2023 Annual Conference & Exposition
Baltimore Convention Center, MD | June 25 - 28, 2023
The Harbor of Engineering Education for 130 Years
Paper ID #39304

Mechatronics Research Projects: Engaging First-Generation Students and Others

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Abstract

Retention of students within Mechanical Engineering, particularly first-generation students, is a challenge for many Mechanical Engineering programs. Collaborative, project-based learning has been shown to improve retention in first year students. Microcontrollers offer an increasingly easy to use and affordable platform for engaging project-based learning at all levels of the Mechanical Engineering curriculum. In this paper, the use of microcontrollers for collaborative, project-based research projects in a first-year programming course will be examined. In this course, a scaffolded set of three projects took the students from an initial sound and light display project to a full, mechatronics-based, research project. In this final project, teams of students learned about research, developed a hypothesis, designed a microcontroller-based experimental design, analyzed data using Matlab, and presented the results publicly to the university community. Surveys of students participating in the course assessed what factors in the course most supported their learning. Students responded that project team members formed an important support to their learning outside the classroom along with office hours. This survey demonstrated the importance of developing community with such project-based learning. Additionally, survey results demonstrated that first-generation students may have additional obstacles to their learning outside the classroom including family and work responsibilities. Finally, the survey results indicated that including a project focused on engineering research increased students' knowledge of and interest in the research enterprise of the university.

Introduction

Prior to the pandemic, the Mechanical Engineering department had begun a careful examination of the retention of first and second year students and, in particular, underrepresented and disadvantaged groups including women, underrepresented minorities, and first generation students [1]. In this work, it was found that retention of women to graduation was as good (87.8%), if not better, than other students (77.6%). However, under-represented minorities (65.4%) and first-generation students (64.7%) did not fare as well. A number of studies have demonstrated that first generation students, in particular, face some unique challenges [2]–[5]. These students can lack the cultural capital their continuing peers have including the skills and knowledge to build social networks with their academic peers and the ability to tap institution resources.

These observations have encouraged us to consider implementing changes to our freshman level courses that can support the development of social networking skills and encourage the identification and use of resources such as faculty and graduate teaching assistant office hours. Additionally, over the pandemic we have seen our undergraduate students become disengaged with campus life and with the research enterprise of the university. We have seen fewer students participating in undergraduate research and fewer graduates considering graduate programs. To tackle these issues, this paper will examine collaborative, project-based learning in a freshman, Mechanical Engineering programming course. This course teaches basic programming skills using a low-cost microcontroller platform (Arduino Uno) that is programmed in the C++ programming language and Matlab, a programmable numerical computing platform. To engage students in developing community, collaborative team projects have been created. These scaffolded projects started with a simple sound and light display and culminated in a mechatronics research project in which teams learn about research, develop a hypothesis, create an experiment to test the hypothesis using the Arduino Uno platform, and analyze the data using Matlab. The teams prepared a research poster to present publicly to the university community. In this paper we will examine the design of these projects and the impact of this collaborative, project-based work on supporting learning and encouraging engagement in research in all students and in first-generation students.

Course Overview

At the University of Kansas, the course ME 208 Introduction to Digital Computing Methods is a 3 credit hour course required of all first-year Mechanical Engineering students. The course's primary objective is to introduce Mechanical Engineering students to programming and to prepare students for subsequent courses including courses in numerical methods, experimentation and instrumentation, and system modeling. This course also serves as one of three courses introducing first-year students to Mechanical Engineering. While the course has existed for some time, it began a transition to its current form in Fall 2019. The course introduces students to C++ programming on the Arduino platform and programming in the Matlab numeric computing platform. The course focuses on fundamental programming concepts such as variables, conditional statements, loops, arrays, and functions and on programming applications in mechanical engineering.

The learning outcomes of the course are that a student should be able to:

- Break down engineering problems into logical steps and code those steps in computer code.
- Write programming code from scratch and problem solve errors until a goal is achieved.
- Program in the C++ programming language in the context of Arduino microcontrollers
- Program in the Matlab programming and numeric computing platform
- Apply programming methods to the solution of engineering problems including recording data and solving mathematical problems.

The course has three major components, a 1-hour weekly lecture, a weekly laboratory session (currently 2 hours), and a weekly discussion section for project team meetings (Figure 1). Since Fall 2019, the pandemic had a significant impact on the structure of the course. In Fall 2020 and Spring 2021, the course operated in hyflex mode with students both in the classroom and attending remotely. The transition to hyflex required several modifications including the development of pre-recorded tutorial videos and the incorporation of the Microsoft Teams team collaboration hub for connecting project teams.

Fall 2020 hyflex	Spring 2021 hyflex	Fall 2021 in person	Spring 2022 in person	Fall 2022 in person
Monday, 1 hour Zoom overview	Monday, 1 hour Zoom overview with teams active learning online	Monday, 1 hour Active learning with teams	Monday, 1 hour Active learning with teams	Monday, 1 hour Active learning with teams
Prerecorded Tutorial Videos	Prerecorded Tutorial Videos	Prerecorded Tutorial Videos	Prerecorded Tutorial Videos	Prerecorded Tutorial Videos
Discussion MS Teams 2 group projects	Discussion MS Teams 3 group projects	Discussion MS Teams 3 group projects	Discussion MS Teams 3 group projects	Discussion MS Teams 3 group projects
Lab – 1 hour hyflex	Lab – 1 hour hyflex	Lab – 2 hour	Lab – 2 hour	Lab – 2 hour

Figure 1 The course has transitioned several times over the pandemic. In Fall 2020 and Spring 2021 the course was taught hyflex, with both online and in person students. Labs were shortened to 1 hour to allow for more sections with smaller class sizes to prevent COVID spread. From Fall 2021 on, the course returned to a traditional, in person, structure. Two pandemic elements were retained, pre-recorded tutorial videos that covered primary course topics and project team meetings on the Microsoft Teams team collaboration hub.

The course consists of several assignments (Figure 2):

1. Weekly active learning assignments within the Monday lecture. Students are encouraged to work with their project team to complete these Canvas quiz assignments in class.
2. Weekly individual lab assignments that allow students to practice key programming concepts. Students complete a programming assignment and receive immediate support and feedback from the instructor and/or graduate teaching assistants.
3. Weekly individual homework assignments that build on the lab assignments.
4. Three exams, two on Arduino C++ programming and one on Matlab
5. 3 projects (2 in Fall 2020) that are completed by project teams with weekly deliverables and end of project reports.

A secondary goal of the course is to encourage retention of first-year mechanical engineering students through engaging content and community development. Previous work in the department identified retention of first generation students as a significant issue [1]. Firstgenerations students can have several definitions, here we will use the definition of students whose parents/guardians have not completed a bachelor's degree. At the university, only 64.7% of first-generation students who started in Mechanical Engineering graduated from the university within 6 years, compared to 79.8% of continuing generation students [1]. This compares to 87.8% of female students and 65.4% of under-represented minorities [1]. Since research has found that first-generation students can lack the cultural capital and social networks of their continuing education peers, an important goal for this course is to help all students develop these networks through:

1. Developing student teams to facilitate networking through group projects and active learning exercises,
2. Inclusion of graduate teaching assistants in group deliverable discussions to facilitate personal connections,
3. Deliberate communication of course expectations through the course learning management system and in class announcements, and
4. Availability of an online discussion platform to encourage questions and communications through Microsoft Teams.

Week		Monday Lecture Active Learning Exercises with Project Teams	Individual Laboratory Exercises	Individual Homework Exercises	Project	Project Deliverables
0	Introduction, Arduino: Digital I/O, LED	MLK Day	LED blink	LED blink	Project 1: Arduino Sound and Light Display	Deliverable 1
1	Arduino: If/else, Button, Switch, Piezospeaker	Active Learning	Button, Speaker	4 Button Piano		Deliverable 2
2	Arduino: Analog input, Serial commmunication	Active Learning	Analog Input	Night Light		Deliverable 3
3	Arduino: Loops, Arrrays, Ultrasound Distance Sensor	Active Learning	Distance Sensor	Mean Distance		Report
4	Arduino: Analog Output, RBG LED, Functions	Exam 1	RGB LED	Proximity Light	Project 2: Arduino Useful Device (Sensor & Motor)	Deliverable 1
5	Arduino: Servomotor, LCD, Functions, Flowcharts	Active Learning	Servomotor, LCD	Stopwatch		Deliverable 2
6	Arduino: Functions with Arrays and Gearmotors	Active Learning	Gear Motors	Hypnodisk		Deliverable 3
8	Arduino: Review	Active Learning	Serial Communication	Data Collection		Report
9	Matlab: Basics, Plotting	Exam 2	Retirement Analysis	EMG Data Analysis	Project 3: Matlab and Arduino Hypothesis-Driven Research	Deliverable 1
10	Matlab: Loops, Arrays, Statistics	Active Learning	Mean, Standard Devation	Linear Regression		Deliverable 2
11	Matlab: If/else, Statistics	Active Learning	Conditional Statements	Statistics in Data Analysis		Deliverable 3
12	Matlab: Functions	Active Learning	Functions	Map Game		Deliverable 4
13	Matlab: Numerical Methods	Active Learning	Euler's Method	Tank Game		Thanksgiving
14	Matlab: Numerical Methods	Active Learning	Root Finding	Thermodynamics Eqn. Solving		Deliverable 5
15	Wrap up, Review	Active Learning				Report
	Final Exam	Final				

Figure 2 The course structure includes active learning exercises, laboratory exercises, homework exercises, and three projects. The individual labs and homework exercises change each semester. During Fall 2020, only 2 projects were present. The first project was added the following semester. In Fall 2021, the third project was transitioned from a Matlab game design competition to the research project described in this paper and figure. (Figure modified from [6]*)*

For the course, the students are asked to purchase the Sparkfun Inventor's Kit (Sparkfun, Niwot, CO). This kit was selected as it has a good supply chain and reliable components that made it accessible for a large class. The kit contains and Arduino Uno style board (either the Arduino Uno or Sparkfun Redboard depending on the kit ordered), two motor types (servo motor and gear motor), an array of sensors (photoresistor, temperature sensor, potentiometer, switches and buttons), LEDs (both simple and RGB), and an array of jumper wires and resistors. Students are able to access the Arduino IDE software for free and have access to a university license for

MATLAB. Finally, we use tinkercad.com as a useful site for prototyping and simulating the Arduino Uno board and programming.

Projects

With the exception of Fall 2020, when only two projects were present, three team projects were created for the course. The overall goals of these projects were to develop community within the student groups, to have the students practice teamwork skills, and to allow students to use their programming skills creatively. Teams typically consisted of 5 to 6 students. Microsoft Teams was used to build team collaboration. Microsoft Teams allows groups to organize their work and to easily collaborate and show their work. Group members were able to send chat messages, video meet, and communicate in other ways with each other and with the instructor and graduate teaching assistants.

The first project was added in Spring 2021 to allow for team development earlier in the course, when programming skills are still limited. In this project, the team creates a sound and light display using LEDs and a piezospeaker. The teams work together to create the wiring diagram and code and to complete a project report. However, every member of the team must build their own version of the project and create a video demonstrating their working version. This simple project was created as a warm up to allow the teams to work on team dynamics while the skills learned in class were still limited.

In the second project, the teams were given free range to create a useful device. The requirements for this second project were that the device needed to include at least one sensor and one motor. The device needed to have a useful purpose or function. It could perform a task or demonstrate a scientific principle. Devices that have been created for this project include a toilet flusher, an automated cooling fan, and a roving alarm clock. Like the first project, each team designed and coded the project as a team. The team submitted a group report. In addition, each team member was asked to build their own version of the device and create an individual video of their version of the device. In Spring 2023, this project was shifted to a specific task, design of an automated animal (cat/bird/dog) feeder.

The third project is the focus of this paper. In this third project, students were asked to develop a hypothesis and test that hypothesis using their Arduino microcontrollers and available sensors (both those in their kits and others available from the department). They were asked to collect their data using the microcontrollers and then use Matlab to analyze the data. This project was initiated in Fall 2021 when we returned to in person learning (prior to that the third project was a Matlab game design contest). The learning objectives of this project were for the students to:

- Be able to formulate a research question/ hypothesis
- Be able to integrate data collection using the Arduino Uno and data analysis using Matlab

- Be able to use one of two basic statistical methods to assess their hypothesis (t-test or linear regression)
- Be able to display data graphically and communicate their results in a research poster

This 6-week project had weekly deliverables culminating in a final report and research poster. The teams presented their posters and an associated presentation video at the university's virtual research showcase. The deliverables included interviewing faculty about engineering research, developing their own research questions, developing an experimental setup using their Arduino Uno board, developing Matlab code to analyze data, and creating their research poster and presentation. As part of the research, the students used a Microsoft OneNote within Microsoft teams as a laboratory notebook. Each week, while meeting with their assigned graduate teaching assistant, the team would present their deliverable from their laboratory notebook during a Microsoft Teams meeting. Every member of the team was expected to be the lead presenter for a deliverable at least twice during the semester and every team member need to be present (or have an excused absence) to receive credit for the deliverable.

Assessment of the Third Project

A rubric was created and implemented through grading software to assess the third project posters and reports. The rubric has seven dimensions:

- project requirements,
- background and research question,
- researcher interview,
- methods,
- results and graphs,
- cohesiveness, conclusions, and layout, and
- spelling and grammar.

Students are evaluated at four levels, expert, proficient, apprentice, and novice (Appendix 1).

Survey

During the five semesters encompassed by this paper, a survey was conducted to assess the course's components and how well they did or did not support learning. The survey also assessed what obstacles to learning were present. 88 students (of 393 students from Fall 2020 to Fall 2022 (22% of all students)) participated in the anonymous, end-of-term survey with approval of the University of Kansas Human Subjects Committee. For this paper, two primary questions were examined and compared between three groups (all students, first generation students, and under-represented minorities):

1. How important were each of the following resources in supporting your learning?
    a. Professor’s office hours
    b. Graduate teaching assistants’ office hours
    c. Project team members
    d. Other classmates not in team
    e. People outside class
    f. Internet source: Arduino.cc
    g. Internet source: Mathworks.com
    h. Other internet sources
2. How much were each of the following obstacles to your success in this class?
    a. Work responsibilities
    b. Family responsibilities

For the class as a whole, the students who responded to the survey relied heavily on their project team members and the graduate teaching assistants for supporting their learning (Figure 3). For first generation students who responded, they reported a heavier reliance on the professor and graduate teaching assistants but still also received very important support from their project team members (Figure 4). Underrepresented minority students reported relying more heavily on the graduate teaching assistants and their project team members (Figure 5).

In looking at obstacles, only 9% of the class as a whole reported work responsibilities as a major obstacle and 10% reported family responsibilities as a major obstacle. For first generation students, 30% reported work responsibilities as a major obstacle and 20% reported family responsibilities as a major obstacle. For under-represented minorities, 7% reported work responsibilities as a major obstacle, and 14% reported family responsibilities as a major obstacle. From these results, it is clear that first generation students in particular struggle with significant outside demands that could impact their course performance.

Only about one quarter of all students responded to the survey, so this may not be fully representative of all students. It is possible that these responses represent students who are more vested in the course and may not reflect those who are less vested. Some semesters had better participation than others. We saw 38% of students participate in Fall 2020, but participation dropped the following semester.

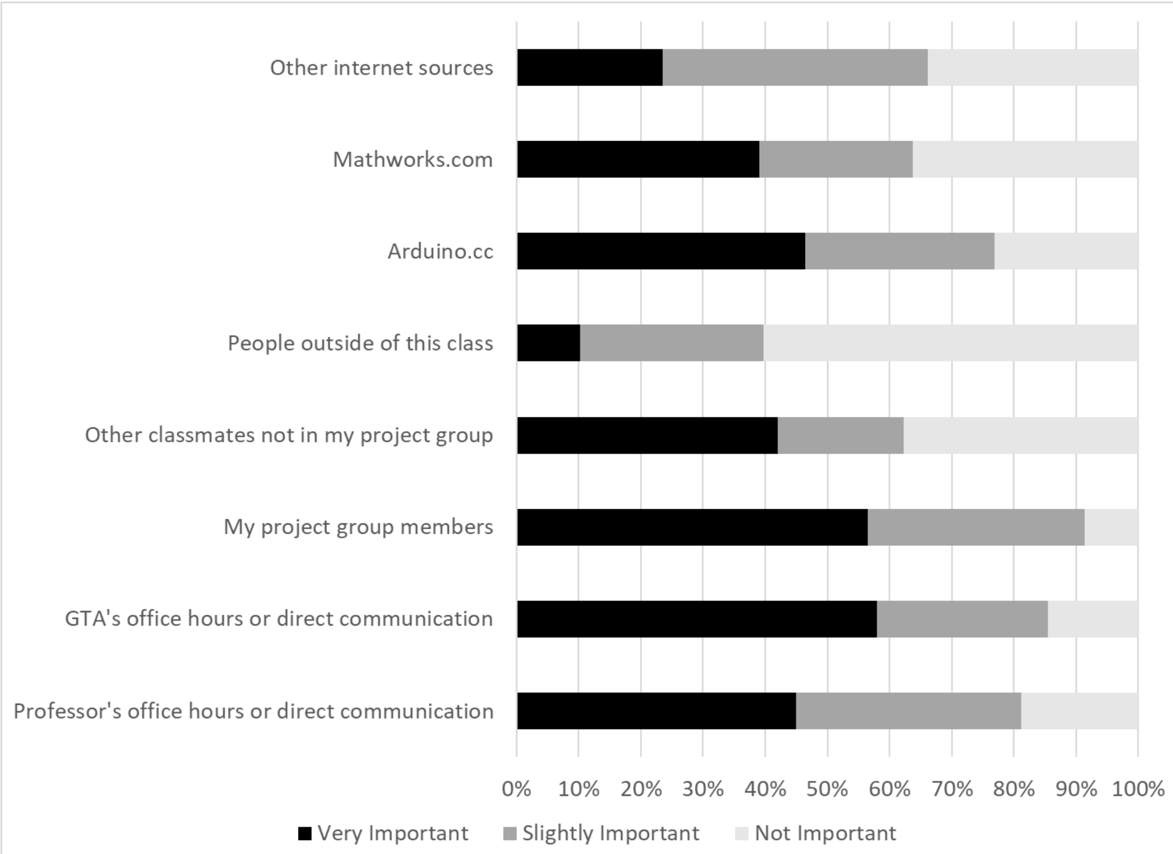

Figure 3 Answers to the question "How important were each of the following resources in supporting your learning?" for all participants of the survey. Overall, the students relied on the graduate teaching assistants, their fellow team members, and the professor's office hours for support.

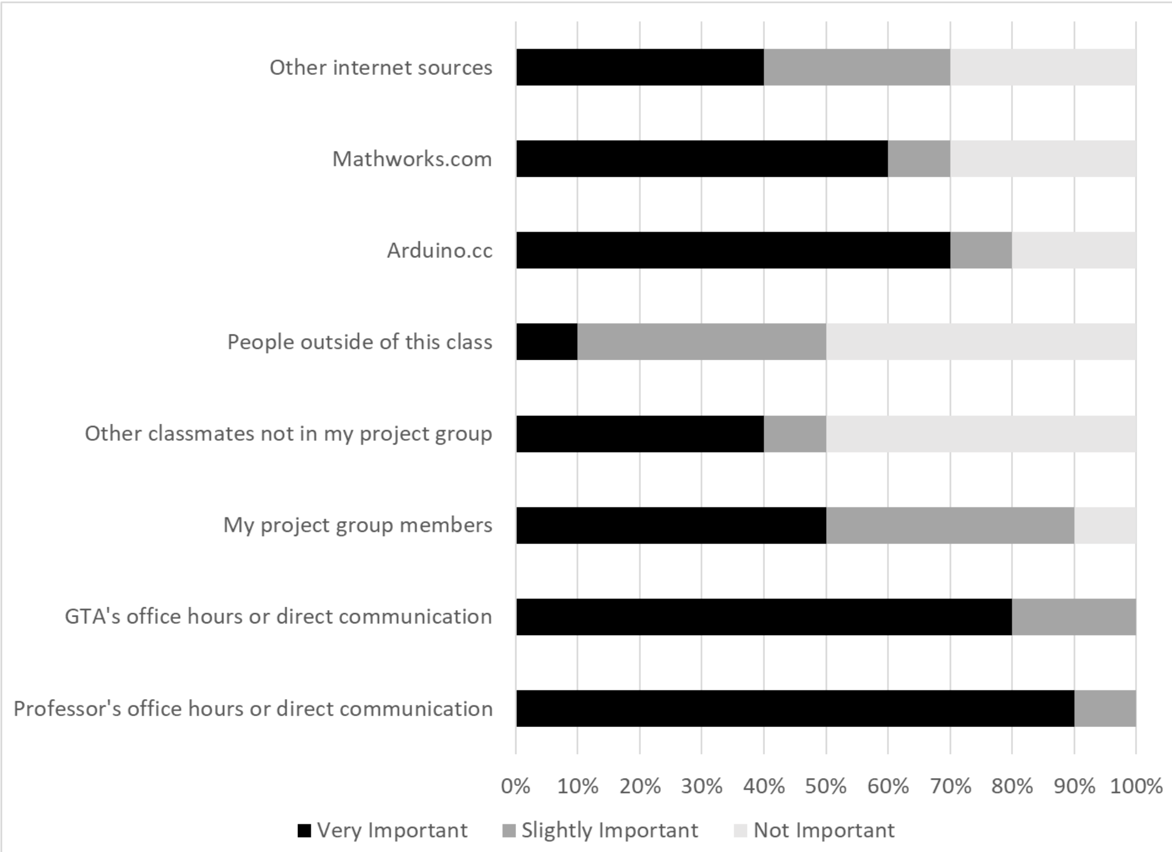

Figure 4 Answer to the question "How important were each of the following resources in supporting your learning?" for first generation students. First generation students reported relying more heavily on the professor and graduate teaching assistants for support, but still found support also from their team members.

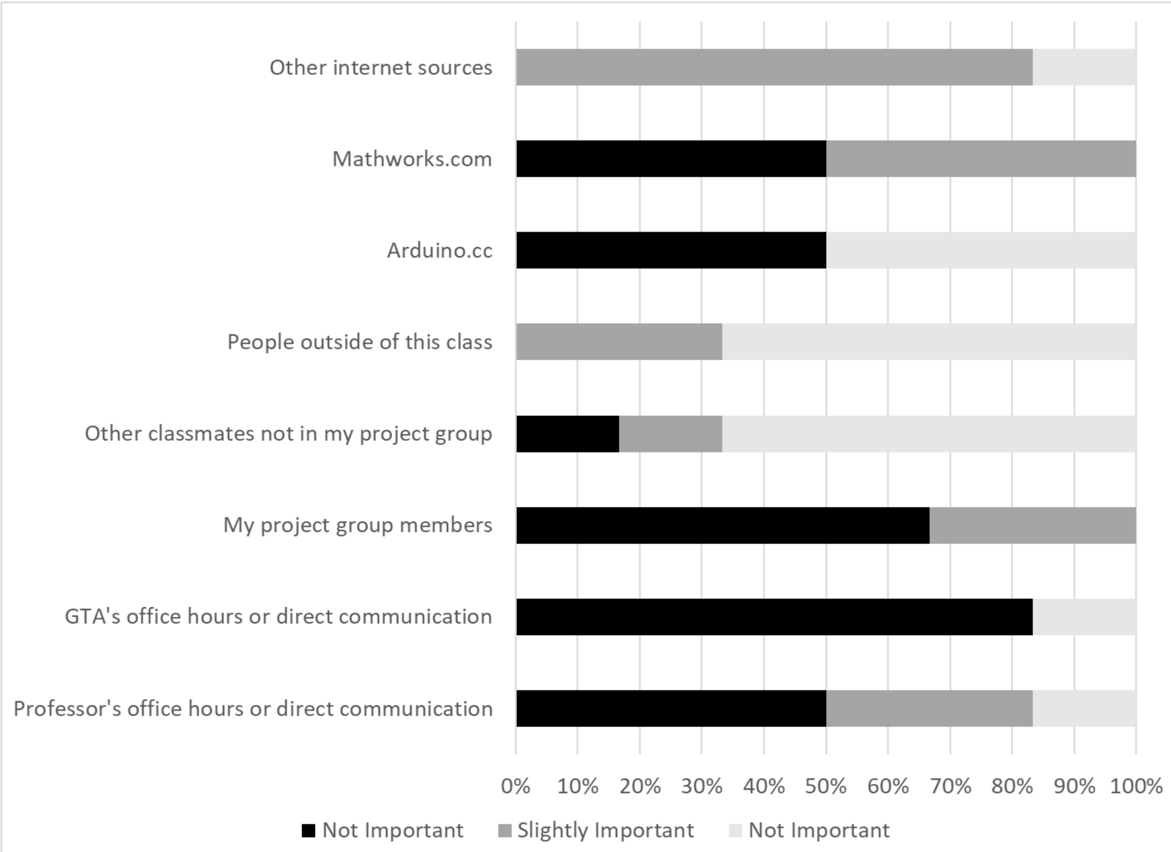

Figure 5 Answer to the question "How important were each of the following resources in supporting your learning?" for under-represented minority students. URM students reported relying more heavily on the graduate teaching assistants and project team members for support.

Reflections on the Mechatronics Research Project

This course has been evolving over the several years, and in the face of a global pandemic, to better engage Mechanical Engineering, first-year students to improve retention and connection with the discipline. The team projects were created to develop teamwork skills while also encouraging community building within the student population. Findings from previous work suggested we particularly needed to build support for first generation students who might lack the cultural capital and networks of their continuing generation peers.

Group projects have been important in creating a sense of community and connection among students in the course. In Spring 2020, after shutdowns, students had just completed a project with Arduino microcontrollers and were moving to working with Matlab. Given the difficulties of the early weeks of the pandemic, attendance at Zoom lectures was optional (sessions were recorded), and often focused on answering student questions. While coordinating group projects proved difficult, several students found them helpful for preserving a sense of connection and community in a difficult semester. This has continued has we have moved from the initial shutdown to hyflex and back to in person classes.

Many of the student groups have formed connections that extended beyond the required interactions. When the course was taught in-person, these group bonds also extended to student interaction in the classroom, leading to more efficient group work and a better sense of community within the classroom. The teams also provided a space for instructors and graduate teaching assistants to interact in an informal way with the groups—answering questions, facilitating group work, monitoring progress, and interacting informally with students even when the course was not meeting face-to-face (or between class sessions, when the course was in person).

The mechatronics research project was started in Fall 2021 as a response to a disconnect observed in our undergraduate students. Undergraduate students were less involved in campus life after a year of hyflex courses and less aware of the research enterprise within the university. Graduate school recruitment had fallen due to this disconnect. Our students were less active in undergraduate research participation. The mechatronics research project was created to engage students in research. In Fall 2022, a question was added to the survey examining the impact of the third project and participating in the university research showcase. The participants were asked if, after project three, they:

- Understood more about research in engineering
- Had increased interest in participating in undergraduate research
- Understood more what graduate students do for research
- Understood more about what professors do for research
- Understood more about how coursework was connected to engineering work

From the survey results, it is clear that the project did increase understanding of the research enterprise and the role of their graduate teaching assistants and professors in it (Figure 6). It also demonstrated that the project helped the students better understand how the course connected with engineering work generally.

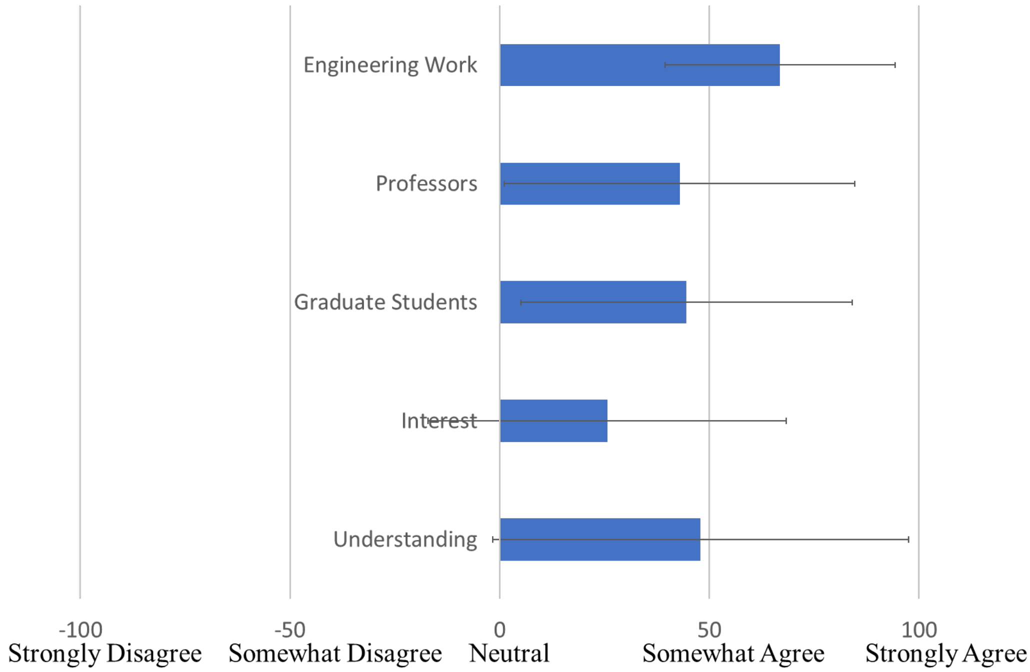

Figure 6 Answer to the question "After project 3, I understand more about.." Project 3 increased students understanding of the connection between the course and engineering work, the research activities of professors and graduates, and research in engineering generally. Most respondents indicated that the project increased their interest in undergraduate research.

Conclusion

In conclusion, collaborative, project-based learning can help to create community among first year students. Survey results suggest that such activities can create a support network, particularly for our first-generation students. A project focused on research has the potential to engage first-year students in research at the beginning of their academic career. Programmable microcontrollers such as the Arduino Uno offer a platform for simple research projects that can teach students about the research cycle and prompt interest in further undergraduate research. In the future, we will continue to refine this course. The purchased kits have a limited number of sensors that can limit the types of research questions that may be asked. While other sensors are available from the department, only a few groups have accessed them. In the future, we will look at ways to encourage exploring a broader array of sensor options. In the future, we would also like to examine the downstream impact of these changes. Are more students following through and becoming engaged in undergraduate research? Do students do better in downstream instrumentation and experimentation courses? Finally, while it may be difficult to separate pandemic related impacts, we would like to examine how retention to the sophomore year has been impacted by these course changes.

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Appendix

Project Assessment Rubric

	Expert	Proficient	Apprentice	Novice
Project Requirements	Project meets all requirements: 1. Develop a hypothesis that can be tested using one of the available sensors. 2. Use the Arduino-board and at least one sensor. 3. Use Matlab to analyze the data including either a t-test or linear regression. 4. Create graphics within Matlab to represent data. These could include plots of the data, bar graphs, or histograms.	Project meets most requirements but is missing or incomplete in 1 category.	Project meets many requirements, but is missing or incomplete in 1-2 categories	Project is missing on several requirements.
Background and Research Question	Clear concise background and research question. Hypothesis clearly stated. Hypothesis and research question match with methods and results presented.	Hypothesis and/or research question clearly stated and match methods and results.	Hypothesis and research question stated but not well formed or may not match methods and results.	Hypothesis and research question not clear and not matching methods and results.
Researcher Interview	Research described clearly including a description of overall research questions and methods used by the reviewer in clear language.	Research described with a description of the overall research questions and methods. Language may contain jargon or be less clear.	Overall research questions and methods described but not clearly.	Lack of description of research questions and/or methods.
Methods	Arduino data collection includes description of circuit diagram, sensors used and coding approach. Post processing in Matlab clearly described including statistics. Clear figures used. Methods could be reproduced from description.	Most elements of data collection are described but lacking in a few details that may make the collection more difficult to reproduce.	Several elements of data collection are not described, or figures are unclear.	Significant aspects of the data collection are unclear.
Results and Graph	Clear graphics demonstrate the findings of the research. An appropriate statistical tool is selected (linear regression or ttest or other) to assess the hypothesis. Text complements graphics and makes findings clear to all readers.	Graphics demonstrate findings of the research. Some elements of the presentation of results may be less clear to all readers.	Results are presented both in text and graphically, but some findings are unclear.	Significant elements of the results and graphics are unclear or missing.
Cohesiveness, conclusions, and layout	The poster is clear and well laid out. Research questions align with methods and results. Conclusion summarize findings, explain implications of findings, and describe limitations and/or future directions.	Poster is generally clear. Conclusions could be better formulated.	Poster is disjointed or not well structured. Conclusions could be better formulated.	Poster is poorly structured. Conclusions are lacking in detail such as limitations and future directions.
Spelling and grammar	No spelling &/or grammar mistakes.	Minimal spelling &/or grammar mistakes.	Noticeable spelling & grammar mistakes.	Unacceptable number of spelling and/or grammar mistakes.