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A Model for Course-Based Undergraduate Research in First-Year Engineering

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Abstract

The Association of American Colleges and Universities identifies undergraduate research experiences as a high impact practice for increasing student success and retention in STEM majors. Most undergraduate research opportunities for community college engineering students involve partnerships with universities and typically take the form of paid summer experiences. Course-based Undergraduate Research Experiences (CUREs) offer an alternative model with potential for significant expansion of research opportunities for students. This approach weaves research into the courses students are already required to complete for their degrees. CUREs are an equitable approach for introducing students to research because they do not demand extracurricular financial and/or time commitments beyond what students must already commit to for their courses.

This paper describes an adaptable model for implementing a CURE in an introductory engineering design and computing course that features applications of low-cost microcontrollers. Students work toward course learning outcomes focused on computer programming, engineering design processes, and effective teamwork in the context of multi-term research and development efforts to design, build, and test devices for other CUREs in science lab courses as well as for other applications at the college or with community partners. Students choose from a menu of projects each term, with a typical course offering involving four to five different projects running simultaneously. Each team identifies a focused design and development scope of work within the larger context of the project they are interested in. They give weekly progress reports and gather input from their customers. The work culminates in a prototype and final report to document their work for student teams who will carry it forward in future terms.

We assessed the impact of the experience on students' beliefs about science and engineering, STEM confidence, and career aspirations using a nationally normed survey for CUREs in STEM and report results from five terms of offering this course. We find statistically significant pre-post gains on two-thirds of the survey items relating to students' understanding of the research process and confidence in their STEM abilities. The pre-post gains are generally comparable to those reported by others who used the same survey to assess the impact of a summer research experience for community college students. These findings indicate that the benefits of student participation in this CURE model are comparable to the benefits students see by participation in summer research programs.

Introduction

The Association of American Colleges and Universities identifies undergraduate research experiences (UREs) as a high impact practice for increasing student success and retention in STEM (science, technology, engineering and math) majors [1] [2]. Studies credit undergraduate research with benefiting students' sense of belonging, increasing their interest in graduate studies, and contributing to their development of attitudes and thinking habits important to success in STEM curricula.

The implementation of undergraduate research in a community college engineering transfer program presents several challenges. Most community college faculty do not lead a technical research program and generally lack the facilities and equipment necessary to do so. Community college students typically have limited availability to engage in extra-curricular activities. As a result, the classic mentor-based research model in which undergraduates gain experiences working with graduate students in an established research lab is not generally a viable model for community colleges. Consequently, most undergraduate research opportunities for community college engineering students involve partnerships with universities and typically take the form of paid summer experiences. Even then, many students have limited ability to relocate for summer programs due to other commitments such as family.

Course-based undergraduate research experiences (CUREs) offer an alternative model with potential for significant expansion of research opportunities for students. This approach weaves research into the courses students are already required to complete for their degrees. CUREs are an equitable approach for introducing students to research because they do not demand extracurricular financial and/or time commitments beyond what students must already commit to for their courses. CUREs provide authentic learning experiences, raise the level of expectations for all students, and support the development of a community of learners [3] [4] [5] [6]. These experiences can support students' development of self-efficacy, interest and identity in STEM [4] [7], contribute to improved course outcomes [8], and generally result in higher retention and persistence [9].

The second course in Whatcom Community College's first-year program for entering engineering students, ENGR 151: Introductory Design and Computing, features a CURE in which students research and develop applications of low-cost microcontrollers. Students work toward course learning outcomes focused on computer programming, engineering design processes, and effective teamwork in the context of multi-term research and development efforts to design, build, and test devices for other WCC CUREs in science lab courses as well as for other applications at the college or with community partners. Students choose from a menu of projects each term with a typical course offering involving four to five projects running simultaneously. Each team identifies a focused design and development goal within the larger scope of their project of interest. They give weekly progress reports and gather input from their customers. Their work culminates in a prototype demonstration and final report to document their work for teams who will carry it forward in future terms.

Course Structure

The ENGR 151 course is taught on an 11 week quarter system. It begins with a three week introduction to computer programming and microcontrollers. Class time is dominated by a series of lab activities. Each lab starts with one to three microcontroller circuit tutorials that integrate new programming and electronics concepts before students complete a mini-design challenge to integrate new learning into a small design project implemented on their breadboard. This work is complemented by brief lectures and peer instruction using multiple choice questions on key programming concepts. Homework includes interactive reading assignments, videos, and programming assignments that provide additional coding practice in the context of math and physics applications. The approved course outcomes are listed below.

Upon successful completion of this course, each student should be able to…

1. Apply the engineering design process.
2. Generate design ideas using strategies such as brainstorming and design heuristics.
3. Formulate a detailed specification of constraints and performance criteria by analyzing a design problem.
4. Communicate engineering design work using reporting formats such as proposals, presentations, technical posters, and reports.
5. Develop a project team through practices including peer feedback, communication protocols, team process reflection and meeting documentation.
6. Program a microcontroller to perform tasks involving inputs, outputs, and a control algorithm.
7. Develop and debug computer programs of moderate complexity that include data type control, variable assignments, arrays, loops, branching, and functions.
8. Design, build and troubleshoot simple electronic circuits.

Instruction in weeks four and five shifts focus to an introduction to the engineering design process in the context of a highly scaffolded team project to design, build, and program a model traffic signal as shown in Figure 1. This “warm-up project” provides context for students to practice new programming skills and learn to work with the team they will continue with for the larger research project that follows.

Figure 1. Student teams working on their traffic signal models as a warm-up.

After completing the traffic signal, the research project is assigned. Weeks five through seven also introduce some new programming content as students are engaging with the information gathering, problem specification, and initial idea generation phases of their project. Starting week eight, class time is nearly entirely devoted to student work implementing and troubleshooting their projects. See Table 1 below for more details on how the project integrates with other course topics and activities.

Project Details

CUREs are differentiated from other course-based engineering design projects (e.g. design competitions) by the following characteristics [10]:

- Course outcomes are developed in context of new research questions/directions each term. Research efforts progress and shift focus term-to-term.
- Students engage in authentic practices representative of research in the field.
- Students must troubleshoot, problem-solve, and repeat aspects of their work.
- Students have opportunities to share project results with interested stakeholders outside the classroom.

We describe the fall 2019 course offering to illustrate the approach to the research and development projects. Students ranked their preferences from a menu of five projects. Their preferences were one of the main factors considered when forming student teams along with schedule compatibility and diversity. The project menu for fall 2019 was as follows:

1. Remote Collection of Ticks for Biology Research (started Fall 2018)
2. Stream Flow Remote Monitoring for Geology Research (started Fall 2018)
3. Pump Filter Monitoring for WCC Facilities (new for Fall 2019)
4. Running Code Developed in MATLAB on Arduino Hardware– motor control (started Fall 2018)
5. Spray Chamber Development for Chemistry Research (started Spring 2018)

The detailed project description for option 5 is included below to illustrate the continuous and open-ended nature of these multi-term projects. This is an example of one of the five project descriptions students reviewed to rank their preferences before teams were formed in week 3.

> *A chemistry research project at WCC is investigating the development of doped metal oxide thin films for applications in photocatalysis and photovoltaics (solar cells). The deposition method involves spraying an aqueous solution of nitrate salts on a hot substrate leading to rapid evaporation and thermal decomposition of the nitrate salts into a doped metal oxide film. The project team will develop a low-cost spray chamber that facilitates the application of thin films on a substrate through the controlled application of an even and fine (atomized) mist of the aqueous solution. To date ENGR 151 project teams have developed a prototype system using an ultrasonic atomizer and a repurposed hot plate from the chemistry lab. A team of students further developed and refined the design throughout winter, spring, and summer 2019. The focus areas of the fall 2019 team will be to add a temperature sensing cover to the solution reservoir. The team will*

> *also work toward a user interface system that allows chemistry students to control the operating parameters and collect data without the need to understand MATLAB code.*

The management of the course for the second half of the term simulates the function of a small engineering research and development company. Students start the project by reviewing final reports of previous teams, meeting with their client(s), researching relevant components, and identifying important engineering and physics principles applicable to their problem. They develop a project brief that narrows down the scope of the project to something they think is achievable in five weeks. The project brief presentation in week 6 provides an opportunity to get feedback from their client, the instructor, the lab technician, and the other student teams as they work to formalize their scope into a detailed set of project requirements. The project continues with design reviews in Week 7 that lead to a detailed design proposal, proof of concept testing in Week 9, and a final prototype demonstration and final report submission in week 11. One of the main stakeholders for their final design documentation is the team of students who will pick up where they left off. The general flow of the project milestones in the context of the overall course is shown below in Table 1. Team development is supported with periodic feedback using CATME [11].

Table 1. Project schedule and milestones with concurrent class activities still developing some of the core programming topics in the course.

Week	Project Activities	Other Class Content/Activities
5	Project Assigned Teams have first meetings with customers	Graphing with MATLAB
6	Background Research Project Brief Presentation	Loops Microcontroller Lab (mostly homework) Auto-graded Programming Assignment (homework)
7	Design Review Presentation Design Proposal Due (end of week)	More complex programming Microcontroller Lab (mostly homework) Auto-graded Programming Assignment (homework)
8	Peer Feedback (CATME Survey) Implementation	MATLAB Programming Exam (in class)
9	Proof of Concept Milestones	
10	Alpha Prototype Demonstration Poster Session	
11	Final Project Documentation Peer Evaluation (CATME Survey)	

This project approach has a couple important differences compared to a typical first-year engineering course design project that align more with the CURE model presented above. Each student team generally inherits some prior work, moves it forward a little (or finds a dead end) and then hands off work to new teams the next course offering who will choose new focus areas as each project progresses. This model is more representative of professional engineering work in which engineering teams generally work on smaller pieces of a larger product or system. It also simulates professional work in that future students (not the instructor) are the most important audience for the design documentation work. Another key difference is that each student team works on a different project. This situation helps engender a supportive classroom environment with teams giving each other feedback during design review presentations days that do not repeat five presentations on the same design problem.

Methodology

We chose a pre-post administration of the CURE survey developed by [12] because there is benchmark data available to compare how student responses to the ENGR 151 CURE compares to results from other types of undergraduate research experiences (UREs). The pre-post matched survey items are listed in Table 2.

Table 2. Survey items, referenced by number in the results that follow in figures 2-6.

CURE Survey Items (matched pre and post)	
1. I have a clear career path.	13. I have learned laboratory techniques.
2. I have skill in interpreting results.	14. I have an ability to read and understand primary literature.
3. I have tolerance for obstacles faced in the research and/or design process.	15. I have skill in giving an effective oral presentation.
4. I am ready for more demanding research.	16. I have skill in science/engineering writing.
5. I understand how knowledge is constructed.	17. I have self-confidence.
6. I understand the research process in my field.	18. I understand how scientists/engineers think.
7. I have the ability to integrate theory and practice.	19. I have the ability to work independently.
8. I understand how scientists/engineers work on real problems.	20. I have the ability to work effectively in groups.
9. I understand that scientific assertions require supporting evidence.	21. I am becoming part of a learning community.
10. I have the ability to analyze data and other information.	22. I have a clear understanding of the career opportunities in science/engineering.
11. I have an understanding of science/engineering.	23. I have confidence in my potential to be a teacher of science/engineering.
12. I have learned about ethical conduct in my field.	24. I have confidence in my potential to be a research scientist or engineer.

The following research questions guide our analysis:

- RQ1. Are students making gains on outcomes associated with UREs?
- RQ2. How do outcomes compare to other types of UREs?

We collected survey data over four offerings of the course: spring 2018, fall 2018, spring 2019, and fall 2019. The pre survey was administered at the end of week 2 and the post survey was administered at the end of the course (week 11). In total, there were 72 responses that had a pre/post response match.

Results and Discussion

Figures 2-4 compare responses on the pre and post administration of the survey. Students reported meaningful gains on two thirds of the survey items as shown on Figures 2 and 3. Statistical significance (p-values reported on the figures) is computed with a paired two-tailed t-test.

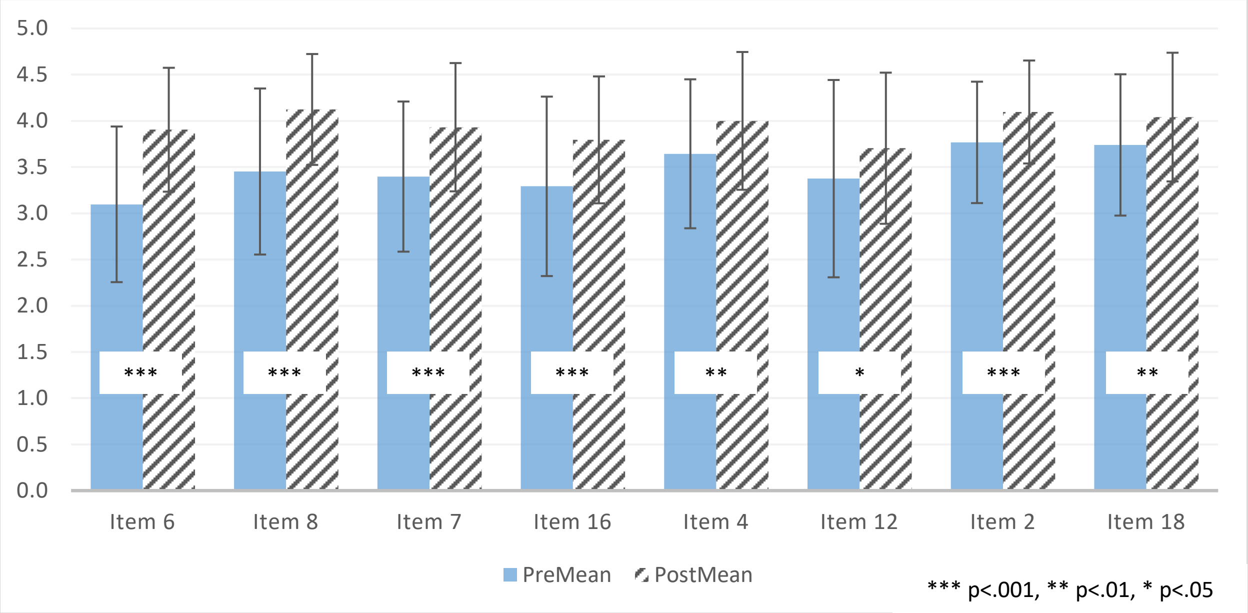

Figure 2. Pre/post survey results for the eight survey items with the largest gains.

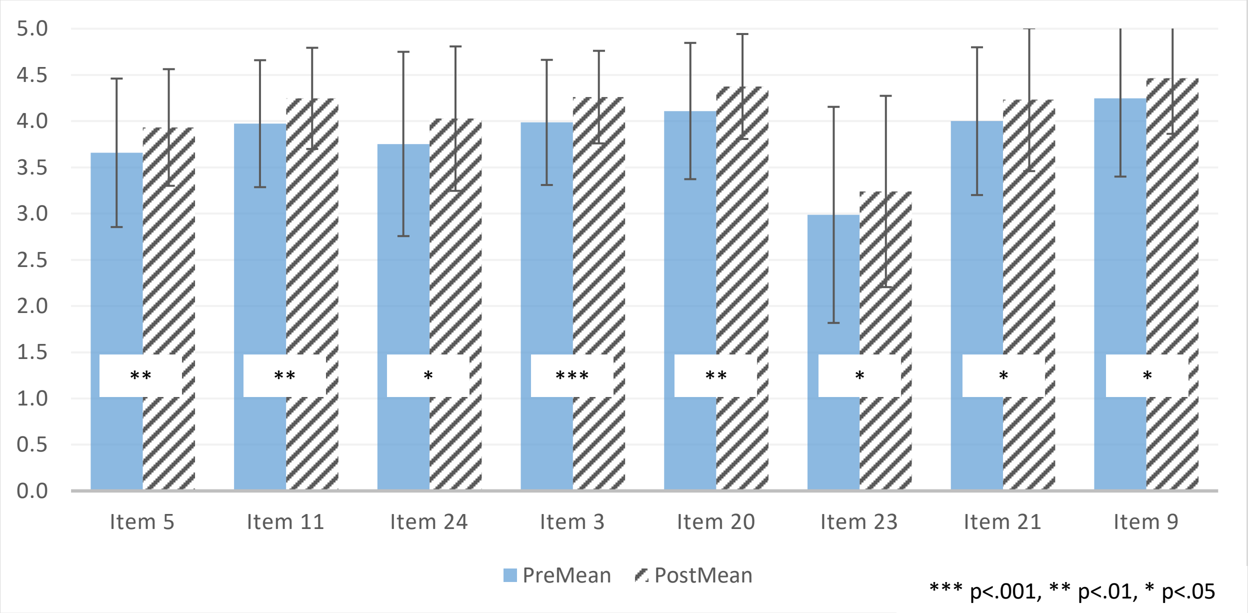

Figure 3. Pre/post survey results for the eight survey items with medium gains.

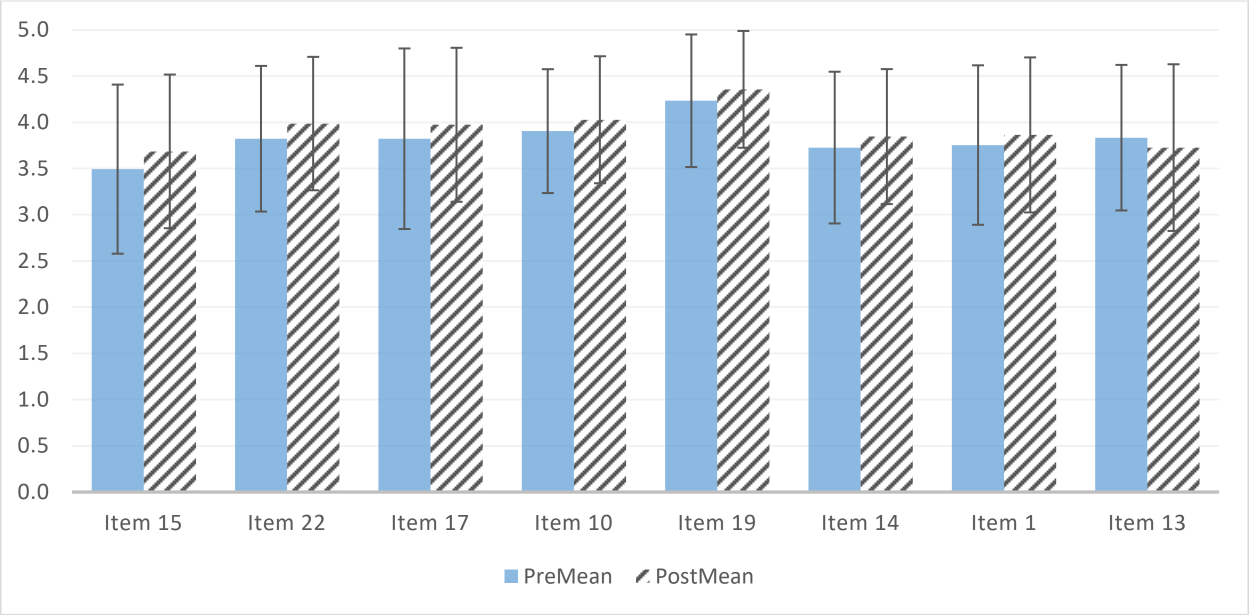

Figure 4. Pre/post survey results for the eight survey items with negligible gains.

To put these results in context of other UREs, we compare to national benchmark data [12] in Figure 5. We see that the post-class survey results for ENGR 151 are higher than the benchmark data for nearly all items. The national CURE benchmark data includes CUREs in all science disciplines at both two-year and four-year colleges but does not actually include any engineering courses. The national SURE survey covers other types of undergraduate research experiences such as summer programs and mentor-based research and includes some engineering experiences. Based on this comparison, we conclude that student reported gains in response to their experience of the ENGR 151 CURE is on the high end STEM UREs nation-wide.

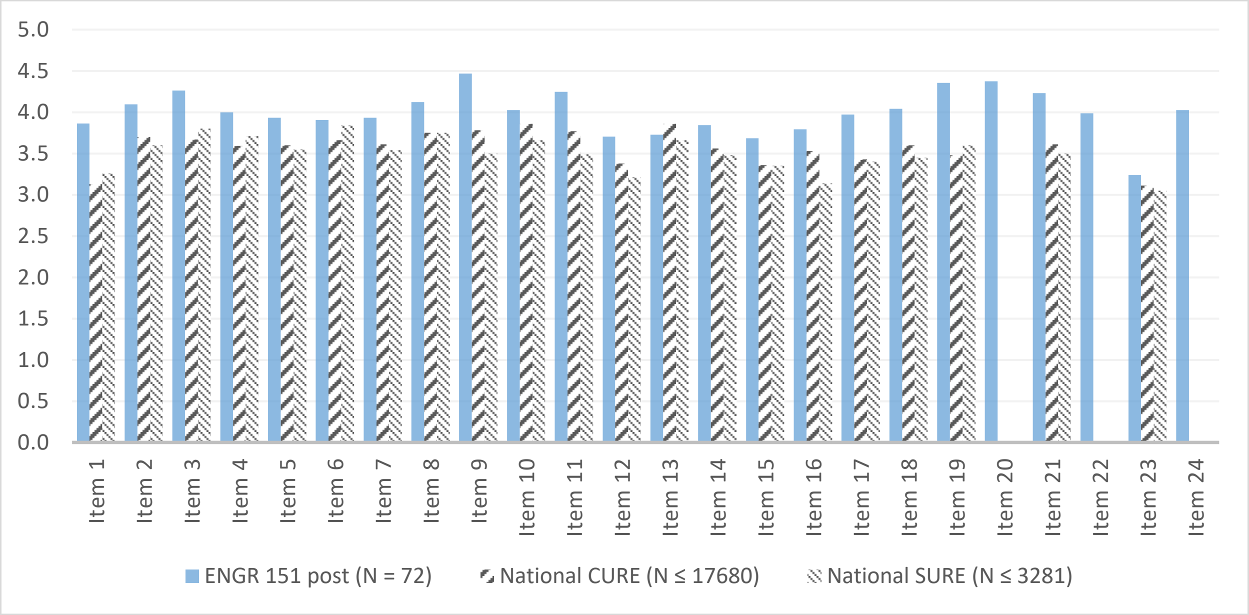

Figure 5. Comparison of ENGR 151 post-course survey data to national benchmarks.

We found a potentially more relevant comparisons in survey data reported on a summer URE for community college students [13]. Figure 6 compares pre/post gains in the current study with those reported in [13]. We find that the ENGR 151 CURE students reported significant gains ($p<.05$) on items 2-9, 11, 12, 16, 18, 20, 21, 23, 24 compared to reported significance on items 2, 3, 6-8, 10, 15, 16 in the summer experience. This result provides evidence that the CURE impacts on students are comparable to the impacts of the summer research experience.

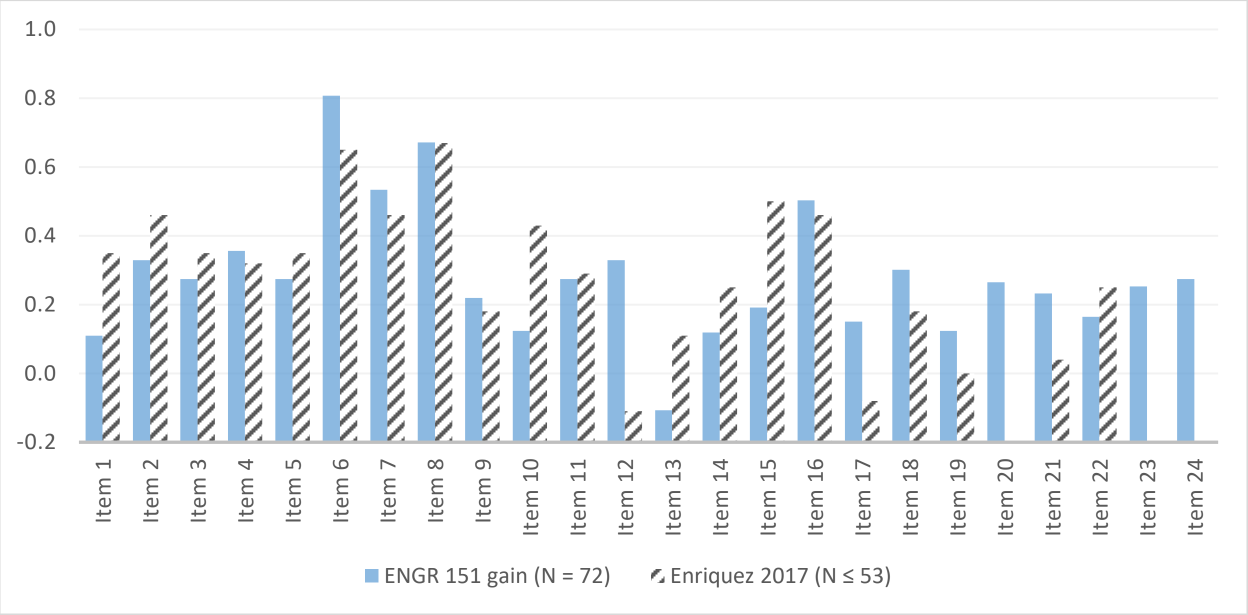

Figure 6. Comparison of ENGR 151 pre/post gains to those reported for a summer research program for community college students [13].

Conclusions

This paper presents a model for embedding a research experience into a first-year engineering computing and design course taught at a community college. Student teams contribute to multi-term projects developing a variety of microcontroller applications with multiple stakeholders beyond the classroom. Survey results and comparison to benchmark data indicate that students perceive they are making gains on multiple skills and attitudes that have been connected to undergraduate research experiences in general. This CURE model offers an approach to exposing larger numbers of students to authentic research experience in a way that can be delivered within the practical limits of the community college setting.

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