Also, one participant was a prior student in the Technology Leaders Program for three semesters before leaving the program. This participant was coded as a non-TLP student. Her prior involvement in the Technology Leaders Program may have influenced her actions taken during this study. Another participant was a TLP student majoring in Computer Science. Her statements were coded as a TLP student but not as an ECE student.

Also, there exists the Demand-Characteristic Effect (citation) which says participants may "form an interpretation of the experiment's purpose and unconsciously change their behavior to fit that interpretation." This theory may be applicable to the Systems Engineering participants who may act atypical due to belief the Engineering Design Activity is heavily electrical and computer engineering focused.

6.0.5 Parallel Events

There are periods where parallel events will occur. For example, two participants can be constructing materials in the distribution box while two students are coding or two participants are coding, one participant is testing electrical sensors while one participant is sitting quietly. Concurrent events can affect the coding of groups based on design task and also make it difficult to hear all conversations. The coding of concurrent events is addressed in the description of each coding scheme affected (section 4.2.2).

7 SOURCES

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8 APPENDIX

8.1 Design Activity Prompt

Introduction

The **Sunapee Daily**, with its 120+ history, is undoubtedly a big SSU tradition, as noted by the following from www.cavalierdaily.com:

> *"Founded in 1890 under the name College Topics, The Sunapee Daily is the independent daily newspaper at the Sunapee State University. The Sunapee Daily is Sunapee's oldest collegiate daily and the oldest daily newspaper in the area. Since the summer of 1996, The Sunapee Daily has been the only daily newspaper at the University, with a print circulation of 10,000 distributed on Grounds and in the surrounding area. The Sunapee Daily is an entirely student-run, non-profit organization with an operating budget accrued solely through advertising."*

Despite claims of reaching over 10,000 people per day, a recent study found that an average of only 3,800 print copies are removed by readers from distribution points each day. In order to better understand the distribution of its papers across campus, the Sunapee Daily would like to know more information about the time and amount of newspapers picked up throughout the day. They have hired your team to construct a mechanism that records the time each newspaper is taken and the amount of newspapers taken at that time. The mechanism should be easily attachable to the distribution box, not hinder the consumer in anyway and allow for easy extraction of the data recorded by the mechanism. From this data the Sunapee Daily hopes ultimately to create an optimal distribution plan to reach more readers (and consequently be able to increase the price of ads) but also, being an environmentally responsible organization, avoid any outcry over the huge number of papers recycled each day.

Project Details

For ease of prototyping the Sunapee Daily has provided an exact replica of their distribution box along with a stack of old newspapers. Your team will also be provided with a mixture of hardware (i.e. electronic sensors, microprocessors, analog to digital converters, etc) to complete the task. The hardware provided are the only materials the Sunapee Daily will use for mass production of your finished prototype. In addition, to save time in designing your prototype, your team will be provided with a laptop that can be connected to the system. However, as a team, do your best to consider a realistic situation where leaving a laptop with the distribution box is not an option and there are no power sources available for use. Your end product should be a standalone mechanism that can be constructed inside of one distribution box for a minimum period of 3 days. However, your priority for right now is to create a demo prototype using a laptop and power source if necessary. Also, an important part of this prototype design is the ability to easily extract the collected data. Your prototype should allow for the Sunapee Daily staff to easily obtain and view the data for analysis. Assume you have a maximum budget of $100 to produce one prototype.

8.2 Data Set A: Additional Information: SunDaily Distribution Data

You are provided with data from a previous one-time study of 70 distribution points during 4 business days. The data shows the number of papers at 8:00a and at 5:00p. Based on prior studies, roughly 75% of papers (that are to be taken) are taken by 1:00p and 90% are taken by 4:00p. The data included is actual data collected by Sunapee Daily staff over a year ago and as such, it is not perfect. SSU Recycling recycles papers sometime late in the day (the exact time is not known). If a distribution point is listed as empty at 5:00p, there is some chance that this is due to the papers being recycled, not due to readers picking up the papers. Any other information needed will be provided upon request from Sunapee Daily.

8.3 Data Set B: Additional Information: Data on Why Distribution Box Opens
****(Based on 5 hours of observation at two distribution points)*
87% - one newspaper is taken
5% - nothing is taken, sometimes due to no newspapers left in the box

- Of this 5%, 80% of consumers eventually went to another box that same day

4% - more than one newspaper was taken
3% - Other

- A consumer put back a newspaper.
- A consumer accidentally let the box close before grabbing a newspaper, so reopened the box to grab one.
- A child or someone is playing around with the door.

1% - someone restocking or collecting newspapers for recycling.

8.4 Focus Group Questions

- What was your team's overall strategy for approaching this activity? Describe the process of how your team went about finding a solution.
- How did your team go about dividing the work needed to be done for this activity? How did you decide who was responsible for what?
- What difficulties did you find, if any, with working on this team for this project?
- Why do you think you were or were not successful in designing and building a working prototype? How do you know?
- If you had to start over what about your approach would you change? Why?
- Did you incorporate knowledge learned through classes for this activity? How so?
- What do you think a group of your peers who are not in the CEP would do differently in this study?
- Does this distinction between interdisciplinary / multidisciplinary help you characterize how your team worked?
- Please reflect on the multidisciplinary / interdisciplinary. What are the strengths or weaknesses of each?

8.5 Assessment Survey Questions

- What was your role on your team on this project? In what way did you contribute to the team and project?
- How do you feel about your contributions to the overall project?
- How do you feel about the relative contributions of each student (including yourself) on your team to this project?
  - 1 - Little / No Contributions
  - 2
  - 3 - Expected Level of Contributions

    - 4
    - 5 - Significant Contributions
- On your team, who had the hardest work on this project?
- On your team, who had the most important work on this project?
- How do you think the students NOT in your major feel about your relative contributions to this project?
- What was each student's role on your team on this project? In what way did each student contribute to the team and project?
- How do you think the students NOT in your major feel about your relative contributions to this project?
    - 1 - Little / No
    - 2
    - 3 – Moderate
    - 4
    - 5 – Significant
- Did each of the students appropriately value your contributions to this project?
    - No, s/he undervalued my contributions.
    - Yes, s/he valued my contributions appropriately.
- What range does your GPA fall into?
    - 2.49 or below
    - 2.50 - 2.99
    - 3.00 - 3.49
    - 3.50 or above
- What other materials or information would have been helpful for you to complete this activity?