Examining Influences on the Evolution of Design Ideas in a First-Year Robotics Project

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Abstract. Presented here is a data-supported analysis of design ideas from first-year students completing a group robotics assignment. While classroom learning is typically assessed through content exams and final project presentations, an alternative approach is taken that analyzes four group members throughout the entire design process as they develop their project, from initial brainstorm of ideas to finished robot. Using video data of students working together, this paper examines how the group negotiated various influences and explores the evolution of design ideas on two dimensions: *possible* versus *impossible* and *must have* versus *like to have*. The paper concludes by discussing implications for robotics education and further development of methods used to evaluate student work.

Keywords. First-year engineering, Robotics Education, LEGO NXT, Project-based learning, Interdisciplinary learning.

1 Introduction

The multidisciplinary learning that a robotics curriculum affords has prompted many universities to add one or more robotic courses as part of their offerings for undergraduate engineers. Past and current courses have leveraged robotics to teach professional skills [1], the Robotic Operating System (ROS) [2], interdisciplinary design [3,4], teach students the basics of engineering [5], or a combination of the above [6]. For schools not offering relevant courses, many robotics competitions [7,8,9] provide opportunities enabling students to independently learn relevant skills outside the classroom. While these courses and competitions have challenges engaging students in the technical activities of constructing and deploying robots [5], little work has been done to fully understand the engineering design process and skill learning in which students engage while working on these types of projects. While specific expertise like fluency in programming languages are easier to measure, a team's or individual student's capability to effectively negotiate constraints and limitations and make quality design decisions is not. Yet, these abilities are important for future work as professional engineers, researchers, or roboticists [10,11]. Within this context, this study examines the iteration of design ideas in a group of four students working on a class-based robotics project.

Past studies have examined the way novice to expert engineers design [12,13,14,15,16,17]. These studies have characterized design practices commonly exhibited by beginning designers to professionals at different stages of the design process. Yet, most of these studies examine a single designer creating only a conceptual design in a laboratory setting and provide little insight into how teams of students design within a

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class context and how the tasks assigned within the classroom develop deeper design practices in the students themselves. The goal in the data collected and analyzed here is to examine a class project (worked on by a team of four students, both in-class and back at the dormitory) to gain a better understanding of the types of activities in which students engage, influences on design decisions related to the project, and the negotiations and choices with which students contend as they complete their projects. In general, robotics projects are interdisciplinary, design based, and technical, so provide an excellent context full of student initiated design choices, resulting in a rich dataset for analysis. This study is the first of this type of investigation, with the methodologies and analysis to be extended in the future to additional groups of student engineers and other styles of project assignments for further support and to generalize the findings.

2 Theory

When new projects begin, students often engage in brainstorming sessions that produce a wide variety of ideas, development directions, and potential solutions in order to complete their project. From that point on, students then need to negotiate, as a group, the various constraints and limitations that directly influence decisions made during development. These constraints under which the final artifact is created range from professor expectations, grade/formal assessment, available time, acquired content knowledge, skills possessed, available resources, team dynamics, and peer opinions of their work. These influences shape their project trajectory. While we don't have access to their (individual or group) underlying motivations when balancing these influences, each team member values these influences differently and the project as a result is directly affected. Despite not knowing all the details, examining the design trajectory over time of how the student group worked, evidence exists of how the students struggle and how resolution is achieved within different scenarios.

When negotiating a particular design idea, we have identified two dimensions on which it falls. First, the *must have* versus *like to have* dimension. *Must have* ideas capture the core requirements of the project, either dictated by the assignment or personalized aspects required by the individual/group based on passion. *Like to have* ideas are more decorative in nature and, while not required by the project, add to project quality and overall impression. Ideas that begin on one place on the spectrum may move from *like to have* towards *must have* as other *must haves* are completed or more sills are learned. While rubric specifications may determine many of the initial *must haves*, students may feel certain ideas are necessary to impress clients, peers, or the professor. The second dimension ranges from *possible* versus *impossible*. While expert engineering teams may have a better sense of their own internal skills, content knowledge, and abilities (and thus have less "spread" on the axis), early engineers still exploring the topic struggle with ideas ranging from what is *possible* (components students are able to implement with the knowledge/skills already possessed) to those that are *impossible* (from the fantasy, e.g. time travel, to the technically difficult, e.g. advanced/complex systems). Ideas positioned here, in between the two ends of the spectrum, indicate how much learning is required in order to accomplish implementation. This ranges from an idea closer to *possible* only needing a little new knowledge compared to those nearer to the other end (*impossible*) requiring larger, and perhaps unattainable, gains in understanding. The external and internal influences dictate, for a particular group, where individual ideas fall on these two spectrums and as a result directly shape the decisions made en route as well as final solution the students eventually create. This paper examines the details of how one group negotiates these influences in the creation of class-based robotics project.

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3 Course Description

Tufts University has shifted, over the last few years, to a system where first-year engineering students in their first semester have a selection of courses from which to choose as their initial Introduction to Engineering exploration. Across a variety of topics, representing content from the various departments within the School of Engineering, these courses provide an opportunity for students to explore a particular content area prior to declaring their major (at the conclusion of their first year). One of these courses, *Simple Robotics*, highlights a wide range of engineering material (mechanical to structural to electronics to programming/computer science) through robotics.

The *Simple Robotics* course, similar to many of the other courses, offers opportunities for engaging in additional practices (beyond just core content) of professional engineers through the structure of weekly assignments. Emphasizing innovation and creativity on behalf of the students, the presented challenges require the students to struggle with a wide range of relevant constraints as they negotiate working within small groups to design, build, program, test, and showcase their creations. These constraints vary such as a set time limits , materials, acquired knowledge, etc. Within this context, presentation skills are emphasized as well, acknowledging the importance of being able to communicate and share their engineering creations beyond just the process of creation; while often in-class demonstrations to their peers, sometimes larger displays are orchestrated and opened to the public, further encouraging final products that are reliable, robust, repeatable, and ultimately engaging to the audience.

One assignment, from the 2013 fall semester, had students working on robotic additions to a "Haunted House" exhibit produced in collaboration with an on-campus dormitory celebrating Halloween. Students in the *Simple Robotics* class were aware, beyond just creating an interactive robotic artifact to satisfy class requirements, that the best performers would be featured in the showcase that would be open to the entire campus to experience for several hours throughout the evening. As such, beyond the in-class specifications of creating a functioning product that sensed the environment, processed inputs, and reacted through actuator outputs, student groups had to consider both the environment in which their creations would be presented as well as the eventual "clients" who would be interacting with these robotic Halloween creations: other students from throughout the university visiting the haunted house.

This project, occurring in late October, fell approximately 2/3rds of the way through the semester. Project number seven in sequence (six smaller weekly assignments preceded it), this was the first in which students had more than a single week to complete the assignment; as such, partially completed prototypes were required for a mid-project in-class presentation to demonstrate progress as well as receive classmate, teaching assistant, and instructor feedback. While initial assignments during the semester were completed in pairs, starting with project 5 the small groups were combined together; thus, in the "Haunted House" project explored here, these four students were now working together for the third project in a row. This is significant because at this point in the semester the team dynamics and interpersonal relationships had been previously explored, in terms of personality, expertise, etc.

At the beginning of the project, which required students to create a robot using the LEGO MINDSTORMS robotic toolset and program using the LabVIEW graphical programming environment, students were additionally provided a selection of scary props for incorporation into their creations, such as plastic knives, fake skulls and bones, pretend spiders, and other Halloween-themed decorations. Additional materials, collected by the team, were allowed to be incorporated into their creations. While some in-class time was

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provided for working and presenting, the majority of the work students did was at home; overall, the students worked on the project over a period of 10 days.

4 Data Collection

Within the class, students groups (in which all members had consented, at the beginning of the semester, to participate in the research investigation) were given a video camera in order to record any work related to the project that occurred in-class or at home. For the research subjects examined here (four students: two males and two females), the "Haunted House" assignment resulted in about six hours of video recorded by the group. The video was transcribed and analyzed according to the various ideas negotiated by the group and significant design decisions made throughout the project.

From the supplies provided in class, the students in this group chose a fake bone and plastic knife in order to create a "Scary Sword" (Figure 1) actuated by the motors and triggered by a sensor. During the initial brainstorm portion of the project, ideas ranged from incorporating sound effects, sparks, a skeleton hand, fog, fake blood, etc. In the final design, there were three components to their project that will be examined in more detail here: the *Swinging Sword*, audible *Scary Sounds*, and visual *Flying Sparks*.

Figure 1. Picture of Scary Sword project

Analysis of the video, broken into five-minute increments throughout the six hours of recorded project work, reveals moments where details of each project component was discussed, negotiated, or developed. Figure 2 depicts a visualization of the data analysis, showing iterations on ideas related to each component over time.

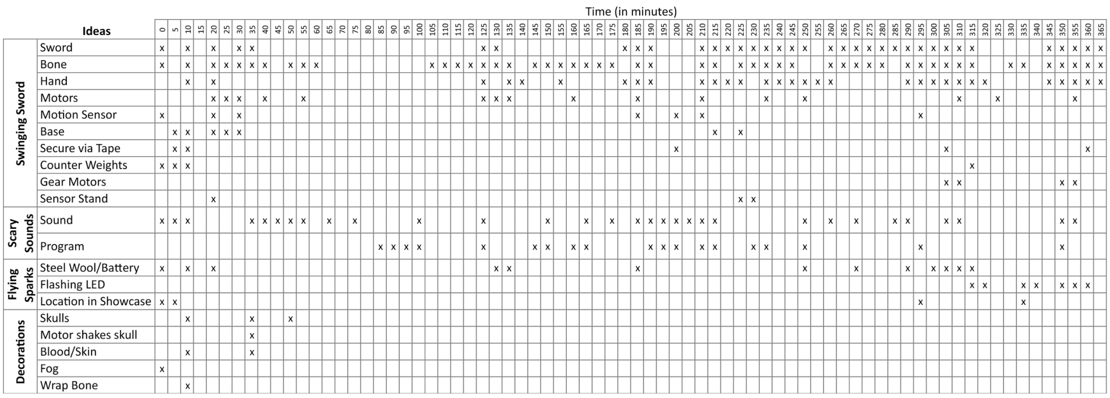

Figure 2. Sequence of design idea development over time for "Scary Sword" project

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An example of the analysis process is illustrated in the following transcript segment, taken from minutes 180 to 185 of the video data where a member of the group summarizes the status of the project mid-way through development. The words in bold indicate project ideas being specifically identified during this time period. (Due to the overview provided by this student, multiple concepts are discussed simultaneously; for most transcript segments, the group focused on only a few ideas in tandem.)

> [182:41.17] *Student 1:* It's going, okay, so this [the **bone**], the **hand**'s attached to this and the **sword**'s like being held by the hand. And it's **motion triggered** so when you walk by it swings the sword at your feet and then we're gonna put a piece of **steel wool** on the ground and a **battery** on the sword so it sparks. And then they're doing **sound effects** and it's this girl going "I don't wanna dieeee."

5 Analysis

5.1 Statistical Analysis

Concept	% of work time
Bone	10.40
Motors	18.79
Sword	1.68
Hand	8.05
Sound	17.45
Sparks	13.42
Set-up/Location	2.68
Base	5.03
Program	11.41
Overall Prototype	11.07

Figure 3: Percentage of Time spent on concept development

Using Figure 2 and additional tabulated data, the table in Figure 3 details the percentage of time students spent on each component. As there were multiple students in the group, many times a number of these ideas were made simultaneously. Each of these segments of time worked were added together to create the total time worked. The above percentages are the percentage of the total segments that were dedicated to that piece of the component. The greatest amount of time spent discussing and making were dedicated to attaching the motors to the bone and putting the sound file on the NXT. While the attachment of the motor to the bone was a *must have* as determined by the project description (moving actuators), the sound effect feature was chosen as a *must have* desired by the students, while not explicitly required by the project. More details of this case are discussed below.

5.2 Case Studies

Through the examination of the students' ideas, a pattern of idea development emerged, as it appeared the negotiation of ideas by the group would consistently follow a set of possible design directions. The Idea Flow Diagram, shown in Figure 4, captures the set of potential progressions observed. After initial idea brainstorms, time was spent iteratively working on the development of the particular ideas associated with a component of the project. This either resulted in a successful implementation (idea achieved) or the students realizing it wasn't possible (failure). In either case, that idea might be enhanced through continued refinement of the details and the process started again. Otherwise, the achievement was considered sufficient and the idea was completed, or the idea was abandoned due to the failure to implement.

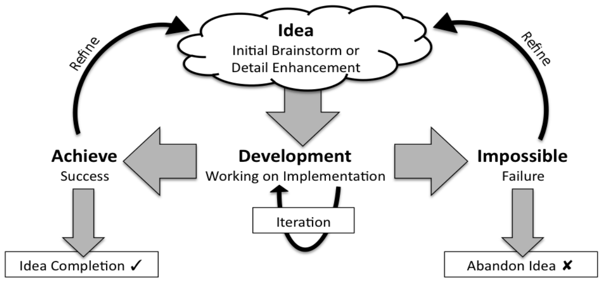

Figure 4. Idea Flow Diagram

The following demonstrates three examples observed within the data of the group negotiating constraints as they progressed through this process when developing ideas associated with their project. The three ideas explored are implementing sound effects, sparks, and fog.

For the implementation of sound effects (see Figure 5), the group spent a significant amount of time (multiple iterations) implementing the code in LabVIEW (and on the NXT programmable LEGO brick). Once this was achieved, the idea was refined for the inclusion of multiple sound effects, which were then easily implemented and completed. While the sound effects were a *like to have* as determined by the group and not core to the robotics project, they strove to implement this feature due to knowledge that it was *possible*. (Although, despite it being known to be possible, for this particular group a significant amount of time, encompassed in the multiple iterations, was spent on this feature due to a lack of specific content knowledge on how to initially implement.)

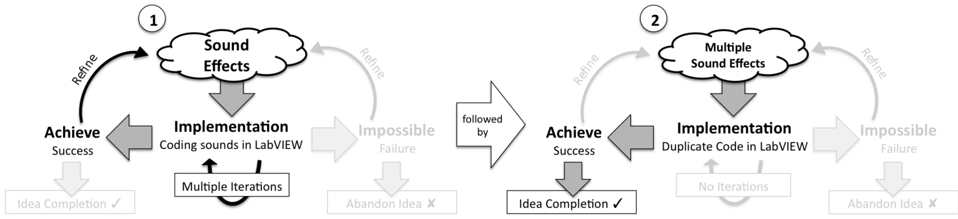

Figure 5. Idea Flow Diagram for implementation of sound effects

For the implementation of sparks (see Figure 6), the group's initial idea was to use a battery attached to the sword that would come in contact with steel wool and produce sparks. Through iteration on the physical design, they developed a prototype, but the sparks created would have started a fire (deemed unsafe). While this didn't rule out the idea completely, the initial idea was refined where "sparks" were simulated through a flashing light. Thus, a touch sensor and light were implemented (fairly easily/quickly) as an alternative. This feature, while not a component directly related to the given robotics assignment (and thus, not related to their class grade), was determined by the group as a *must have* within their implementation, due to other motivations around peer-perception and perceived "coolness" of the project implementation. As such, when the battery/steel wool version was deemed *impossible*, the updated idea (flashing light triggered by touch sensor), while not considered ideal by the group, was known to be *possible* and thus the direction this design decision proceeded.

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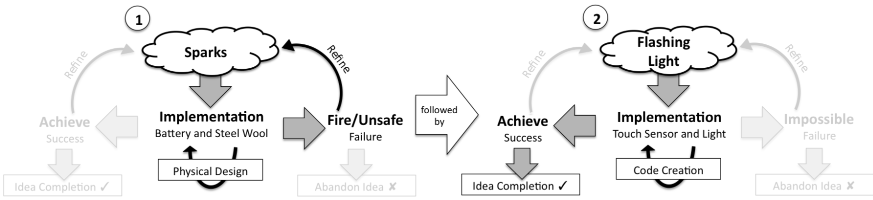

Figure 6. Idea Flow Diagram for implementation of sparks

For the implementation of fog (see Figure 7), the initial idea was to use fog to hide the presence of the Swinging Sword in order to enhance the scariness of the robot. However, this idea was quickly (only through verbal discussion, as no prototype was needed) identified as *impossible*/not a priority and quickly abandoned. In terms of project scope, the fog was most certainly considered simply a *like to have* by the entire group, which made the realization of non-implementation a fast decision. As seen in the sequence of design idea development (Figure 2), discussions occurred very early in the design process and once the idea was immediately dropped, never reemerged.

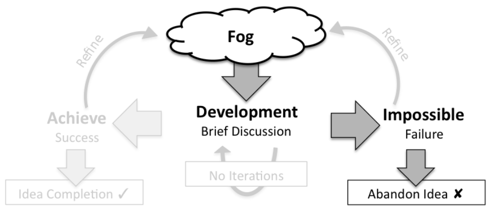

Figure 7. Idea Flow Diagram for implementation of fog

These three examples highlight ways in which the group progressed through this process, sometimes performing multiple iterations, but transitioning from step to step based on the negotiations of the different constraints and limitations within the project. At each point along the way, the positioning of the idea on the *must have*/*like to have* and *possible*/*impossible* spectrum motivated the time, energy, amount of discussion, and implementation effort dedicated to the idea (and individual step) by the group.

6 Conclusion and Implications

As educators, preparing students for future participation in the technical workforce goes beyond just transferring content; additionally, we should be helping develop student skills in the context of completing engineering projects within constrained scopes. Working in groups on open-ended projects, such as often given in robotics education, students are required to negotiate through the limitations of their own abilities and those of the group as a whole, all of which directly affect the design decisions and the eventual products they create. This work examined the performance of one group of students creating a "Scary Sword" interactive robot as part of a Haunted House themed assignment. While implementing the various ideas associated with components of their design, the students navigated the space of *must have*/*like to have* features, as well as those that fell somewhere on the *possible* to *impossible* scale. As the ideas developed, iteratively through discussion or when struggling to create, design decisions by the group dictated when students achieved success implementations, failed and abandoned the work, or refined the ideas through additional feature specifications.

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While important to see students iterating, it is also necessary to identify the times when continual iteration on an idea is non-productive (e.g. spending significant time on a feature deemed *impossible*) and should be abandoned, or prolonged development on features that are only *like to have* in a time-constrained situation (e.g. when essential *must have* details still remain). In order to best train students to understand these differences, they should have exposure to situations that require struggles of this type. Thus, providing authentic assignments where students are required to balance a set of constraints (ideally personally meaningful) in order to understand the impact of these factors on their own design decisions and eventual output. Maintaining project parameters that are flexible and can be determined by the students themselves achieves both of these: allowing personalization of features and empowerment to the designer(s) with regards to the specific design decisions.

Accessing the underlying process through which the students participated in creating their final artifacts is also essential to better understand the quality of and the application of the design decisions incorporated into the project. Simply analyzing the resulting product is not sufficient for assessment of those decisions and associated transitions leveraged during development. However, given the current environments in which assignments like these are implemented, this information is often not available (or, as in the case here, requires intense labor to analyze/generate). If educators wish to utilize this information during evaluation (and, more importantly, provide the opportunity for students to self-reflect on the experience themselves), new tools for faster, automated, and more complete study of relevant data need to be developed.

Finally, this study focused on one group of students during the completion of a single assignment. While insights emerged regarding the features of the project on which efforts were focused, constraints under which the students struggled, and factors that affected important design decisions, more analysis is needed in terms of fully understanding the impact of how their time was spent and the quality of the work performed. Further, a model was developed here that captured the transitions of the group through the design space, but additional examinations of other groups and across different styles of assignments is needed to fully understand the applicability of these ideas in the generalized case. Where there exists the possibility of equivalent negotiations in other student project groups, every project is set in a unique context of environment, external influences, and internal student motivations. More work also needs to be done to fully classify this context and understand the correlation between the situation and the enactment of the engineering design process by the students. With a more detailed data analysis, across a wider range of assignment types, populations, universities, etc. it should be possible to start to understand larger trends and formulate more generalized understandings about the role of defined problem (scope, constraints, etc.) and the quality of the negotiation schemes experienced by the students.

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