Self-Efficacy Versus Gender: Project-Based Active Learning Techniques in Biomedical Engineering Introductory Computer Programming Courses

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Engineering education has increasingly embraced active learning techniques within a variety of curricula. In particular, project-based active learning techniques have a significant potential to enhance students' learning experience. In this study, we implemented project-based techniques in biomedical engineering (BME) classes, and we investigated the effects of active learning on students' self-efficacy as an effective predictor of students' academic persistence and their career decision-making. Differences in self-efficacy were compared across genders. A high level of internal consistency was observed for both academic and career-oriented scales, as determined by Cronbach's alpha values of 0.908 and 0.862, respectively. While average scores of all survey questions indicated improvement in students' academic and career-oriented self-efficacy measures, significant improvements were observed in "clearer vision of programming application in engineering" and "BME careers," as well as in "expectation of success in a future BME career that involves developing medical devices" after the completion of the project-based activity ($p = 0.002$, 0.023, and 0.034, respectively). For two of the survey questions, female students reflected a significantly lower "self-confidence about understanding the most complex course material" as well as a significantly lower "willingness to have a future career in BME that involves intensive computer programing" as compared to male students ($p = 0.035$ and 0.024, respectively). We have further discussed possible explanations for the observed differences and multiple potential ways to enhance gender equality in STEM fields from a self-efficacy standpoint. [DOI: 10.1115/1.4047924]

Introduction

Active learning has been increasingly considered in academic settings within a wide variety of undergraduate and graduate curricula. In previous studies, researchers reported significant improvements in students' examination, performance, and educational achievements in active learning classrooms as compared to those using a passive learning approach [1,2]. In biomedical engineering (BME), an inherently multidisciplinary field [3], active learning can be incorporated through various pedagogical innovations and within unlimited platforms. In science, technology, engineering, and mathematics (STEM) fields, problem- and project-based learning are among the most suitable techniques that can be easily implemented within new or existing course syllabi [4]. Such approaches increase students' engagement and enthusiasm, leading to a deeper and more efficient retention of new concepts. While examination performance can serve as an easily available metric to analyze the effectiveness of problem- and project-based learning techniques, confounded factors such as stress and anxiety can impede unbiased conclusions. Hence, additional measures recorded throughout an entire semester can provide valuable data for qualitative and quantitative investigation of active learning techniques and their effectiveness on students' academic performance and overall success.

Initially introduced by Albert Bandura in 1977, the term *self-efficacy* describes "the belief in one's capabilities to organize and execute courses of action required to produce given attainments" [5]. During the past two decades, perceived self-efficacy has been increasingly considered as a highly effective predictor of student motivation and persistence [6,7] as well as an important contributor to academic development [5]. Career decision-making self-efficacy is of equal importance in engineering education, as it reflects a student's ability to make an informed decision about a career path to pursue in the process of securing meaningful employment [8]. Several studies in the literature also suggest that self-efficacy is closely linked with stress and anxiety, affecting a student's performance, overall wellness, and personal adjustment in both direct and indirect ways [9–12]. In other words, students with higher levels of academic and career self-efficacy tend to demonstrate higher motivation, have more strategies in their self-regulated learning, attain higher levels of achievements, and experience less stress and anxiety [9]. Hence, understanding self-efficacy in academic settings is of great importance to enhance students' learning experience and provide them with helpful resources and perspectives to support informed career decision-making.

Previously, researchers have investigated the role of gender in computing-related self-efficacy [13] and tracked self-efficacy development in a first-year engineering design course [14]. When it comes to computer programming, however, gender-biased social expectations as expressed by parents and the consequent gender differences in students' beliefs about their capabilities are among the potential reasons for females' lower participation in computer-related fields [9,13,15–18]. In this study, we hypothesized that project-based active learning techniques used in a semi-advanced computer programming class in undergraduate BME curricula positively affects students' academic and career-oriented self-efficacy. Furthermore, we analyzed the differences of self-efficacy across genders before and after the completion of a project-based active learning experience, discussed potential

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causes for these differences, and introduced solutions to enhance gender equality in every aspect of educational experience. This study is based on a computer programming course which is also taken by junior and senior students, who are more actively involved in the decision-making process for their internships and future career options. Therefore, the findings of this study would yield valuable information by addressing both academic and career-oriented self-efficacy measures.

Methods

This study was carried out under an official exemption by the Institutional Research Board at The University of Akron and was implemented in a sophomore-level Biomedical Computing course (4800:220) that focuses on fundamentals of computer programing in biomedical applications using MATLAB (MathWorks, Natick, MA). In the three sections of the course in which the 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, as discussed in our previous publications [19,20]. In this approach, students were provided with three introductory mini-lectures on the Arduino platform and basic circuits and electronic elements as well as instructions to help them interlink the Arduino and MATLAB platforms. It should be noted that Arduino kits including all necessary circuits and electronic components were purchased by the department (one for each group with an approximate cost of $50 per kit) and were maintained in the bioinstrumentation laboratory after the completion of the projects for future sections of the course and other departmental educational needs. Subsequently, students were instructed to install the MATLAB Mobile application on their smart phone devices through the academic license available to engineering students at The University of Akron, use this application to extract acceleration data from the sensors embedded within the device, and appropriately store the acceleration data on their computers. In the following stage, the students embarked on the experimental portion of the project, which consisted of developing computer programs to record and process smart phone sensor data while they walked around the bioinstrumentation laboratory space under two separate scenarios: either holding their phones in their hands or keeping their phones in their pockets. Through the synced MATLAB and Arduino platforms, students also created an "activity goal tracker": upon the user's request (by pressing a button on the circuit), this system would blink an appropriate number of LEDs to indicate an approximate ratio of the real-time calculated number of steps to a preset "daily" goal. During the hands-on experience sessions, the instructor and teaching assistants (TAs) stopped by students' group tables and provided any further instruction or assistance required.

Students' performance in this project-based activity was evaluated with respect to the efficiency and accuracy of the developed program in counting the correct number of steps taken, as well as the quality of a five-page report submitted by each group for course credit. For bonus credit on the project, students were encouraged to consolidate their innovative ideas—through scientific written descriptions and/or actual developed programs—to further enhance the accuracy of their devices. These ideas included—but were not limited to—more accurately distinguishing between walking and other activities with similar arm motion patterns (such as waving to a friend or erasing a whiteboard), or distinguishing between active and passive movement (such as climbing the stairs versus using an elevator).

Seven-point Likert-scale anonymous surveys with 14 questions were collected prior to (Week 6) and following the project (Week 14) from students in all three sections of the course. Completion of the surveys was optional with no effect on course grades. Questions 1 through 4 and Questions 9 through 14 were designed to evaluate career-oriented measures and students' perspective about the necessity of computer programing training in BME curriculum, while Questions 5 through 8 were adapted from a previously validated instrument [21] to assess academic measures of students' self-efficacy. Although reordering the survey questions into lumped categories would potentially enhance visual presentation of the results, the questions are presented and discussed in the original ad hoc format to avoid neglecting potential psychological effects caused by the order of the survey questions [15]. The survey used in this study is presented in Table 1. The score for each question ranged from 1 (indicating "Not at all true of me") to 7 ("Very true of me"), as specified on the questionnaire. Cronbach's alpha reliability test was used to ensure internal consistency for each of the career- and academic-oriented scales. A Kolmogorov–Smirnov normality test was used to confirm the normality of the data ($p > 0.2$) and eligibility of parametric statistical analyses. Two-way analysis of variance (ANOVA) including the TIME*GENDER interactive term followed by post hoc Tukey's tests were used to statistically compare the preactivity and postactivity self-efficacy scores across genders. Significance level was set at $\alpha = 0.05$.

Results

A total of 61 (31 females) and 60 (27 females) students thoroughly completed and submitted the surveys preacitivity and postactivity, respectively, which were used for the purpose of the analyses. Four submitted surveys did not include self-identified gender information and were excluded. A high level of internal consistency was observed for both career- and academic-oriented scales, as determined by Cronbach's alpha values of 0.862 and 0.908, respectively.

The results indicated that for both male and female students and for all survey questions, the average scores generally improved after the project-based activity, except for the responses for female students on three of the questions (Fig. 1). Nevertheless, for the entire cohort of participants combined, the overall average scores improved following the completion of the active learning approach. In particular, the average scores for *clearer vision of programming application in engineering* (Question 1) and *BME careers* (Question 3) significantly improved upon the completion of the hands-on project with p-values of 0.002 and 0.023, respectively. Similarly, for the entire cohort, the *expectation of success in a future BME career that involves developing medical devices* (Question 14) significantly increased ($p = 0.034$) after the students completed the project-based activity. The average score for *believing in programming as an essential element of engineering training* (Question 2) improved following the project-based activity, with a marginal p-value of 0.057.

As demonstrated in Fig. 1, given the combined preactivity and postactivity scores, a significant difference ($p = 0.035$) was observed between female and male students' *self-confidence about understanding the most complex course material* (Question 6): the combined average score of the female group was 4.81 ± 1.37 ($N = 58$), as opposed to a combined average score of 5.33 ± 1.23 for the male group ($N = 63$). In addition, female students were significantly less willing to *have a future career in BME that involves intensive computer programing* (Question 11) ($p = 0.024$; a combined average score of 3.23 ± 1.90 for females and a combined average score of 3.99 ± 1.60 for males).

The interactive term TIME*GENDER was not found to be statistically significant for any of the survey questions, indicating that the effect of the project-based active learning technique from preactivity to postactivity was not significantly different between female and male students. Nevertheless, post hoc pairwise comparisons revealed a significant improvement only among the male students in one's *clear vision of the application of programming concepts in engineering and BME careers* (Questions 1 and 3). In preactivity results, the average scores for these measures were rather higher in female students as compared to male students; however, the postactivity average scores for female students were below those of the male students (Fig. 1).

Discussion

The results of this study agree well with the existing literature on the positive impacts of active learning techniques on students' learning experience [1,22,23]. Hands-on projects provide students with an opportunity to apply their theoretical knowledge to solve a real-life problem, which enhances their perspective on the practical applications of the course material and boosts their self-efficacy in relatively complicated topics such as computer programming.

The significantly lower *self-confidence about understanding the most complex course material* and *expectation of success in BME careers with intensive programming* observed in our female students can be attributed to multiple factors, including but not limited to less prior experience in computer programming that is confounded with sociocultural barriers for women entering STEM fields [24]. On the other hand, the higher preactivity average score of female students' in *clear vision of the application of programming in engineering* and *BME careers* can be interpreted as the relatively more informed decision of female students upon entering engineering fields, potentially due to the foregoing sociocultural factors. The continual rise in national initiatives such as Girls Who Code, Black Girls Code, Hour of Code, and Rails Girls are deemed a long-term success in eliminating sociocultural barriers and improving women's self-confidence and self-efficacy toward computing-related STEM fields.

Another thought-provoking observation was the lower postactivity average score of female students for Questions 9 and 10 as compared to the preactivity average scores. Through Questions 9 and 10, female students demonstrated a decreased willingness to pursue and decreased expectation of success in a BME career, either one that involves intensive computer programming or one that does not. Surprisingly, through Questions 11 and 12, the average scores of female students indicated an increased willingness and expectation of success in a BME career that involves intensive computer programming. Assuming the observed difference has not occurred due to the more convoluted language of Questions 9 and 10 as compared to Questions 11 and 12, a potential explanation can be made in light of the average score of Question 8 about the expectation of receiving an excellent grade in the class. Given the marginally equal preactivity and postactivity average scores of Question 8 for female students in contrast with the increased average score in male students, we speculate that some of the female students were extremely successful in the course and experienced an increased self-efficacy and willingness for a BME career that involves intensive computer programming. In contrast, other female students did not meet their personal expectations in the course and had a lower willingness and expectation of success in such careers toward the end of the semester. Unfortunately, the limitation of anonymous surveys, as further discussed in the Discussion section, did not allow us to track an individual student's scores and performance and to perform correlation studies in order to verify this speculation.

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 another question in the survey. While the survey question does not quantify prior awareness of the field, we speculate that this finding could imply students' prior knowledge about 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." Alternatively, the lesser improvement in willingness to pursue such careers may be linked with lesser open-mindedness toward new opportunities, which would possibly require a longer duration of self-perceived success in the field to boost overall self-efficacy and consequently raise willingness and open-mindedness toward those careers as viable options.

We had previously implemented a problem-based active learning approach in a different section of the same course and observed nonsignificant improvements in only seven (out of 14) survey question average scores, with other seven questions

Table 1 Survey used to assess students' academic and career self-efficacy and expectation of success preactivity and postactivity. The verb tenses were adjusted to reflect the time of survey collection.

	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

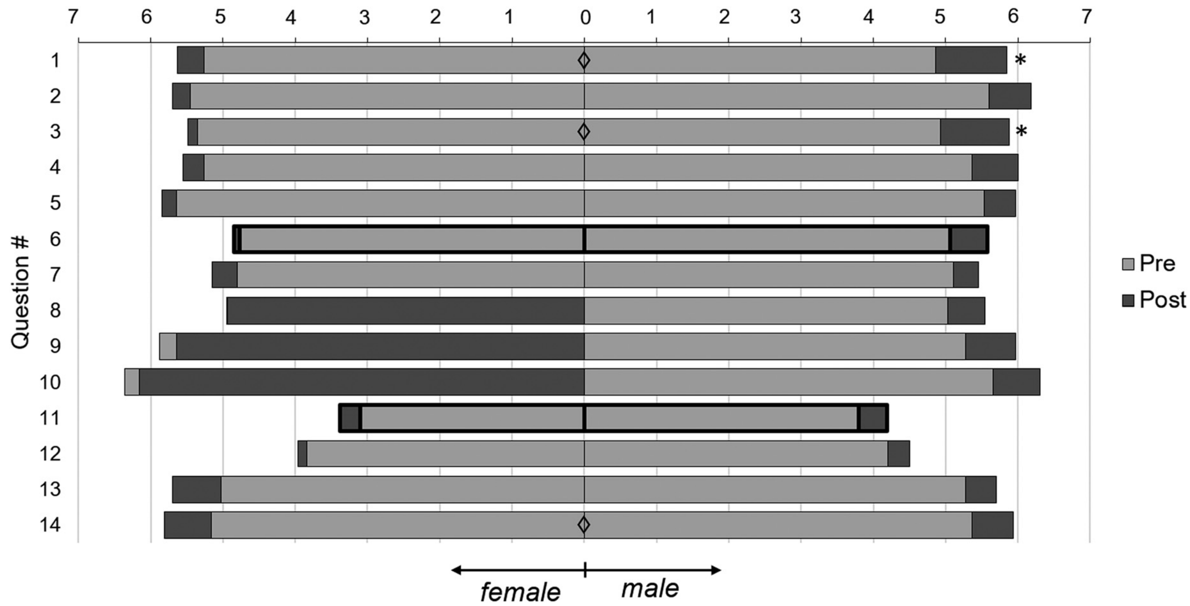

Fig. 1 Average scores of survey questions for preactivity and postactivity, as well as for female and male students, where "*" indicates significant differences between preactivity and postactivity scores within gender, while "¤" indicates significant difference between preactivity and postactivity within the entire cohort. Bold outlines indicate significant difference between average scores of female and male students.

indicating equal or lower scores [19]. While a more comprehensive study design including control groups would allow a more systematic comparison, given the lesser improvement observed in the problem-based approach as well as the anecdotal feedback from students of all sections, we believe that the observed improvements in the present study have mainly resulted from the project-based activity, and any effects from other potential factors have been controlled in the comparison with a problem-based approach. While previous studies have reported the educational benefits of problem-based pedagogical techniques [4,19], our classroom observations imply that students may find project-based experiences more practical and closer to engineering career responsibilities. Furthermore, students may solely view problem-based learning as an "extended" form of regular assignments, which would not lead to a boost in their self-efficacy and self-satisfaction created by the situational interest [25,26] that a hands-on experience could provide.

We assigned the students into teams based on their overall demonstrated performance within the first five weeks of the class to improve team dynamics and make sure that a student with a relatively low performance would not feel "inferior" to other group members and would maintain active participation. Additionally, we strived to enhance team dynamics by allocating 5% of the project grade to peer evaluations, in an effort to encourage more active participation and improved communication between team members. However, previous research has shown that gender and race may also affect teamwork experience in undergraduate classrooms [27]. More sophisticated instruments such as CATME Team-Maker [28] can be incorporated in future studies to ensure systematic improvements in team dynamics.

From an educator's perspective, the amount of time required to implement an active learning approach is typically a major concern. In this project, the amount of time required for instructor preparation was nearly equal to that of a regular lecture. The only anticipated time commitment beyond the regular class syllabus is roughly 5 h required to prepare the aforementioned mini-lectures, the content of which is mostly available on MATLAB and Arduino websites in the form of tutorials and examples. Preliminary instructions for the selected project can be presented during a regular class session and can even be integrated into the course materials, and additional hands-on and brainstorming sessions can be scheduled depending on instructor availability and preference. Students can be encouraged to use TA office hours to gain access to the equipment for further trials and experience, if needed, with TA assistance and supervision. Alternatively, at the discretion of the instructor and department, the equipment packages can be loaned to student groups to ensure more continuous and convenient access throughout the semester. The schedule and duration of the active learning experience in the course syllabus can be modified by the instructor to suit the class size and the level of difficulty of the defined activity. In the three sections of this course, we encouraged students to have weekly group meetings and submit progress reports as a requirement to fulfill a small portion of their project grades. We recommend that instructors take advantage of the video submission capabilities of their learning management systems (LMSs) and ask students to submit their progress reports as short videos in which all group members are present and explain their individual efforts in the collaboration as well as their group's overall progress and challenges. Based on our observations, presence and active participation of students at the time of recording video progress reports is closely linked with their overall performance, as well as their received peer evaluation. In contrast, an individual-based, written progress report would not necessarily require attendance at group meetings and active participation in the project, and it cannot reflect the general excitement and facial expressions arising from the self-confidence and self-satisfaction of active engagement in the group activity. We believe that this approach has a potential for encouraging active contribution of all group members, would encourage the groups to work on the activity throughout the weeks allotted for the activity, and would allow the instructor to more closely assess team dynamics and individual contributions throughout the semester.

Prior to and during the implementation of project-based activities such as the presented example, a variety of factors must be carefully considered to ensure inclusivity. From a socioeconomic standpoint, the instructors need to ensure that each and every student had access to all the required equipment for participating in the project. In this study, as mentioned previously, Arduino kits were purchased by the department and provided to each group without any student financial contribution needed. Students were encouraged to use rental smart devices that are freely available at on-campus libraries if they did not own a smart phone or were not comfortable with using their own devices for the project. Failure to consider financial factors can influence students' self-efficacy and persistence for active participation. Additionally, for projects that inherently involve physical activity, students with physical limitations such as wheelchair or crutch users must be considered in the definition phase of the project. In the case of the presented activity tracker project, the project outcomes can be modified to require "all students" to develop their computer programs such that the number of wheelchair propulsion cycles and/or number of steps taken with crutches can be calculated as well.

This study has limitations that should be considered when interpreting the results. First, the survey instrument used in this study was partly designed ad hoc and partly adapted from a previously validated questionnaire. Our ad hoc survey questions were specifically designed to investigate students' self-efficacy and expectations of success within the course objectives and future careers, as well as their perspectives on the necessity of computer programming instruction in engineering training. These measures provide valuable information for educators and will enable them to adjust course materials and curriculum development in order to enhance the students' learning experience. Although a Cronbach's alpha of 0.862 indicated a high internal consistency within our ad hoc survey questions, adaptation of a validated career-oriented self-efficacy instrument and careful consideration of theoretical models such as expectancy-value theory [29,30] and social cognitive career theory (SCCT) [31] in designing ad hoc surveys for future studies will enable a more accurate and systematic evaluation of students' self-efficacy.

Another 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. However, the anonymous nature of the surveys prevented us from being able to quantify the change in an individual student's self-efficacy scores over time, which would have provided more reliable statistical analyses. Moreover, the lack of preactivity and postactivity data points for each individual does not permit us to look into other measures of students' learning experience such as exam scores and downstream changes in their academic performance. Future studies can implement anonymization techniques into the study design to enable a holistic investigation of the effects of active learning techniques on students' self-efficacy.

Third, our survey demographic question regarding gender inconsiderately included only male and female choices. Within the entire cohort of the study, four students did not provide an answer to the gender demographic question, even though they provided responses to other demographic questions. This finding emphasizes the need to include alternative options in future surveys to accommodate gender fluidity in the scope of the study while maintaining a high statistical power via the fewest possible factor levels. It should be noted that by including choices that reflect gender fluidity, a higher degree of attentiveness and strategy must be practiced when finding a solution for the aforementioned issue of anonymous surveys, to maximize personal information privacy. On the other hand, we included race demographics questions in our survey in accordance with previous research that has reported the effect of race on students' learning outcomes and self-efficacy [32–35]. However, a large number of students did not provide responses to this question, resulting in the elimination of this factor from the analyses. Future studies can use online resources or LMS features to allow uncompromised data collection through the surveys.

Finally, it is noted that all instructors of the studied course sections identified as male. Having a female instructor could have potentially affected the self-efficacy scores of the female students, as female students would have a more "relatable" figure who would provide a model of a future career in the field of engineering. Hence, future studies must consider the effect of instructor gender in the study design to increase the reliability of the findings.

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. The lower average scores of the female students, measured in a number of self-efficacy and expectation of success questions, further justifies the need for the continual efforts of "Women in Engineering" programs and K-12 outreach programs in order to raise public awareness regarding the aforementioned sociocultural factors. Earnest efforts in this area will help to eliminate barriers for women entering STEM fields and will enhance their corresponding self-efficacy and expectation of success. For both female and male students, we strongly believe that the foregoing improvements achieved through the completion of hands-on projects have a direct influence on student motivation and performance and would maximize the accomplishment of learning objectives.

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