Examination of Student Self-assessed Learning in a Project-based Freshman Robotics Course

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***Abstract*— This innovative practice full research paper offers insight into a course instructor's use of three varied projects within a first-year engineering course and the students' self-reported learning surrounding these projects. First-year courses are designed to both excite students about engineering and increase retention and thus have become a staple at many engineering institutions. However, there is space to gain a deeper understanding of how students perceive their own learning as gained from these first-year projects and how they could be impacted by different problem contexts.**

Keywords— engineering, reflection, project-based learning, human-centered design

I. INTRODUCTION

In recent years, more universities have been restructuring their first-year engineering courses to expose students to engaging hands-on design projects earlier in their academic careers. Such courses are believed to better pique student interest and improve retention in the engineering discipline [1, 2, 3]. Studies examining such re-designed freshman courses have focused on student feedback as a means of assessing the course's impact on student interest and learning in engineering [4, 1]. Other means of course assessment rely on more quantitative data around student retention statistics and ratings around their overall classroom experiences.

However, the studies which offer student perspectives as a means of course assessment often rely on surveys administered often only at the end of the semester. While these exit surveys give students some space to reflect on their classroom experiences, they provide limited insight as to the evolution of student learning throughout the entirety of the course. Other research, however, has demonstrated the use of student portfolios throughout the course as a means of providing students space to reflect on their learning but place less emphasis on course design and assessment [5, 6]. While these studies provide students with more space for reflection on learning, they often only focus their attention on one type of project context. Building from previous works detailing student-reported learning in engineering coursework, we hope to:

a. investigate what kinds of learning moments students see as most salient in their first-year course experience with respect to the different assignment contexts and

b. highlight the potential of student reflections as a tool for shaping course design, and/or reinforcing course objectives.

This paper seeks to explore these questions by examining open-ended surveys conducted after three different assignments completed by 23 first year engineering students. Through this research, we hope to offer insight into the trajectory of student learning during their first semester and the implications of course design on such learning.

II. LITERATURE

A. Reflection as a Learning Tool in Education

Reflection, defined as the capturing of one's progress, achievements, and details of one's work throughout a cognitive task, has been proven to aid in systematic self-reflection, communication skills, and appreciation for one's individual development [7, 8, 9]. Literature has cited the benefits of allowing students to be active participants in assessing and managing their own learning [5, 6, 10], yet little time is typically built in to accommodate such practices in engineering coursework [5, 11, 9]. Various works have demonstrated the implementation of mechanisms for reflection on learning, including Barrett's work with ePortfolios [6], Kolodner's implementation of design journals with middle school students [7], and Turns's use of portfolios in a yearlong university level engineering course [12].

Researchers and professors who have made the effort to implement tools and space for reflection often do so as a learning tool for the students, an assessment tool, or both [7, 9, 14]. Especially in university level engineering, we see

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portfolios employed as a means of capturing student work as a tool for when students apply to jobs. These works have identified various benefits to both the students and to the instructor in unpacking the learning experiences that occurred over the course of a semester. In Turn's work, she shows how portfolios allowed students to see value in learning moments beyond the technical knowledge acquired in the classroom and realize that their extracurricular activities could be impactful in shaping their identity as an engineer [5]. In allowing students to actively monitor and report on their own learning, it was found that the students felt less of a disconnect between the technical knowledge obtained from their course instructor and other hands-on experiences [5].

B. *Student Reflections as a Means for Course Assessment*

In contrast to Turns's approach, Oakes et al. at Purdue University [1] leveraged end-of semester surveys as a means of capturing student learning. In this case, students reported positively on their hands-on experiences through the EPICS project-based model and helped the researchers validate the program objectives. The EPICS model, which pairs interdisciplinary student teams with local sponsors as their client, has objectives spanning technical skills, communication skills, teamwork skills, resourcefulness, and professional ethics. Surveys taken at the end of the EPICS Program asked students to report what they had learned the most from their experience in the program, and aspects ranging from technical skills to "soft" engineering skills are detailed [1]. With these promising results, however, there is still space to better understand the components of coursework that led to these self-reported learning moments and gain more insight into the milestones of the students' learning.

While such end-of-semester efforts to capture student reported learning may afford some cognitive benefit to the student, the product of such efforts are primarily used by instructors as they consider course design and objectives. This method may be productive in capturing a more holistic, general view of what students thought they learned; however, in providing students more regular opportunities to offer perspectives on their own learning, researchers and course designers may gain more insight into the impacts of individual assignments and projects on students. Further, recent literature has sought to characterize the cognitive growth and attributes of novice to expert engineers [16]. In offering what novice engineering students see as most salient in different types of learning experiences, we may contribute to this growing body of literature.

III. STUDY BACKGROUND

In an earlier study at Tufts University, researchers conducted student interviews at the end of a first-year robotic course as a means of assessing the course structure and gaining insights into what the students had learned. The researcher conducting reflective student interviews discovered that some students reported that the act of the interview itself was helpful in processing their own learning and fully recognizing their growth over the course of the semester. Additionally, Swenson et al.'s work suggested that "the 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." Researchers additionally noticed the differences in criteria students hold themselves to when designing for a user [2, 17]. Considering these findings, as well as earlier works evidencing the benefits of reflecting in-action as opposed to retroactively trying to piece together learning moments [10], researchers at Tufts University sought to create more room for student reflection in the subsequent version of the course. The professor of this course not only asked students to report upon their experiences after three assignments space out throughout the course (beginning, middle, end), but also intentionally designed the three assignments in such a way that would expose students to a breadth of engineering design knowledge areas, from technical to non-technical.

IV. STUDY CONTEXT

In our continued examination of project-based freshman courses, we wish to understand the effect of different assignment contexts on student-reported learning. Tufts University's Introduction to Engineering course *Simple Robotics*, studied here, is the current embodiment of a course that has evolved over the past decade leveraging the LEGO MINDSTORMS robotics toolkit and LabVIEW graphical programming, to have first-year engineering students explore engineering design and introductory robotics concepts through hands-on projects. While this course still delivers the technical foundations expected of an introductory course, it also aims to incorporate various other aspects including emphasis on creativity, incorporation of cross disciplinary work, collaboration, communication, and engineering ethics and societal contexts [2]. The professor (who is also a paper co-author), following project-based learning pedagogies, implemented a series of group projects throughout the semester, and includes a reflection survey after three of them (at the beginning, middle, and end of the semester). Each of the three highlighted projects consisted of requirements ranging from technical aspects and specifications (such as incorporation of at least one input and output) to non-technical aspects (such as project documentation and conducting user surveys). The three major projects, and the resulting survey data, examined within this paper are summarized in Table 1.

Twenty-three students (four female and nineteen male), out of the total twenty-eight enrolled in the *Simple Robotics* course, consented to be included in this research study. They are all pre-major (declaring a major happens at the end of the first-year within the School of Engineering at Tufts University).

TABLE I: OUTLINE OF MAJOR COURSE PROJECTS

Project Name and Project Summary	User or Context	Project Duration	Materials
Robotic Animal: Create a robotic animal that includes "inputs" (sensors) and "outputs" (motors, or other). Try and capture the look, feel, and movements of the animal you choose. Your animal must also react appropriately to some set of inputs.	None	1 Week	LEGO EV3 MINDSTORMS kit and dorm room/found materials
Astronaut Tools: Simulate the tools used by astronauts during extravehicular activity (aka EVA, aka spacewalk). You will first build a tool that could help an astronaut to accomplish a common task on the International Space Station: moving nuts between bolts or routing wire. Then, you will demonstrate the use of your tool in-class in simulated spacewalk conditions.	Zero gravity on the International Space Station and astronauts	2 Weeks	LEGO EV3 MINDSTORMS kit
Playful Creation: For the final project of the semester you are to invent, design, develop, build, test, refine, and showcase a new toy for children between ages 4 and 8 years old that supports productive play.	5 to 7-year-old children	3 Weeks	Multiple LEGO EV3 MINDSTORMS kits (as needed), craft materials, wood, projectors, and other requested materials

V. METHODS

This study is grounded in previous literature emphasizing the importance of critical self-reflection for students as they develop as engineers. Further, we follow the claim that students play an active role in the construction of their own learning, and we cannot assume that academic experiences themselves make a cognitive impact on the learner [5]; rather, student learning is impacted by how students *think* about their experiences and draw connections between them [5, 18]. Therefore, in considering the impacts of a course on the evolution of the student engineer, it is valuable to look beyond student artifacts and discourse and consider the reflections of the students themselves.

At three points during the semester (beginning, middle, and end; directly following the three projects described in this paper), the instructor administered to the students a non-graded reflection survey consisting of 6 open-response questions. The same questions asked each time were:

- *What is the biggest thing you learned from completing the project?*
- *How successful did you feel in completing this project?*
- *After completing this project, what would you have done differently? How might you change the way you do the next project?*
- *How many iterations of your project did you go through? What contributed to this?*
- *What three design features do you think were the most important in your solution?*
- *What is the biggest thing you've learned in this class?*

In our data analysis across responses, the instructor and two graduated students adopted a coding scheme similar to earlier examinations of student perceptions of success in engineering [19]. Initial review of the data revealed that similar overall themes emerged out of the student reflection surveys and the coding scheme in Table II was adopted [19]. However, upon deeper examination various subthemes emerged within the design process, as the findings will describe.

TABLE II: GENERAL CODING SCHEME FOR STUDENT REFLECTIONS

Technical	Design Process	Client Considerations
"...We were able to get the steady control with some haptic feedback and wireless communication working, so I would label this as a success."	"Yes, we spent a lot of time trying to decide what we were doing, how we were doing it, and how to present it, and it felt like it paid off...."	"...that when designing something for a consumer, it's necessary to understand the taste of the consumer. It's clear kids are fascinated by sounds and colors. We failed to incorporate that into our toy and that affected the feedback we got from final projects."

VI. SURVEY FINDINGS

Having coded the survey responses across all three projects according to the three prescribed themes in Table II (*Technical, Design Process, Client Considerations*), the responses were then further coded based on the emergent sub-themes. It was found that students organically focused on not just the syllabus and project objectives (as detailed in the project description and rubric), but also on various less-technical and non-technical aspects of their project experiences. These sub-themes are summarized in Table III below and Figure 1 and Figure 2 show the breakdown of the appearance of these sub-themes across the 3 projects. Fig. 1 compares all the reported technical skills (hardware and software related) to the non-technical skills (from group dynamics (G), to problem scoping (PS), to time management (T), to iteration and testing (I)) while Fig. 2 breaks out those associated with engineering design.

TABLE III: EMERGING SUB-THEMES IN STUDENT-REPORTED LEARNING

(G) Group Dynamics	Group organization and coordinating, cooperation, task division
(PS) Problem Scope	Acknowledging complexity of problem scope, realizing constraints and criteria
(T) Time Management	Starting early, realizing the amount of time needed for task completion
(I) Iteration and Testing	Recognizing the need for testing design features, obtaining user feedback from prototyping sessions

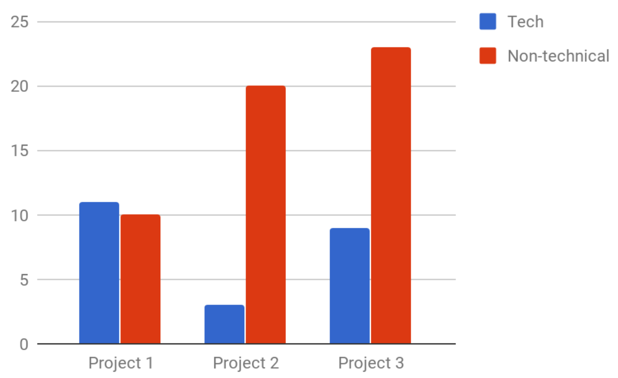

Fig. 1: Technical vs. Non-technical Lessons Learned

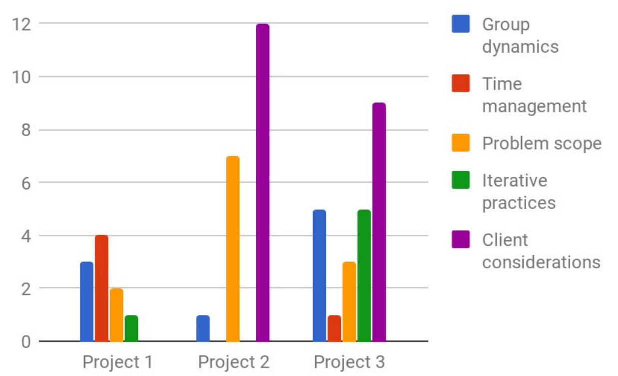

Fig. 2: Student-Reported Learning Around the Design Process

Further, the number of total learning references themselves, whether technical or non-technical, grew from 21 to 32 between the first and last project, despite the prompt only asking for the single most important *thing* they learned.

Project 1: Design a robot that mimics an animal

Both charts reflect fewer overall reported learning instances in the first project than in subsequent ones. However, the first project did see the highest reportings of having gained new knowledge in technical areas, ranging from hardware related (e.g. "*LEGOs fall apart very easily*") to software related (e.g. *"LabVIEW and on-brick programming"*). It is perhaps not surprising that the acquisition of technical knowledge saw the greatest amount of references, given that the assignment was administered the first week of the student's college career and that many indicated having no to little prior knowledge of LEGO robotics. Additionally, at this point in the semester, students are growing accustomed to the demands of college-level coursework and the time management skills needed to adjust to these demands; the high reporting of "time-management" reflects students acknowledging this transition into university life. The course professor (and paper co-author) had designed this first assignment with consideration of these factors and intentionally did not add the extra complexity of a "client" with less defined constraints until the subsequent project.

Project 2: Design a tool for an astronaut

A large shift is evident between project one and two in terms of what non-technical aspects of the design process students saw as most salient in their experiences. Students found that coping with the scope and complexity of the project task overshadowed the acquisition of other skills (particularly technical skills). Seven out of the nine students (77.8%) who focused on technical knowledge in project 1 switched to an emphasis on more attributes of the design process. Again, these findings are reflective of the professor's goal to allow his students to obtain a technical foundation in the first project, and wait to introduce more complex constraints and objectives in the second project (while still including technical objectives). Fig. 3 provides examples that illustrate the shift seen in the majority of students between projects one and two; this figure highlights three individual student comments matching their responses and demonstrating the shift from technical issues (here, software issues detailed) in Project 1 to non-technical considerations in Project 2.

Project 1		**Project 2**
"LabVIEW programming basics"	→	*"Human-oriented design"*
"How to program on-brick"	→	*"That ease of use needs to be taken into account."*
"Personally, I learned a lot more in programming in LabVIEW, specifically using loops in my program."	→	*"I learned that sometimes an idea will not be directly be translated into the prototype you create. Also, I learned that communication is key when in competition."*

Fig. 3: Student Shifts Between Projects 1 and 2 from Technical to Non-Technical Emphases

It is interesting to consider that both of these assignments had technical requirements built into the syllabus, and further that between the first and second assignment, the students were asked to make the transition from simple programming with the LEGO MINDSTORMS robotics to fully graphical programming within the LabVIEW environment. Yet, the largest focus was on accommodating the needs of the client, and the various environmental difficulties that they might encounter in outer space. As previous literature suggests, novice students may struggle more initially with larger project scopes with ill-defined problems [13]. The professor seems to recognize the need for additional scaffolding in this open-ended project and provides the students a with a standard testing platform to be used across all groups as they develop and iterate on their astronaut tool. However, in project three, the students are left to develop their own system of testing and obtaining feedback on their creations.

Project 3: Design a toy for a child

Yet another shift of student-reported learning is seen between the second and third projects. The new emphasis on iterative practices perhaps isn't surprising given the final project's emphasis on designing for an end-user and feedback sessions with the clients (4 to 6 year old children). The importance of testing one's design was only mentioned once between the prior two projects; additionally, several students at the end of project one even suggested that "there was nothing they would do differently" given the chance to iterate on their project (as indicated in the survey responses). However, by the end of project three, we see a shift towards responses that are mindful of possible improvements or features that could be incorporated:

"...when designing something for a consumer, it's necessary to understand the taste of the consumer. It's clear kids are fascinated by sounds and colors. We failed to incorporate that into our toy and that affected the feedback we got from final projects."

"The biggest thing I learned from this project is that there are always ways in which you can improve a project."

In the final project, we also see a re-emergence of references to technical learning moments that seemed to be lacking in project 2. When these responses are more closely examined, it can be seen that many of the technical references were mentioned in conjunction with a specific client need or constraint. For instance, one student quoted that once they learned how to make the throttle on their game easier to handle, it greatly improved the usability for younger children. This indicates an understanding and realization on behalf of the students as to the client-driven needs of features created through engineering design.

VII. Conclusions and Future Work

In detailing the design of three open-ended projects and the correlating student reflections, we may better understand the types of knowledge and skills students see as most salient given these different contexts. These self-reported learning instances may be helpful for course instructors in more effectively emphasizing their own course objectives through different types of class projects. Further, this work offers a coding scheme that may be applied to qualitative student reflections, which may in turn inform educators whether student's perceptions in fact align with assignment objectives and course goals.

This work additionally highlights different considerations the professor took into account when designing the progression of project assignments. The findings indicated that students at least recognized that a spectrum of skills, from technical to non-technical, were emphasized in their course experience. This is valuable feedback as professors continuously re-evaluate first year course design in order to best align their course objectives variety of skills ABET requires of engineering students [20]. As suggested through previous literature, it is important to monitor the progression of student learning and cognition as they grow as engineers so that we may better support them through careful coursework design and academic experiences.

Further work, however, still needs to be done to examine how the act of reflecting itself may have benefited the students. While this research offers insight into what students see as significant learning moments in different project contexts, our scope did not examine how students might see the space for reflection as useful itself. While we might conjecture that this allowed them an opportunity to realize their own progress and learning as other studies have suggested, no post interviews or surveys explicitly examining such questions were conducted. Additionally, it is important to acknowledge the small sample size of this study at 23 students. Nevertheless, this study provides insight into what types of themes in terms of engineering skills might be expected in different contexts, and explicitly contributing the emergence of several non-technical themes that are valued within engineering design and that the projects elicited. We hope that future work may continue to explore the opportunities of student reflection in engineering and how making habit of reflection might a) benefit the student as they grow as engineers and b) explicitly inform the instructor, in real-time during the semester, as they consider their course design's implications on students, allowing mid-course redesign of assignments in response to student learning.

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