Project-Based Active Learning Techniques Enhance Computer Programming Academic and Career Self-Efficacy of Undergraduate Biomedical Engineering Students

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Introduction

During the past two decades, active learning techniques have received a growing attention in educational research. Particularly in science, technology, engineering, and mathematics (STEM) fields, traditional lecturing has indicated a 55% increase in failure rates of undergraduate students, compared to active learning methods [1]. Furthermore, active learning has proven to significantly enhance students' examination performance and educational achievements compared to passive learning [1, 2]. In Biomedical Engineering (BME), active learning can be incorporated through various techniques such as problem- and project-based learning [3]. Such approaches lead students to a deeper and more efficient retention of new concepts. Moreover, these methods provide students with the opportunity of active engagement in class sessions and applying course materials into solving real-life problems.

Initially proposed by Bandura in 1977, self-efficacy is a term that describes "the belief in one's capabilities to organize and execute courses of action required to produce given attainments" [4, 5]. Perceived academic self-efficacy has been increasingly considered as a highly effective predictor of students' motivation and persistence [6, 7], as well as an important contributor to their academic development [4, 5, 8]. Career decision-making self-efficacy is of equal, if not greater importance in engineering education, as it reflects students' ability to make an informed decision about a career path to pursue in the process of securing meaningful employment [9]. Several studies in the literature also suggest that self-efficacy is closely linked with stress and anxiety, affecting students' performance, overall wellness, and personal adjustment in direct and indirect fashions [10-13]. In other words, students with higher levels of academic and career self-efficacy tend to demonstrate higher motivation, more strategies in their self-regulated learning, have higher achievements, and undergo lesser stress and anxiety [10]. Hence, understanding self-efficacy in academic settings is of great importance to enhance students' learning experience and provide them with helpful resources and perspectives toward an informed career decision-making.

An important feature of self-efficacy that must be considered in educational psychological research is that it is domain specific: self-efficacy measures are particular to certain tasks in certain situations [4, 5, 14]. To put it differently, self-efficacy shall be defined and studied for a specific task and situation, as opposed to a "general" measure for an individual's behavioral characteristic. Over the past two years, we investigated the hypothesis that project-based active learning techniques used in a biomedical computing class enhance the computer programming academic and career self-efficacy of undergraduate BME students.

Method

This study was carried out under an official exemption by the Institutional Research Board at the University of Akron. Both project- and problem-based active learning techniques were introduced to the students approximately six weeks before the end of the semester. This timing in the course syllabus was selected to allow students effectively learn fundamentals of computer programming, while providing them with a sufficient time for successful completion of the activity.

In one section of this course, a problem-based learning approach was incorporated, where three-member student groups were instructed to design a biomedical-oriented problem statement and push the boundaries of their acquired programming skills to solve that problem. Additionally, they were required to review five journal papers on the application of computer programming in a biomedical engineering and present a short lecture. In order to maximize the benefits of literature review within the entire class, specific research categories were randomly assigned to student groups. These categories included orthopedic biomechanics, cardiovascular mechanics and surgery, cell and tissue engineering, imaging, and artificial intelligence and machine learning in BME. For problem statement design, students were encouraged to seek help from the course instructor and graduate teaching assistants to come up with practical and innovative ideas while maintaining a difficulty level appropriate to their programming knowledge and skills. Student groups presented a summary of their findings through 15-minute presentations in a dedicated class session. Presentations were evaluated through rubric forms distributed among groups to encourage students' active participation and mutual attention and respect during the presentations.

In three sections of the course where our project-based learning approach was implemented, three-member student groups were instructed to build a heart rate monitor/activity tracker using Arduino UNO microprocessors interfacing with MATLAB and MATLAB Mobile (Fig.1). In this approach, students were provided with basic instructions on Arduino platform, required circuits and electronic elements, and how to connect Arduino platform to MATLAB. Subsequently, students were instructed to use MATLAB Mobile on their cell phones, extract acceleration data from their cell phone embedded sensors, and appropriately store the data on their computer. In the following, they started the experimental part of the project, and developed computer programs to record and process cell phone sensors data while walking around the lab and holding their phone in their hands and pockets (two separate scenarios). Using MATLAB in line with Arduino platform, students also created an "activity goal tracker": upon user's demand by pressing a button on the circuit, this system would blink an appropriate number of LEDs to indicate an approximate ratio of real-time calculated number of steps over a preset "daily" goal. Students' performance was evaluated based on the accuracy of their developed program in counting the number of steps and climbed floors, as well as the quality of their submitted five-page report. As a "bonus" part to the project, students were encouraged to submit their ideas—through scientific written explanation and/or actual developed programs—to further enhance the accuracy of their device. These ideas included but were not limited to more accurately distinguish between walking and other activities with similar arm movement patterns—waving to a friend or erasing the board—and accurate distinguishing between floors climbed by stairs or elevators/escalators.

Seven-point Likert-scale anonymous surveys with 14 questions were designed and collected prior to and following the problem- and project-based activity within all sections (Appendix). Questions 1 through 4, and 9 through 14 evaluate career-oriented measures, while questions 5 through 8 assess academic measures of students' self-efficacy. Although re-ordering survey questions into two lumped categories of academic vs. career self-efficacy measures would enhance visual presentation of the results, the questions are presented in the original ad hoc format to avoid neglecting potential psychological effects caused by the order of survey questions [15].

Survey results from the problem-based group were used to control against other potential factors affecting perceived self-efficacy. Due to the anonymous nature of the surveys and the insufficient number of subjects in the problem-based group for parametric statistical analyses, non-parametric Mann-Whitney U test with significance level set at $\alpha=0.05$ was used to statistically compare the pre- and post-activity self-efficacy scores for the project-based (N=69) and problem-based (N=14) approaches.

Results

The overall students' median score for all academic- and career-oriented survey questions improved following the project-based learning activity (Fig.1). Among career-oriented questions, overall median score for *clearer vision of programming application in engineering* (Question 1, $p<0.001$) and *BME careers* (Question 3, $p=0.006$) significantly improved upon the completion of the hands-on project. Similarly, *believing in programming as an essential element of engineering training* (Question 2, $p=0.03$) and *BME training* (Question 4, $p=0.046$), as well as the *expectation of success in a future BME career that involves developing medical devices* (Question 14, $p=0.044$) significantly increased after students completed their project (Fig.1).

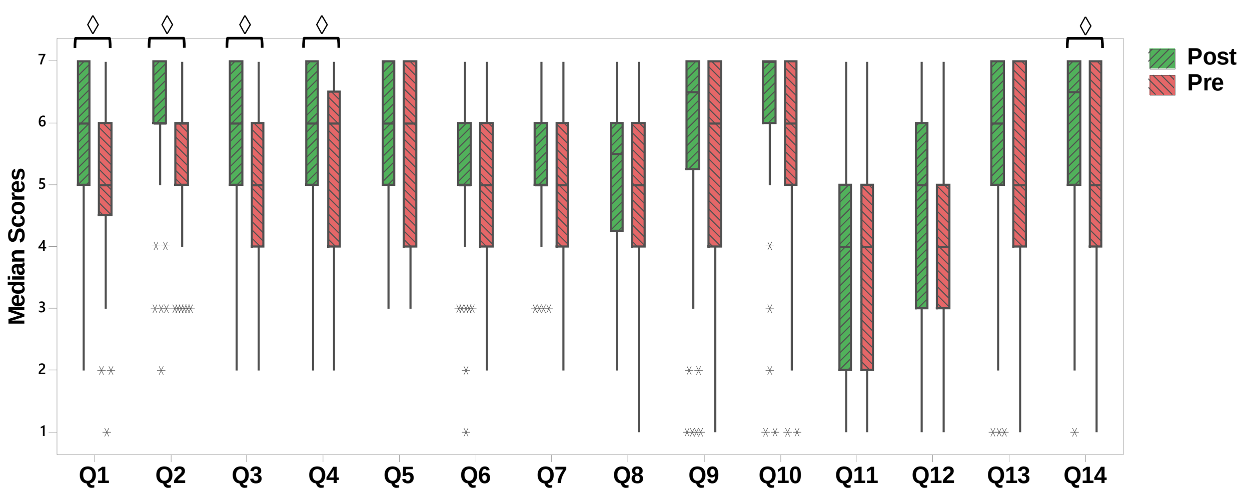

Figure 1. Median pre- and post-activity scores in survey questions within project-based approach. "◊" indicates statistically significant difference.

Surprisingly, for the problem-based approach, we observed improved median scores in only seven questions, while other questions indicated unchanged or decreased median scores. No significant difference was observed between pre- and post-activity scores within any of the questions (Fig.2).

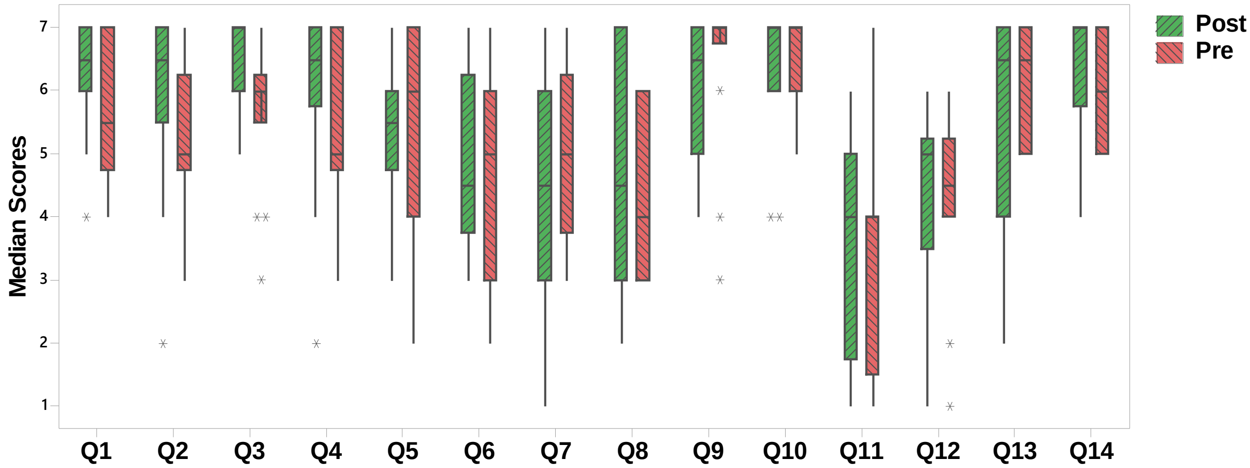

Figure 2. Median pre- and post-activity scores in survey questions within problem-based approach. No significant difference was observed between pre- and post-activity median scores within any of the questions.

Discussion

The results of this study agree well with the existing literature on the positive impacts of active learning techniques on students' learning experience [1, 16, 17]. Hands-on projects provide students with an opportunity to apply their theoretical knowledge into solving a real-life problem, which enhances their perspective on the practical applications of course material and boosts their academic and career decision-making self-efficacy in relatively complicated topics such as computer programming.

For project-based approach, we observed a significant improvement in students' expectation of success in a career that involves developing medical devices, without a significant increase in their "willingness" for such career—according to Question 13 within the survey. This finding implies that students were already aware of the nature of such careers, and that the enhancement in their expectation of success is a sheer indicator of improved self-efficacy, and not due to obtaining "new information".

In spite of our anticipation for more consistent and greater improvements in students' perceived academic and career self-efficacy following a problem-based activity, the observed results can be discussed from several aspects. Primarily, students may find project-based experiences more practical and closer to engineering career responsibilities, compared to problem-based learning. Furthermore, students may solely find problem-based learning as an "extended" form of regular assignments, which would not lead to a boost in their self-efficacy and self-satisfaction that a hands-on experience would provide. On the other hand, a larger group of participants in the problem-based approach could potentially affect our inferential statistics and indicate significant improvements in certain median scores. Our future studies will include more participants in both problem- and project-based approaches to assure statistical reliability of the results.

The ad hoc survey instrument used within this study investigates students' academic and career self-efficacy, expectation of success within the course objectives and future careers, as well as their perspective toward the necessity of computer programming in an engineering training. These measures provide invaluable input for educators to adjust course materials and curriculum development toward students' enhanced learning experience while ensuring ABET accreditation requirements. Nevertheless, implementation of a generalized and well-evaluated self-efficacy instrument in future studies will empower investigating the effect of active learning techniques on students' self-efficacy in a more accurate and systematic fashion.

A noteworthy limitation of this study is the anonymous nature of the surveys. We believe that anonymous surveys would encourage individual students to provide more truthful and honest responses, leading to more reliable data. However, anonymous surveys prevented us from being able to track the self-efficacy improvement of individual students. This limitation affected our statistical analyses, as we are not able to quantify the change in individual students' self-efficacy scores and directly compare the impact of problem- versus project-based learning approaches. Moreover, the lack of pre- and post-activity data points for each individual will not allow us to look into other measures of students' learning experience such as exam scores and downstream changes in their academic performance. Our future study will more attentively look into this issue in the study design phase to enable a comprehensive investigation of the effects of active learning techniques on students' self-efficacy.

The amount of instructor preparation required for either problem- or project-based activity is very close to that of a regular lecture. The instructions for either approach can be presented during a regular class session, and additional hands-on and brainstorming sessions can be scheduled upon instructor's availability and preference. The schedule and duration of either approach within the course syllabus can be modified by the instructor to suit the class size and the difficulty level of the defined activity. We encouraged students to have weekly group meetings and submit progress reports to fulfil a small part of their project/problem grade. This approach will potentially ensure contribution of all group members and will also encourage them to work on the activity throughout the designated time.

In summary, the results of this study confirm our hypothesis that project-based active learning techniques enhance computer programming self-efficacy and expectation of success in BME careers in undergraduate biomedical engineering students. Problem statement design, literature review, and completing a hands-on project will all provide the students with a wide range of practical applications of the course material. Hands-on projects, however, have a higher impact on improving students' perceived self-efficacy and expectation of success, as compared to problem statement design and literature review alone. All of the foregoing improvements achieved through the completion of hands-on projects have direct influence on students' motivation and would maximize the accomplishment of learning objectives.

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Appendix

Survey used to assess students' academic and career self-efficacy and expectation of success pre- and post-activity. The verb tenses were adjusted to reflect the time of survey collection.

☐ Male ☐ Female ☐ Hispanic or Latino ☐ Not Hispanic or Latino	☐ White ☐ Black or African American ☐ American Indian/Alaska Native ☐ Asian ☐ Native Hawaiian/Other Pacific Islanders	☐ Biomechanics ☐ Biomaterials and Tissue Eng. ☐ Instrumentation

	Not at all true of me 1	2	3	Somewhat true of me 4	5	6	Very true of me 7
1- I have a clear vision of the application of programming concepts in engineering careers.	1	2	3	4	5	6	7
2- I believe that programming is an essential element of an engineering training.	1	2	3	4	5	6	7
3- I have a clear vision of the application of programming concepts in Biomedical Engineering (BME) careers.	1	2	3	4	5	6	7
4- I believe that programming is an essential element of a BME training.	1	2	3	4	5	6	7
5- I am confident I can learn the remaining concepts taught in this course.	1	2	3	4	5	6	7
6- I am confident I can understand the most complex material presented by the instructor in the remaining weeks of this course.	1	2	3	4	5	6	7
7- I believe I can do an excellent job on the remaining assignments and tests in this course.	1	2	3	4	5	6	7
8- I believe I will receive an excellent grade in this class.	1	2	3	4	5	6	7
9- I would like to have a future career in BME either one that involves programming intensively or one that does not.	1	2	3	4	5	6	7
10- I expect to be successful in a future career in BME, either one that involves programming intensively or one that does not.	1	2	3	4	5	6	7
11- I would like to have a future career in BME that involves intensive computer programming.	1	2	3	4	5	6	7
12- I expect to be successful in a career in BME that involves intensive computer programming.	1	2	3	4	5	6	7
13- I would like to have a future career that involves development of medical devices (imaging systems, surgery robots, artificial organs, pacemakers, etc.)	1	2	3	4	5	6	7
14- I expect to be successful in a career that involves development of medical devices (imaging systems, surgery robots, artificial organs, pacemakers, etc.)	1	2	3	4	5	6	7