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First-Year Student Perceptions of Course Skills Utilized in Hands-On Final Project

Dr. Nicholas Hawkins, University of Louisville

Nick Hawkins is an Assistant Professor in the Engineering Fundamentals Department at the University of Louisville. He received his B.S. (2016), M.Eng. (2017), and Ph.D. (2020) in Electrical and Computer Engineering at the University of Louisville. His res

Dr. James E. Lewis, University of Louisville

James E. Lewis, Ph.D. is a Professor in the Department of Engineering Fundamentals in the J. B. Speed School of Engineering at the University of Louisville. His primary research focus is Engineering Education and First-Year Programs. He also has interests in cryptography, and parallel and distributed computer systems.

Dr. Brian Scott Robinson, University of Louisville

Brian Robinson is an Associate Professor with the Department of Engineering Fundamentals at the University of Louisville. His primary research focus is in Engineering Education, with highest interest in first-year (and beyond) engineering retention & the effects of value-expectancy theory on student persistence.

Dr. Angela Thompson P.E., University of Louisville

Dr. Angela Thompson is an Associate Professor in the Department of Engineering Fundamentals at the University of Louisville. Dr. Thompson received her PhD in Mechanical Engineering from the University of Louisville. Her research interests are in biomechanics and engineering education, particularly related to first-year students.

First-Year Student Perceptions of Course Skills Utilized in Hands-On Final Project

This complete evidence-based practice paper is focused on assessing student perceptions of key course skills that they used while completing a final project for a hands-on makerspace course. At the University of Louisville's J.B. Speed School of Engineering, all students – regardless of discipline - are required to take a two-sequence introductory course that covers the fundamental concepts of engineering. The second of these courses, *Engineering Methods, Tools, & Practice II* (ENGR 111), is exclusively taught in a 15,000 square foot makerspace and uses active learning pedagogy to instruct students on the practice of common engineering skills.

The primary skills taught in this course cover: technical writing, 3D modeling, circuitry, programming, engineering design, and teamwork. Students in this course apply these skills throughout the semester in various modules that are specific to that skill. Eventually, near the end of the semester, students utilize these skills in a team Cornerstone project that constitutes their final project of the course. For example, this means that students are given modules specific to the instruction of Arduino programming about midway through the course. Students then program an Arduino to accomplish certain computational tasks in their Cornerstone project.

While the intent of instructors is to evenly include each of these skills in the Cornerstone project, students might perceive certain skills to be more applicable to their project compared to others. At the end of each semester, students are asked to complete a survey regarding the course. Included in the survey is a question about these skills in relation to their Cornerstone project: *Which of the fundamental engineering skills practiced in ENGR 111 were most useful in completing your Cornerstone project and why?* Approximately 400 students between the Spring 2024 and Summer 2024 semesters responded to this question with insights as to their perceptions of the Cornerstone project and the skills most useful to it.

Preliminary results show interesting observations both in terms of which skills are most discussed by students and why they mentioned those skills. The purpose of this study is to help determine if students are adequately prepared for the skills they need in their Cornerstone project. If students find certain skills to be more applicable but are not addressed sufficiently earlier in the semester, some modules may need modifications.

Introduction

Engineering education faces various challenges with student engagement and persistence. One of the common improvements to pedagogical efforts to address this is inclusion of active learning techniques, which has seen increased research activity in the last decade [1]. Active learning is an interactive teaching model that puts students at the center of their own learning process through engaging, often hands-on, activities [2]. Active learning often incorporates media to attract and maintain the attention of students to benefit their learning. Ultimately, the purpose of active learning is to prevent students from being passive listeners in a classroom [3]. Active learning techniques have been studied numerous times and results provide strong indications of improved student persistence [4] [5].

One specific example of active learning is project-based learning. Project-based learning places pedagogy in the context of a particular system and often incorporates teamwork to add socialization to the learning process [1] [6]. The purpose of project-based learning often is to tie student learning to meaningful real-world applications that are especially relevant to the engineering profession. The use of project-based learning techniques has been studied widely [7] with results showing improvements for students in terms of material understanding [8] and motivation [9].

This paper will discuss the use of a first-year introduction to engineering course that utilizes project-based learning techniques. In particular, this course uses hands-on activities to scaffold students towards the creating of a culminating final project. This paper will discuss the results of a survey regarding the skills students used in this project and their perceptions of those skills. In particular, the purpose of this study is to examine how prepared students feel for their experience of the final project.

Course Description

The ENGR 111 course is the second of a two-course sequence that introduces students to various engineering skills. Additionally, this course is required for students of all engineering majors and therefore is designed to instruct skills that are universal to all engineers. While there are many skills that are involved in the pedagogy of ENGR 111, the primary skills taught are: technical writing, 3D modeling, circuitry, programming, engineering design, and teamwork.

The overall purpose of this course as compared to its predecessor is to provide a hands-on experience for learning these skills. This course is formally held in a large makerspace and lessons are comprised almost exclusively of active learning. Students work most days in interdisciplinary teams of 3 – 4 to complete lessons that provide a basis for one of the aforementioned skills.

To incorporate this hands-on experience, the majority of lessons in this course include the use of active learning techniques. For the most part, students learn through guided walkthroughs of topics

which are followed by miniature, single-class, projects. For example, when students learn basic Arduino programming, their first lesson involves them writing small segments of given code to accomplish small objectives (such as printing output, using if/else structures, and parsing input strings). To complete this lesson, teams must correctly code a basic calculator in Arduino. The next lesson then gives students a prompt to design and program a "stopwatch" in Arduino, and allows students the entire class to complete it. This means that there is no dedicated "Arduino" lecture and students spend their class time learning by practicing skills.

The Cornerstone project is a culminating experience for students in ENGR 111 that has teams utilizing all of the skills that they learned earlier in the course. In the Spring 2024 semester, the Cornerstone project was a water filtration system. This project required students to read instructions written in a technical framework to create a control circuit for a pump and valve, then design a program that utilizes those electronics to control the flow of water through a miniature sewage system under "flood" conditions. Students also must incorporate 3D-modeled parts that contribute to the operation of this system.

The lessons that teams complete also serve a secondary purpose of adding a scaffolded framework for students' Cornerstone projects. Immediately after students learn about engineering design, they begin working on their first of two "design challenges", which task them with designing the 3D parts they will use in their Cornerstone project at the end of the semester. When students learn about circuitry, they have a lesson early on that utilizes the same motor driver circuit that they will use to control their pumps and valves in their Cornerstone circuit. Similarly, when students first learn about Arduino programming, their "stopwatch" program design is very similar to a code structure they will need in the Cornerstone program.

It is worth noting that the general structure of the Spring 2024 semester was in the order as stated above. That is, students move through the semester in this order: first design challenge, circuitry, programming, second design challenge, Cornerstone project.

After completing these scaffold lessons, student teams are provided with 3 class days to complete their Cornerstone project. At this stage, students are provided with the final criteria on which their projects will be judged. For example, one objective is that a water pump is controlled to only operate when water is present at the inlet so that the pump does not run dry. However, many of these objectives use skills that require little to moderate adjustment from the scaffolding they learned earlier in the semester. Some of the project requirements, such as the 3D-printed designs, will already be complete by this stage.

This strategy is purposeful, as the scale of the Cornerstone project is quite large if examined out of context. If students were required to complete all project objectives without the previous scaffolding, it would be a daunting task for first-year students. Additionally, it would be logistically challenging to instruct students on the iterative nature of engineering design without providing ample time for students to iterate. The scaffolded nature of the lessons in this course allows for

skill instruction to be spread throughout the course while maintaining the consistent goal of the Cornerstone project objectives.

Ultimately, the pedagogical goal for the Cornerstone project is for students to get a challenging experience utilizing a variety of engineering skills. As this course is required for all students regardless of engineering major, the project is intended to be reasonably interdisciplinary while not overly complex.

Methods

At the end of each semester in this course, students are asked to take a survey that covers many different aspects of the course and its features. This survey was administered electronically, though students were given class time to complete it. IRB approval was gained for the purposes of this study. Completion of this survey was required for a portion of students' course grade.

Among these questions is a qualitative one regarding their experience with the skills they learned throughout the class, and which was the most useful for them while implementing their Cornerstone project. The question specifically stated:

Which of the fundamental engineering skills practiced in ENGR 111 were most useful in completing your Cornerstone project and why?

In the Spring 2024 semester, 370 students filled out the end-of-semester survey as a whole. Of those students, 318 provided answers to this particular question. These responses were categorized based on the subject areas that students mentioned, and the most commonly repeated themes are presented in this study

Results and Discussion

The responses that students provided to this survey question were sorted into 6 categories that were commonly mentioned. The frequency of these categories being mentioned are shown in Table 1 below.

Table 1: Occurrences of most mentioned topics in survey results.

Category	Number of Mentions	Percentage of Responses
Programming	161	50.63%
Teamwork / Communication	91	28.62%
Circuitry	67	21.07%
3D Modeling / Printing	50	15.72%
Design / Problem-Solving	35	11.01%
Critical Thinking	12	3.77%
Other	5	1.57%

It's worth noting that these responses do not add to 100% as some students mentioned more than one topic in their response. Table 2 below shows the number of topics that students mentioned in their responses.

Table 2: Number of topics mentioned in survey results.

Number of Topics Mentioned	Number of Students	Percentage of Students
1	237	74.53%
2	60	18.87%
3	16	5.03%
4	5	1.57%

Based on the above results, there are some interesting trends. Firstly, programming being the most mentioned topic is not very surprising due to the structure of when students perform the various pieces of the Cornerstone project. While the project does contain a variety of subjects, items like their 3D-printed designs are entirely completed before they reach the end of the semester. Additionally, most of the circuit they used in the Cornerstone project is the same as a circuit they used in a previous lesson. While students do learn programming techniques that are highly relevant to their projects in earlier lessons, the code that they create during the project is still new to them during the allotted Cornerstone project days in the schedule. Additionally, this course is taught by multiple instructors due to the large enrollment of the course, so there may be inconsistency regarding how the scaffolded items are presented in relation to the Cornerstone project. For example, students may not be explicitly told that their 3D-printed designs are a part of their Cornerstone objectives when the are completing the design.

Alongside the course skills that students mentioned is the reasoning students used for their response. As this is a qualitative question, students have the ability to elaborate on the reason why they selected a particular skill or skills. Below are some common themes amongst student responses in the survey results. Each theme includes a few sample quotes that are representative of the theme.

Relevance to Cornerstone Project:

> *"Programming was the most useful when completing the cornerstone project. The majority of the assignment required code, while only a few parts dealt with circuitry and 3D modeling."*
>
> *"Cooperation and effort, because without these, the 4 man project would not have gotten completed on time."*
>
> *"Circuitry was the most useful engineering skill that I used while completing the Cornerstone project, because it linked everything together and allowed the system to function."*

Some student responses explicitly mentioned what they perceived to be most relevant or pervasive in their project. This was one of the more expected outcomes of this survey question. Perceived importance is a crucial part of how students will consider what they learn useful. While many of the responses of this natures mentioned programming, there were some that mentioned other topics as well.

Ultimately, some of this data could be the result of instructor communication. As 3D modeling and explicit lessons on the engineering design process take place earlier in the semester, students may lose track of how those lessons impact their performance on the Cornerstone project.

Individual Contribution to Cornerstone Project:

> *"To me, the circuitry was. It was what I worked on the most and what I understood the most."*
>
> *"Programming, because I was the person who did the programming."*
>
> *"For me personally it was the CAD stuff we learned in class that helped me most with the cornerstone project because that was my part in our team."*

Some student responses mentioned that it was based on how they contributed to the project. There were a fair number of responses like this that said the most useful skill involved in the project was the skill they used most personally.

Interest in Skills:

> *"3D printing, was the thing I liked the most."*
>
> *"Circuitry because I am electrical engineering."*

Others seemed to pick topics based on preference. While not as helpful for the purposes of this study, this does indicate that interest plays an important role in how students perceive the skills they are taught.

Difficulty of Skills:

> *"Programming, the Arduino program parts of the cornerstone project were the most difficult and involved."*
>
> *"Definitely programming since that was for sure the most difficult part of the project."*

Some students mentioned difficulty as the motivation for the most useful skill in the project. In particular, most students who mentioned difficulty did so with respect to programming. This is a theme that is of great importance to instructors as a large sample could indicate that lessons are

not appropriately preparing students for the Cornerstone project. However, only about 13% of responses fit this theme of mentioning difficulty.

Ultimately, the major themes present in student responses to this survey do not show any concern of inability to complete the Cornerstone project. While some students mentioned how using certain skills was a challenging experience, no student responses indicated that such an experience was overbearing or impossible.

Conclusions and Future Work

The most mentioned skill in this survey was overwhelmingly programming, which was also the most mentioned skill in conjunction with difficulty. This has been anticipated by instructors through anecdotal communication with students throughout the course. The course's current curriculum is designed to provide students with basic skills for each aspect of the Cornerstone project, of which programming is just one piece. Additionally, the final project of a hands-on engineering course involving challenging portions can be a positive influence for student learning if it isn't overwhelming.

As previously stated, the purpose of this study is to examine how prepared students feel for their Cornerstone project experience. Survey results indicate that while some students find certain skill requirements in the final project to be challenging, the majority of students do not mention any issues of this nature. Additionally, students mentioned a variety of course skills, which promotes that the project is somewhat balanced in terms of its interdisciplinary nature. While programming is more heavily mentioned than other skills, there are instructional communication reasons as to why this may have occurred.

In the future, instructors may consider the balance of instructional time as it pertains to the results of this study. Students may need more time to practice programming than they are currently given. Additionally, communication with students about what semester work constitutes a portion of the Cornerstone project should be revised to be clearer. Another consideration is the balance of which work is completed prior to the end of the semester versus the work completed during the project-allotted days at the end. Another potential future endeavor includes looking further into this survey data based on demographics such as gender, ethnicity, and declared engineering major to see how those may have affected student responses.

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