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Examining the Engineering Design Process of First-Year Engineering Students During a Hands-on, In-class Design Challenge.

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Abstract

Engineering design has universally been identified as essential to the practice of engineering. As institutions of higher education seek to improve their undergraduate engineering programs, significant attention has been directed to how to develop and improve students' engineering design practices. This effort often starts in first-year courses as it is coupled with initiatives to retain students. This paper presents both the adaptation of an existing methodology to study design practices to accommodate an in-class design challenge and initial results from the implementation of that methodology to study groups of students in a first-year LEGO robotics-based engineering course at Tufts University. Preliminary results show students engaged in limited problem scoping and information gathering. These results add to differing results about the practices of first-year engineering, suggesting that context may play a large role in how students invoke design practices. Results also indicate that the majority of time was spent in physical construction and management of group communication. The implications of both of these findings are discussed with respect to instructional design for first-year students along with directions for future research and methodology refinement.

Introduction

The release of the new ABET[1] standards in 2000, and the release of the Engineer of 2020[2] and Educating the Engineer of 2020[3] reports as well as feedback from industry have prompted many universities to evaluate and redesign their undergraduate curriculums. With national leaders calling for increased graduation rates of engineers, many schools are examining retention and transition into engineering school of their first-year students.[4,5,6] With this trend, Tufts University has been rethinking its first-year engineering experience by introducing a set of introduction to engineering classes focusing on building excitement about engineering, working on project-based problem solving, teamwork and leadership, disciplinary content, and an idea of the "engineering roadmap." This study examines first-year students solving an engineering challenge in one of these first-year courses entitled "Simple Robotics".

The engineering design process is an integral part of any engineering curriculum and a necessary aid to solving engineering challenges in university courses and engineering practice. Numerous studies have examined the way in which a range of participants, from young children to expert engineers, solve engineering problems.[7,8,9,10,11,12,13,14] This study builds on that literature by examining the design practices of first-year engineering students in the classroom, a context that has received less attention to date. This paper aims to show development of a methodology to examine in-class design projects that will help to explicate how beginning designers work in these contexts and if students are engaging in activities that match the learning goals of the project. With some revision, this may be used as a tool to evaluate projects to determine if students are actively engaging in the intended learning experiences.

Studies of first-year engineering students have predominantly focused on retention and achievement. This has been assessed primarily through the use quantitative data in the form of course grades,[15] course evaluations,[16] and surveys[5,4,6] over a number of years to evaluate the impact of courses or mentorship programs. This study looks to understand first-year students' design practices and group work by studying two groups working on an in-class design and build challenge though qualitative analysis of video data with quantitative summaries.

In this study we adapt the Design Activity coding scheme developed by Atman et al[12] and the addition of Design-Related Conversational moves developed by Wendell[17] to allow for the examination of how groups with multiple participants engage in engineering design when they are tasked with producing a physical artifact to meet a challenge. Our analysis using the revised methodology examines how these first-year students' engineering design practices align with results from previous studies of novice designers or first-year engineers and examines dynamics that may be particular to in-class and hands-on projects.

Literature Review

Previous studies of engineering design practices focus on the trajectory of learning engineering design and capturing a single engineer's design process. A number of studies characterize behaviors of beginner to expert designers. For example, Cross[7] found novice designers chose one solution and work on altering it until it's workable, unable to abandon their first design and start over on what could be a potentially better concept. Crismond and Adams[8] also report in their review of the literature that many studies have found that novice designers oversimplify the problem and begin working on solutions immediately while more informed or expert designers take time to understand and gather information about the problem before they begin working on solutions.

This study builds on a specific body of literature examining how engineers use the engineering design process to solve complex open-ended design problems using the Design Activity coding scheme[10,11,12] in terms of both methodology and results. The Design Activity coding scheme was developed based on verbal protocol analysis (VPA)[18] and asks research participants to verbalize, or think out loud, while completing a design task. A number of studies[19,20,21] have used this method to deconstruct and understand the design process. These studies ask participants to solve conceptual design tasks in a laboratory setting and most are structured as individual tasks.

In addition to VPA and the coding scheme, Atman et al.[10] measured time devoted to the task as well as step of the design process, the number of transitions between design steps, the number of requests for information, the number of alternative solutions developed, and rated the quality of each participant's final solution.

In Atman's 1999 work,[10] freshman and seniors were asked to conceptually design a playground. Freshman spent most of their design time modeling, developing the details of their design, analyzing, and evaluating. They spent little of their time problem scoping, gathering information, and generating ideas. The researchers rated each of the students' designs and found students who progressed through the design steps and spent time evaluating had better designs. The seniors also spent most of their time developing solutions and a small part of their time problem scoping.

In Atman et al's 2005 work,[11] freshman and seniors were asked to complete two shorter conceptual design challenges. The two different challenges provided two different sets of results. In both challenges, freshman spent the greatest amount of time problem scoping followed closely by constructing the details of their design. These two tasks dominated their time and little energy was spent on other parts of the design process. The seniors evenly spent time problem scoping and modeling but spent the greatest amount of time working on the details of their design. Both populations spent almost no time making decisions or communicating their solutions to outside parties.

Atman et al's 2007 work[12] compares the results from the freshman and senior study to expert engineer's design processes when solving the playground conceptual design challenge. In contrast to the freshman and seniors, expert engineers spent a significant amount of time problem scoping, making decisions, and communicating their results. Their problem solving was more evenly distributed over the different stages of the design process and took more overall time to solve the problem.

These studies all suggest that first-year students' engineering design practices are different from experts. However, there is little consensus about what is particularly problematic about their practice and how it can be scaffolded to greater levels of expertise. Our study looks carefully at the design practices in a classroom to begin to unpack the variables of first-year students design practices. Moreover, previous studies focus on single individuals engaged in conceptual design (no artifact is produced) and hence provide information about one kind of design experience. This study looks to develop a methodology that studies engineering design in a team context (multiple individuals) where a physical artifact is being produced.

Class Context

"Simple Robotics" is one of eight introductory engineering courses offered at Tufts University. While still delivering traditional technical content, these courses differ from other engineering "overview" or "introduction" courses due to the simultaneous inclusion of several additional key aspects: (1) emphasis on topical ideas, illustrating the creativity and excitement of engineering, incorporating cross disciplinary work; (2) opportunities for project-based, problem solving tasks, with students working in teams and ideas of leadership and collaboration explored; (3) inclusion of at least one sophisticated engineering software package/tool for design or computation; (4) addressing engineering ethics and societal context in addition to the engineering math and science; and (5) understanding of the "engineering roadmap" regarding engineering education (specifically addressing opportunities at Tufts University) so students could recognize the available pathways beyond the first semester.

"Simple Robotics" is an evolution of a previous course[14] taught throughout the last decade that leverages the LEGO MINDSTORMS robotics toolset (originally RCX and more recently the NXT) as well as the LabVIEW graphical programming environment to introduce students to a variety of engineering topics: from mechanical and structural to electronics and computer engineering to programming and computer science. Leveraging project based learning (PBL) pedagogies, weekly challenges have students working in small groups (from partner-pairs to larger groups depending on scope of particular assignments) not only implementing the technical content in the form of their robotic designs, but learning to negotiate team dynamics, develop presentation skills, and apply iterative analysis and reconstruction to their creations.

While the projects vary for any particular year, they fall into a few similar categories each time the course is taught: from "competition" style formats (soccer, maze solvers), to less "score-based" evaluations but with emphasis on problem-solving and system analysis (robotic bubble blower, interactive video game), to design-based developments (robotic animal, miniature golf course, haunted house). With attention to diversity of solutions throughout the classroom, and leveraging opportunities for peer-to-peer learning, another category focuses on creating visual art or performance-based presentations (robotic dance, musical instrument, puppet show) with the robotics platform. Through providing an assortment of robotic assignments in a large array of contexts, opportunities exist for a wide range of different learners to engage throughout the semester, as well as the ability to emphasize creativity and innovative design as a key component in robotics and engineering in general.

The project examined in the following data is the "Candy Push" assignment, which is a derivative of a robot-sumo style competition found in other robotics courses. For the fall 2013 semester, the "Candy Push" in-class competition fell half way through the semester (mid-October). Back on the first day of class (early September), the students self-assigned into pairs to work through the first several projects. Mid-semester, the pairs of students were randomly combined into larger groups of four to six. The "Candy Push" project was the second project in which these students had been working together in their larger group configuration, after the four earlier projects completed as pairs. In the implementation studied here, the small groups of students were limited to two LEGO MINDSTORMS NXT Education Kits (no additional external materials allowed) to create a remote-controlled robotic vehicle that would collect as much candy as possible from within a circle of tape on the floor. Any candy collected by the car or pushed outside the circle is kept by the team, but the robot is eliminated from the competition if the car fully leaves/exits the circle. Four teams compete simultaneously, and the competition goes until all robots have been eliminated or until the judge (e.g. class instructor) determines the round is over. Prior to coming to class, the students knew they would be doing something related to a remote control car (and so had pre built a simple car and communication system), but only received the details of the assignment (about the candy, circle, rules, etc.) at the beginning of class. At that point, the groups had a total of 30-minutes of development to modify their hardware and software, test out their modifications, and be prepared for the in-class competition.

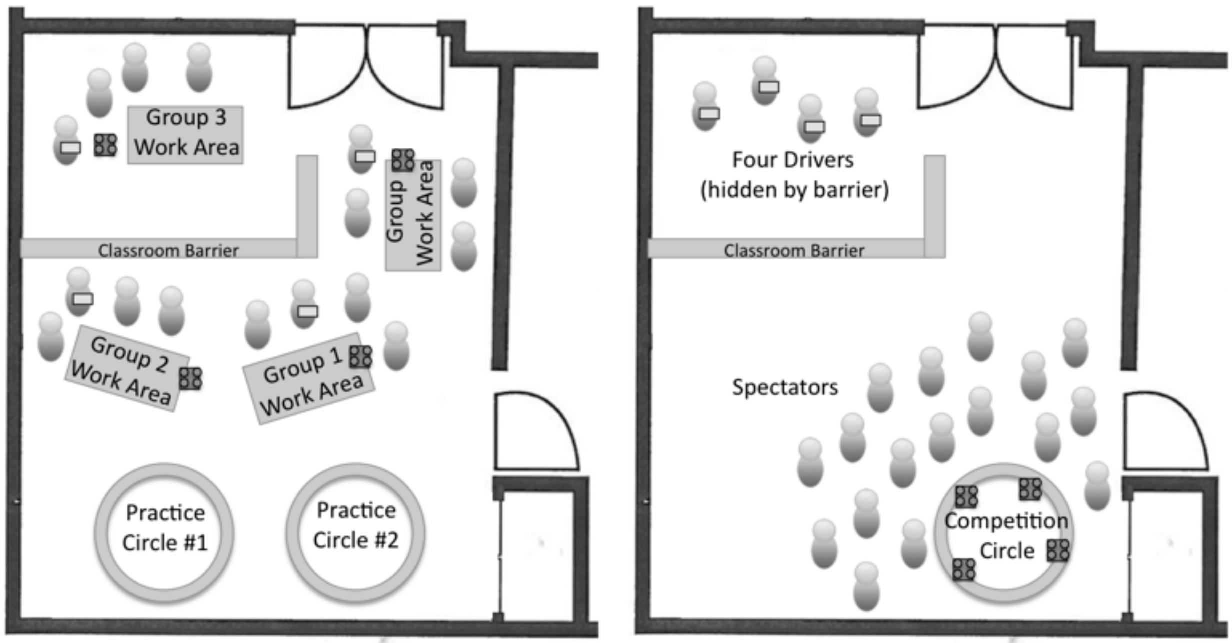

FIGURE 1: Classroom diagram showing development (left) and competition (right) setups. (Note: additional group work areas were in a separate room for additional student groups.)

The competition area was created using white masking tape on a black floor. The size of the circle was approximately 5-feet in diameter. A wide selection of standard candy was used, ranging from Starbursts, Smarties, and Tootsie-Pops to "fun-sized" Skittles, Milky-Ways, and Snickers. These were placed randomly in the middle of the circle, and each robot was required to start at different points along the edge of the circle at the beginning of each round of competition. One addition to the challenge was that the driver of the car would be remotely located and not able to visually see the car driving during the competition (in a different part of the room behind a classroom barrier separator). As such, there was extra emphasis on sensor use: both in communicating between robot and driver, and also in understanding and interpreting sensor data to understand the position/orientation of the robot.

For the "Candy Push" competition, typical robot implementations across the class included a standard car-base (two wheels, capable of going forward/backward and turning) equipped with a light sensor pointing downward (for detecting the edge of the circle) and some "snow-plow" style addition on the front of the robot for collecting candy. Some groups added a second light sensor (from the second NXT kit) to the other end of the robot, so to be able to detect the edge of the circle on either end of the robot. Some groups varied the size/shape of the snowplow (examples in Figure 2), although bigger was not always better as it becomes more difficult to build structurally sound plow and can become caught/hung-up on other robots during the competition.

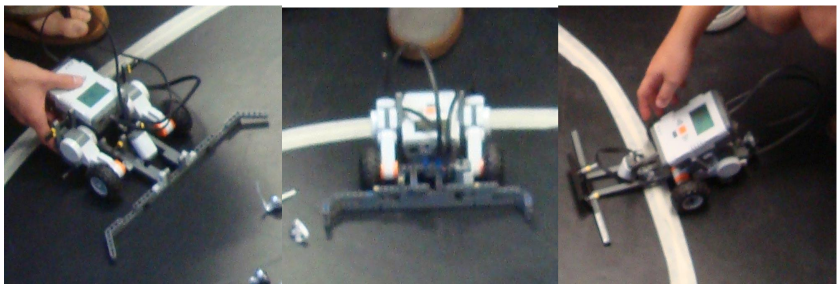

FIGURE 2: Examples of “Candy Push” Robots

Data Collection

For this study, the entire class of 31 students was solicited to participate in the research study. Tufts University is a selective (acceptance rate of 20%) private university in the Northeast with a first-year population of 225 engineering students. The two groups of students selected for this portion of the study were a sample of convenience as every group member consented to be filmed for research and the collected data was audible for transcription. Each of the two research groups had four participants: Group 1 had 4 males, Group 2 had 2 females and 2 males (other groups had four to six students). The research groups contained a representational cross section of students within the class based on class rank (calculated from their final grades at the end of the semester). Table 1 shows the class rank of each group member and the mean rank (with standard deviation) for each group, to provide comparison across the class.

TABLE 1: Table of class rankings for students in research groups (Group 1 & 2) and other class groups (Groups 3-7). *Individual ranks are not reported for some students in groups 3-7 as those students that did not consent to participate in the study.*

	Group 1	Group 2		Group 3	Group 4	Group 5	Group 6	Group 7
Student #1	4	2*		2*	7	-	10	1
Student #2	13*	6		-	10	15	-	5
Student #3	25*	19		22	15	-	24	-
Student #4	29	25*		27	-	-	-	9
Student #5	n/a	n/a		n/a	30	n/a	n/a	20
Student #6	n/a	n/a		n/a	-	n/a	n/a	n/a
Mean rank	**17.8**	**13.0**		**16.0**	**19.0**	**16.0**	**20.0**	**8.4**
Std. dev.	**11.41**	**10.80**		**10.98**	**10.10**	**4.97**	**7.83**	**7.13**

*students tied in rank with other members of the class

The average rank of the students within the three groups studied is comparable to the other groups of students within the class. The standard deviation of these groups is slightly higher, indicating a little wider range of individual student performance in these groups.

The two groups were video taped during their classroom preparation for the "Candy Push" competition. External lavalier microphones were placed on each group's table to capture the groups' discussion.

Methodology Development

To date, a methodology has not been developed that analyzes students' engineering design practices in a group setting where a physical prototype is being developed. For that reason, we started from the existing Design Activity coding scheme[12] and looked to modify it to meet the needs of studying this group-based, in-class design challenge that resulted in a physical artifact.

To begin, video of each of the groups during their in-class work on the "Candy Push" challenge was transcribed. Each video was approximately thirty minutes in length. From the transcription, each group's discussion was divided into utterances, usually when a new speaker began speaking or the individual transitioned to a new design practice. For this study, we chose to code only the first eleven minute while students were actively designing their robot in a fixed physical space, prior to moving to the testing spaces located elsewhere in the room.

We then applied the existing Design Activity coding scheme,[12] which analyzed the utterances of a single participant involved in conceptual design and the Design-Related Conversational Moves added by Wendell[17] to accommodate a larger group discussion of a conceptual design. As we began coding, we found due to the in-class (where instructors and teaching assistants were present) and hands-on nature of the task (students are building with physical pieces), we needed to add three new codes to the scheme to account for building and programming and instructor-student interactions.

The Making (MAK) code was created to capture the talk about building or programming that was not connected to other design activity in previous work -- discussion about finding pieces, putting pieces in a specific location, finding a particular programming component, or connecting the LEGO NXT to the appropriate cables.

The Group Discussion (GRO) code was created to identify conversation pieces in the group that included students organizing themselves, transitioning between tasks, and planning their next design steps. Previous work included codes for making design decisions and communicating design ideas but didn't include codes for students working collaboratively in a busy classroom.

As this task took place in a classroom setting where instructors and teaching assistants were present facilitating the task, the Instructor Explanation (IEXP) code was created to identify instructor and teaching assistant talk.

With an initial revised coding scheme in place, two researchers coded a segment of data looking to establish inter-rater reliability. Inter-rater reliability was found to be only 36% so the researchers revisited and revised the coding scheme definitions. The challenge of students making and designing at the same time necessitated addition clarification and expansion of the code descriptions and examples. The final coding scheme, tentatively titled Engineering Classroom Discourse Analysis, adapted from Atman et al[12] and Wendell,[17] is show in Table 2.

TABLE 2 : Coding Scheme for Engineering Classroom Discourse Analysis (Adapted from Atman et al., 2007 and Wendell, 2013)

Design Activities

Code	Name	Definition	Example from "Simple Robotics" Classroom Transcripts
PD	Problem Definition	Defining what the problem really is by re-stating the problem statement, identifying criteria and constraints, or re-framing the problem.	"Are we even allowed to use this many pieces?"
GATH	Gather Information	Stating the need for, searching for, asking for, or collecting additional information needed to solve the problem.	"I mean, we can test the shade because if we have the, look, if we have the shade. We'll check, we'll test it."
GEN	Generate Ideas	Stating potential solutions (or parts of potential solutions) to the problem, and playing with and fleshing out those ideas. Involves the use of tentative language and suggestive tone.	"Um, let's see, if we do it this way we can reinforce the top more but it's harder if its over out here, you know."
MOD	Modeling	Detailing how to build the tentative or final solution (or parts of the solution) to the problem. Involves making estimates, calculations, or fitting an element into the overall design. *Building or making should be coded MAK.*	"Yeah, you need this curved in, not out."
MAK*	Making*	Discussing making and building without reference to conceptual design ideas. Includes placing and finding pieces while building, or taking in and out pieces of code.	"We can use these black pegs."
FEAS	Feasibility Analysis	Passing judgment on whether a possible or planned solution to the problem (or parts of the problem) will function and meet the problem's criteria and constraints.	"Actually, I don't know if that's gonna work because sometimes the little pegs like come through."
EVAL	Evaluation	Comparing and contrasting alternative solutions or solution elements, along a particular dimension such as strength or cost. Also, testing a design, making observations about it's performance, and accessing results.	"I think that's just too heavy."
DEC	Decision	Selecting one solution to the problem (or parts of the problem) from among those considered, or eliminating a design option or explicitly changing one's mind about the solution.	"We actually don't even need the backwards loops. So we can actually take that out."

COM	Communication	Communicating to external parties (professors and teaching assistants) the elements of the design via oral discussion or physical presentation. decided-upon design, via sketches, diagrams, lists, or oral or written reports.	To the professor “No, um it's LoggerPro, but we're using LabVIEW for human factors. We have a LabVIEW thing. Ummmm…”

Design Related Conversational Moves

REV	Revoicing	Restating one's own or other's idea related to the engineering task to affirm or check understanding.	Speaker 1: "FYI, it's not a uniform circle whatsoever." Speaker 2: “Really, it's totally irregular?" Speaker 1: “It's like egg-shaped."
REQ	Request	Requesting further clarification about an idea, model, design detail, or a response from others about an idea; *not used for requests about instructor's intent.*	“So you want it behind the wheels?”
AGR	Agreement	Without restating, acknowledging understanding of an idea or expressing favorable response. *If favorable response labels a particular discussion of the problem, should be coded EVAL.*	"Yeah, that's true, yeah."
DIS	Disagreement	Expressing disagreement with other's statement or general unfavorable response to an idea, without feasibility analysis.	“Uhh I don't think so…”
GRO*	Group Discussion*	Conversational moves within the group. Specifically transitions, planning, and asking questions (but not requesting information).	"We will be testing in 2 seconds."
INT	Instructor’s Intent	Discussion of the instructional requirements rather than the engineering task; request for clarification about what the instructor has assigned.	“Okay. Let's check. Does anybody have the paper? Oh wait we didn't have instructions.”
IEXP*	Instructor Explanation*	The instructor explaining a concept, their understanding of a design, or any other relevant comments by the instructor.	"Right, right. So somehow you're sending a value to port 3 which is getting driven to this and you're sending to mailbox 2 a new value which is getting driven into this.”
OTH	Other	Conversation not relevant to the problem being solved; none of the other codes apply.	"This is gonna be so hard."

*Indicates codes developed by the authors

Data Analysis

With the final coding scheme in place, the two researchers each coded the designated segments of the two research groups. Inter-rater reliability was found to be 47% for the first group and 51% for the second group. The researchers then discussed the discrepancies in their coding and came to consensus on each segment for both groups. Their consensus coding results are presented in subsequent sections.

Results

Distribution of design tasks types

Table 3 shows the percentage of utterances that the two groups had in each of the design activities categories. Tables 3 & 4 together represent the total activity for each group over the eleven minutes segment (the summation of all the coding categories from Tables 3 & 4 adds to 100% for the individual groups).

TABLE 3: Percentage of Engineering Design Activities for each group and average across groups.

	Group 1 180 utterances	Group 2 153 utterances	Average
Problem Definition (PD)	1.7%	1.3%	1.5%
Gather Information (GATH)	2.2%	0.0%	1.1%
Generate Ideas (GEN)	6.7%	3.9%	5.3%
Modeling (MOD)	6.7%	3.9%	5.3%
Making (MAK)	16.1%	20.9%	18.5%
Feasibility Analysis (FEAS)	5.6%	6.5%	6.0%
Evaluation (EVAL)	7.8%	5.9%	6.8%
Decision (DEC)	2.8%	2.6%	2.7%
Communication (COM)	0.0%	1.3%	0.7%

The table shows that in this hands-on task the overwhelming activity was around the actual construction of the robot and its program (Making - MAK). These Making statements are mostly about the physical construction of the object vs. conceptual discussion of how they would design it or how it would function.

Feasibility Analysis (of ideas) (FEAS) and Evaluation (of comparative ideas and their actual artifact) (EVAL) were the next most common design practices identified followed by Generation and Modeling (of ideas)(GEN/MOD). Decision making (DEC) was minimal. This may be an issue with dynamics of the group discussion and/or the sensitivity of the coding scheme as decisions were made (as the coding scheme did not detect physical modifications to the robot made by a single group member that were not discussed). There was minimal Problem Definition (PD) or Gathering Information (GATH) that occurred as students hurried to finish their device under existing time constraints. Communication (COM) was also rarely seen except when students spoke with the instructor or teaching assistants.

Distribution of conversational moves

Table 4 shows the percentage of utterances that the two groups had for each of the conversational moves.

Table 4: Percentage of conversation moves for each group and average

	Group 1 180 utterances	Group 2 153 utterances	Average
Revoicing (REV)	1.1%	0.7%	0.9%
Requesting (REQ)	11.1%	14.4%	12.8%
Agreement (AGR)	11.1%	11.1%	11.1%
Disagreement (DIS)	4.4%	1.3%	2.9%
Group Discussion (GRO)	8.3%	6.5%	7.4%
Instructor's Intent (INT)	0.6%	1.3%	0.9%
Instructor Explanation (IEXP)	3.9%	9.8%	6.8%
Other (OTH)	10.0%	8.5%	9.3%

Requesting information or clarification (REQ) was the most common utterance followed by agreement (AGR) and group discussion (GRO). This suggests that much of the design time is spent in understanding group members (requesting information) and organizing the activity of the group. These conversational moves (REQ, GRO, AGR) were more prolific than the majority of the design activities with the exception of making (MAK) indicating that there is significant time and energy devoted to just communicating and achieving understanding within a group. There was a small percentage of disagreement (DIS) relative to other categories. Groups had interactions with the instructors or teaching assistants about issues with their design that are reflected in Instructor Explanation (IEXP) counts.

Patterns of interactions

Figure 3 and Figure 4 show the coded utterances graphed versus time for each group.

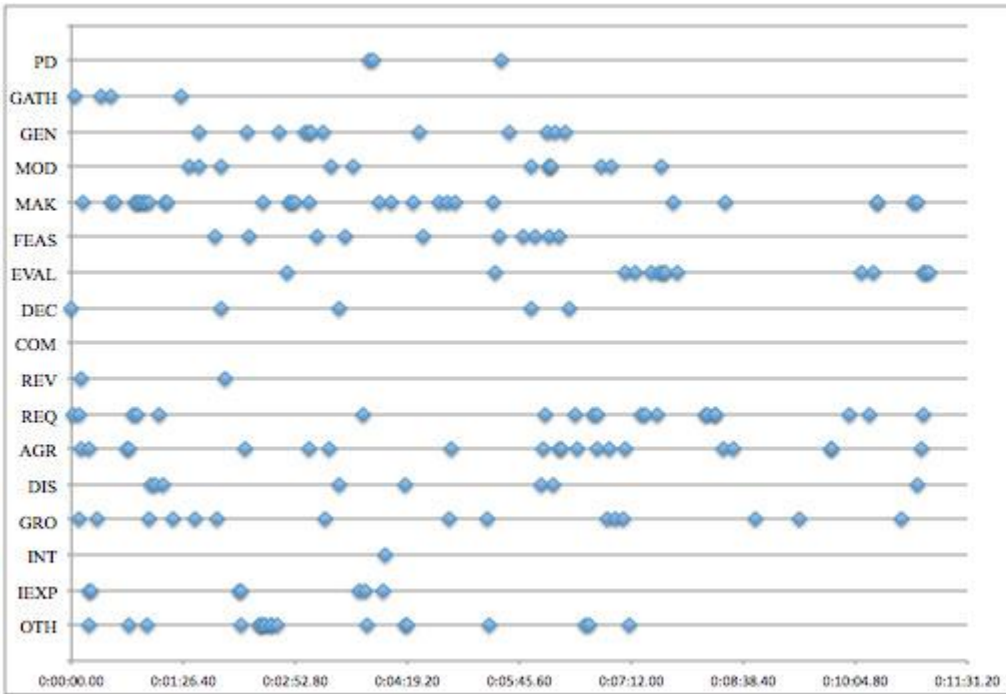

FIGURE 3: Group 1 Design Activities and Conversational Moves (180 utterances). X axis is time [Hours:Minutes:Seconds.Fractions]. Y Axis is Design Activity Codes.

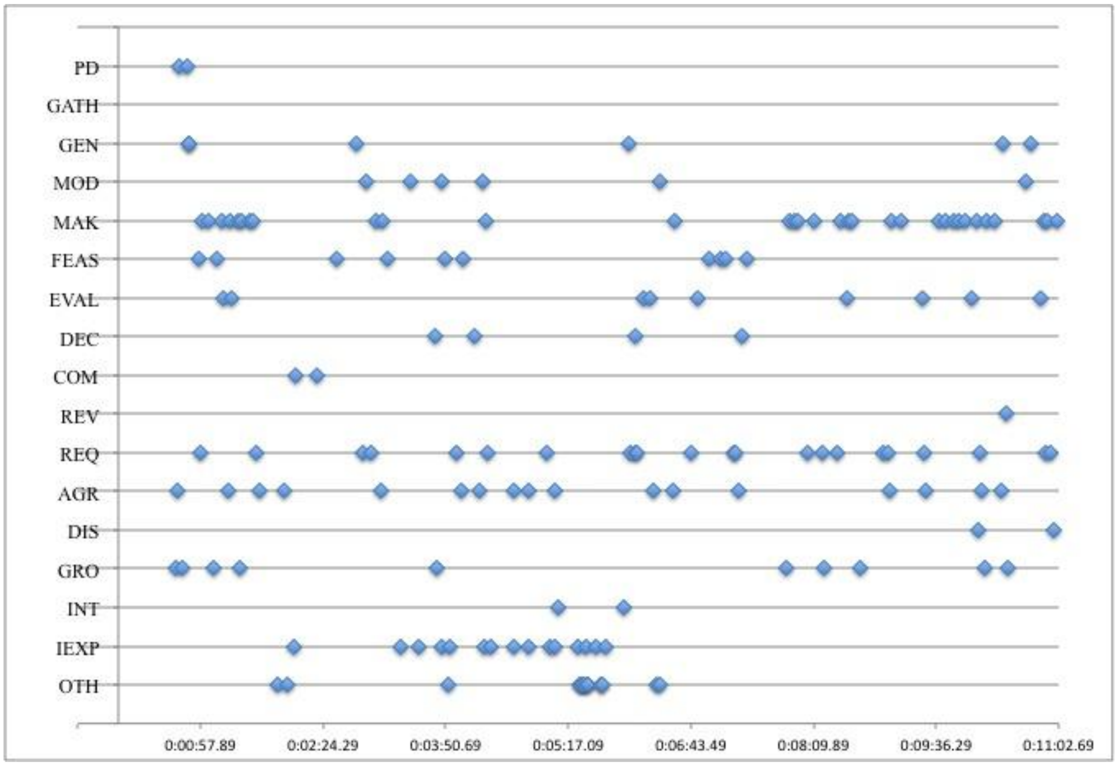

FIGURE 4: Group 2 Design Activities and Conversational Moves (153 utterances). X axis is time [Hours:Minutes:Seconds.Fractions]. Y Axis is Design Activity Codes.

The graphs help to visualize the distribution of utterances divided between conversational moves and engineering design moves. The moves are divided fairly evenly - on average 47% of the groups' utterances were classified as engineering design activities and 53% were on conversational moves emphasizing how much work goes into communication during a collaborative group project. They also show that while the percentage of responses of groups was fairly similar (shown in Table 3 and 4), the distribution of those responses in time varied. For example, we see in Group 1 (Figure 3) that a majority of their making (MAK) was done in the first few minutes while Group 2 did some initial making (MAK) and after some interactions with instructors (IEXP) did additional making in the last minutes.

Discussion

Our analysis of the data yielded two main findings:

1. First-year engineering students' design practices are likely contextually dependent, as our findings add to the work that finds varied behavior in beginning designers.
2. The logistics of the task (Making) and maintaining a common understanding (through Requesting, Group Conversation, and Agreement) dominated the first-year students activity. This raises questions of how to structure first-year students experience and further research directions.

Our first finding, that first-year engineering students' design practices may be contextually dependent, arises from comparing our results to the current work in this area. In our data (Table 3) we see that first-year students spent little time problem scoping (PD) or gathering information (GATH) and most of their time making (MAK), generating ideas (GEN), and evaluating those ideas (FEAS and EVAL). These results are in contrast to the Atman et al's 2005 study,[11] which involved the conceptual design of a ping-pong launching device, where first-year engineering students often spent most of their time problem scoping and failed to proceed to later steps of the design process. However, in Atman et al's 2007 work[12] they found that freshman spent most of their time developing design details. Some of this lack of problem scoping echoes the research summarized in Crismond and Adams[9] from which they summarized that "beginning designers treat design tasks as well-structured problems and make premature decisions by attempting to solve them immediately." Other results of ours contrast with Crismond and Adams.[9] For example, their summary of design research led them to conclude that "beginning designers have a generalized, unfocused way of viewing performance tests and troubleshooting their designs." Our data (Table 3 and Figures 3 and 4) showed first-year engineering students spending time on feasibility and evaluation of ideas throughout the process and focusing on troubleshooting particular elements.

The difference in results suggests to us, not a difference in the capabilities of first-year students, but a sensitivity to the context in which they use those skills. In the Atman et al's 1999 work[10] as well as previous design studies,[9,20,21] students had unrestricted time and were not required to make a physical object. In the case presented here, students had limited time and pressure to create working robot to compete in the "Candy Push" challenge. These different contexts may cue up different engineering practices for students. It could also be hypothesized that students' knowledge of the problem space plays a role. Our students had been working with the LEGO robotics materials for several weeks and had engaged collaboratively in other design challenges with these team members. This is in contrast to the Atman[11,12] work where students were designing a playground, a task where they may have been unfamiliar with the materials, requirements, and other aspects of the problem. Students' familiarity may enable them to do less problem scoping and information gathering and delve more quickly into a design problem (particularly a more structured one, such as the "Candy Push").

Our second finding, that a significant amount of time during hands-on projects is spent on the logistics of creation and group communication, comes from looking at Table 3 and Table 4 as well as Figures 3 and 4. We were surprised that these two activities were the most prolific activity within the session captured. Looking to research in engineering education, we found no documentation about the time students spend on the construction and communication portion of design projects versus other aspects of the project. Hands-on project based group work is often touted as helping students engage in engineering and it seems implicit that engineering practices are occurring during that time. However, our results indicate that, in this context, much of the time is spent on more basic elements of creating an artifact and maintaining communication. We assert that this is a new area to explore in greater detail to better understand what kinds of hands-on work may best develop students' engineering design practices and how much time they need in order to engage in the designing, making, and communicating. The fact that working with specific materials, managing group work, and engaging in engineering design are all new to first-year students may mean that we need to more carefully consider our instructional tasks for first-year students -- where they focus on certain aspects individually rather than trying to develop expertise on all aspects (materials, groups work, and engineering design) at once.

Limitations and Methodology Refinement

There are two main limitations to our study - the small sample size and the current methodology's reliance on discourse. The small sample size make our challenges and additions to existing work tentative. Nevertheless, the sample does provide insight into the variation between design practices in both frequency and time of occurrence.

The methodology is also a limitation of the study. The Design Activity coding scheme[12] uses Verbal Protocol Analysis -- an approach that relies on participants verbalizing their thinking. In a group setting, we would assume that decisions are made via verbal communication. However, in deeper analysis of the video we identified some instances of physical behaviors (manipulation of artifact and glances exchanged between group members) that served to advance the design of the artifact. Previous studies using this coding scheme[10,11,12,19,20,21] occurred in laboratory settings where individuals were asked to verbalize their thoughts as they designed. Due to the classroom context, fast pace of the design, and size of groups, smaller design decisions individuals made may have been missed and not included in our coding.

Our plans to refine the methodology include looking to identify physical indicators of design activities that may be nested in the manipulation of the artifact or other types of non-verbal exchanges between group members. This combined with the evaluation of verbal statements should provide an even clearer picture of the design activity happening within these groups.

Implications & Future Directions

This study provides new insights into the design of instruction for first-year students as well as additional research directions. The finding that students' engineering design practices may be employed differently depending on the context suggests that we may need to think about engaging students strategically in a range of contexts in order to assess their proficiency and allow it to develop. Finding opportunities throughout the first-year for not only incorporating "hands-on, project-based learning" assignments but also varying the style, scope, and size of these projects provides not only exposure to a wide-range of possible scenarios in which students will need to use and develop their abilities, but also gives a chance for students to develop their engineering skills within a variety of contexts and the ability to pedagogically emphasize specific skills (and the interplay of specific skills) within each assignment. For example, a first-year experience may need to consist of smaller individual design projects where students can focus on developing expertise with materials, and understanding how to generate and evaluate design ideas, before working in larger groups with the same materials and more complex design ideas.

While it appears the students benefitted from the sequence of prior assignments that provided background on the materials, as well as understanding of group skills and dynamics, it appears the relatively constrained task of the “Candy Push”, competition-style class structure, and tight time constraints, refocused the work of the students into an iterative pattern of generation of ideas, limited negotiating of those ideas amongst their teammates, and the task of physical implementation (making) of the robot. This seems to have provided relatively few opportunities for students to develop and refine new engineering design skills - suggesting that for this particular course this challenge may not be essential in current form. Refinements to the assignment might focus on how students could engage in more formative engineering design practices (such as problem scoping or generating ideas). For example, a potential instructional change to the assignment might be to give students 10 minutes to formulate and agree on design ideas before they are allowed to start building with the materials.

Understanding the interplay between the structure of the assignment and the types of actions/reactions of the students, especially within the limitations of this population, is important for instructors when designing a semester-long learning sequence for first-year engineers. This work begins the investigation of some of the real-world complexities involved in hands-on work happening within the chaotic classroom (and including interplay with instructors and teaching assistants) and we plan to pursue further research, examining both this assignment in more depth as well as others that happened within this class throughout the semester, to better comprehend how the engineering design practices of first-year students vary across these different contexts, and in which way the context (and sequencing) itself plays a role in both the development and implementation of these skills.

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