Women in Engineering – Focus on Self-Efficacy in Modeling and Design through Project-Based Learning

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Abstract

Ability to model and design engineering systems is central attribute of engineering education. With the rapid technological advances in diverse fields, the practice of engineering profession is taking place in a team environment. The diversity of engineering teams is important not only to promote creativity but also to achieve the goals of efficiency, usability, saleability, and innovation. In recent years, there has been focus on inducting more women in science, technology, engineering, and mathematics (STEM) related field to promote diversity in engineering profession. Within the undergraduate engineering curriculum, the students pursue project-based learning (PBL) especially in courses involving modeling and design of engineering systems. The students learn to work in diverse teams, generate concepts, model and design systems, deploy designed prototypes, and communicate project outcomes. To measure the effectiveness of PBL methodology in undergraduate engineering education, it is important to determine the personal perception of self-efficacy of students. The concept of self-efficacy involves the perceptions of students on their self-belief and optimism to accomplish tasks and produce expected results with the skills acquired during the engineering curriculum. It is a major element to determine their chances of success in future as engineering professionals. To measure the effectiveness of PBL methodology in engineering modeling and design courses, an important research question is: Does the use of PBL methodology affect self-efficacy and course scores of male and female students differently? In this paper, we address this question by highlighting the results from a longitudinal study conducted on students in engineering modeling and design (junior-level) courses at Arkansas Tech University. We have statistically analyzed the collected data to compare the effect of PBL strategy on male and female engineering students' self-efficacy and course scores. The results indicate that PBL approach was equally effective in improving self-efficacy and course scores of male and female engineering students. Significant improvement was observed in self-efficacy and course scores of both male and female students when the project based learning strategy was employed.

Keywords

Modeling and design, teamwork, diversity, engineering curriculum, statistical analysis, self-efficacy.

Introduction

Recent studies have indicated that, at K-12 level, female students' achievement in mathematics and science is on par with their male peers. At the undergraduate level, however, the gender disparity starts to emerge [1]. The figures indicate that women earned 57.3% of bachelor's degrees in all fields since the late 1990s and 50.3% of science and engineering bachelor's degrees. However, women's participation in science and engineering at the undergraduate level significantly differs by specific field of study. Only 19.3% of female students pursue undergraduate engineering curriculum compared to about 43.1% for mathematics [1]. In United States; although women make excellent engineers, they often lack self-belief in it as a credible option. In other countries the gender stereo-typing is not so pervasive (such as in China the women make up 33% of engineering workforce) [2]. The evidence also suggests that women in engineering profession contribute with range of invaluable skills and behaviors that set them apart from their male counterparts. Women have greater talents in creativity, communication, and team-building which are important for success in engineering profession. Improving participation of women in engineering profession has been the focus of number of organizations and programs (e.g. ASEE (WIED), SWE, and IEEE-WIE).

Both male and female engineers significantly contribute to the rapid developments in today's services and products by bringing ideas to reality through innovation, and creativity. The diversity of engineering disciplines such as electrical, mechanical, civil, chemical, and aeronautical means that there is bound to be one aspect of engineering profession that will fit a prospective student's interest. Engineering graduates also benefit from large number of open positions in these diverse fields. The quantitative analysis skills prepare students to handle data and use numerical methods for systematic analysis and design of engineering systems. The students also follow engineering design processes to identify and solve complex problems. Engineering design is purposeful and requires formulation of an explicit goal. The students learn how to select the best possible design option within the constraints of time, cost, tools, and materials. They follow systematic and iterative design cycle that involves planning, modeling, simulation, building, and testing prototypes.

As the success in engineering career largely depends on thorough understanding of engineering design process, the Engineering Accreditation Commission (EAC) of Accreditation Board for Engineering and Technology (ABET) has laid out Student Learning Outcomes in General Criterion 3. Three of the key outcomes of engineering education are: to prepare engineering students to identify, formulate, and solve complex engineering problems, to apply engineering design to produce solutions, and to function effectively on a team [3]. Traditional assessment methods including exams, quizzes, and homework assignments are primarily designed to measure the effectiveness of engineering curriculum in skill development. The skills alone do not guarantee that students will be successful through the engineering program and in their future careers. A major element of success is the will and belief to perform with the acquired skills. It, therefore, becomes important to measure and clearly comprehend changes in the students' resolve as they progress through the curriculum.

A very important subject in the undergraduate engineering curriculum is engineering modeling and design. Rapid technological advances, such as the internet of things (IoT), big data analytics, engineering simulation with virtual and augmented reality, and additive manufacturing, including 3D and 4D printing, have disrupted the traditional design methodology [4]. For success in design related jobs, engineers now require deep knowledge of application, adaptation, and creation of mathematical models [5-8]. Understanding of mathematical models, conventions, and procedures for the design of experiments, data collection, and simulation is essential to operate seamlessly in the multi-disciplinary technological fields [9].

To measure the effectiveness of engineering modeling and design curriculum, it is important to determine self-efficacy of both male and female students. In most of the engineering courses, the quality of students' projects design is highly dependent on their design thinking and the cognitive processes to reflect on their own designs during the process. One of the most used pedagogical models for teaching modeling and design is through project-based learning (PBL). The logic behind the use of PBL in design thinking is that students are exposed to the complex processes of inquiry and learning that designers normally perform in a systems context. They make decisions as they develop the project, work collaboratively with team members, and interact with their peers to complete the project. Design projects have been used as vehicles to motivate and integrate learning [10]. Furthermore, project-based courses were found to enhance students' motivation and retention in engineering through developing engineering intuition by continuously shifting their thinking from theory to interaction with hardware, and hardware and abstract system representations [11]. This learning context allows the engineering students to practice Kolb's model of experiential learning [12].

The engineering modeling and design curriculum enables students to go through hands-on, project-based learning (PBL) activities and develop self-belief and optimism in their competence to accomplish tasks and produce expected results. To measure the effectiveness of this approach and its impact on self-efficacy of students, authors have proposed an instrument to measure students' perception of self-efficacy [13-15]. The developed instrument was used to conduct pre- and post-course surveys of students in engineering modeling and design courses at Arkansas Tech University (ATU) to collect data for analysis. This analysis helped to draw conclusions and improve pedagogy in the course.

Design of Experiment

This study employs a within-subjects design to assess the impact of PBL on self-efficacy and course scores of male and female students in engineering modeling and design courses [13]. The participants were 80 undergraduate third-year engineering students enrolled in Engineering Modeling and Design (ELEG 3003) Course during the Fall 2017, Spring 2018, Fall 2018, and Spring 2019 semesters. The course is offered in the first semester of the third year in BS (Electrical Engineering) program. It covers topics on reduction of engineering systems to mathematical models, methods of analysis using MATLAB and Simulink, interpretation of numerical results, optimization of design variables, three-dimensional Computer-aided Design (CAD), and engineering system modeling and design projects. The course is fully hands-on, providing students with opportunities to model, simulate, and design complex engineering systems. The examples of engineering systems are drawn from various engineering disciplines.

What is Self-efficacy?

The self-efficacy construct referred to in this paper is based on Bandura's Social Cognitive Theory [16-17]. Bandura defines self-efficacy as "the belief in one's capabilities to organize and execute the courses of action required to produce given attainments" [17]. This belief affects the way people make choices, the efforts they put into completing assigned tasks, their will and resolve when difficulties arise, and their skills to cope with difficult situations. An important argument in Bandura's construct is that self-efficacy is not about the number of skills people possess, but what they can accomplish with those skills under different situations. Bandura also identified four major processes that contribute to the development of self-efficacy beliefs [17]. These include cognitive, motivational, affective, and selection processes. More details on these processes can be found in [17]. The self-efficacy construct is very important in the context of engineering modeling and design courses that are focused on hands-on, project-based learning methods. When the students successfully go through the experience of following the engineering design process, it is important to consider that they acquire necessary skills and competencies. As they are going through the curriculum, students develop a self-belief to perform with the acquired skills.

Purpose of the Study

The purpose of this study is to investigate the impact of PBL on self-efficacy and course grades of male and female students in engineering modeling and design courses. More specifically, we examine variation in level of confidence of male and female students based on their preferred learning styles after they are exposed to projects and hands-on class activities during the course. This methodology helps us assess the impact on their perception regarding their abilities in the engineering design process. We address the following specific research questions:

(1) Does PBL affect self-efficacy and course scores of male and female students differently?
(2) Is there a relationship between students' self-efficacy and their grades in a course utilizing PBL strategy?

Instrumentation

The instrumentations used for this study consisted of a demographic survey and a self-efficacy assessment survey. The self-efficacy survey comprised of twenty 10-level Likert scale questions designed to assess students' self-belief in their ability to use the skills learned during the course.

Demographic Survey

- The demographic survey was to collect information about the students' makeup such as gender, ethnicity, learning style, GPA, and familiarity with the use of technology.

Self-Efficacy Survey

- This survey was designed to measure the self-efficacy of students about their ability to perform a specific task at a designated level in accordance with Bandura's guidelines [17]. The survey was used twice during a semester (first week and the last week). For this instrument, the researchers used a 20-item questionnaire and suggested the possibility of three higher order factors: (a) Logical thinking skills (e.g., develop a statistical model of an engineering process, analyze data with a modeling and simulation software); (b) Communication skills (e.g., effectively communicate and document to wider audience progress through the engineering design process); and (c) Problem Solving skills (e.g., work well with hands, think practically to find a solution to an engineering problem). As an example of a Likert-scale question about students' self-efficacy regarding their problem-solving skills, students were asked the following question: I can transform an analytical model into a working code to run on simulation software. Students had the choice to indicate the degree of confidence they can complete that task, where: 0 = cannot do at all, and 10 = highly certain can do. Another question example regarding students' logical thinking skills: I can redesign a prototype if it does not perform according to specifications during testing. Students had the choice to indicate the degree of confidence they can complete that task, where: 0 = cannot do at all, and 10 = highly certain can do.

Data Analysis and Results

The data was initially screened for univariate outliers or missing values. Missing values were identified due to students dropping the course after a few weeks or not completing the end of course surveys due to other reasons. The minimum amount of data for analysis was satisfied, with a final sample size of 80 (using list-wise deletion). The participants in the present study were 80 engineering students (undergraduate), enrolled in engineering modeling and design courses. Participants were engineering major (Electrical and Mechanical) with 74 male and 6 females. English was reported as the native language of all participants. The average reported age of the participants was 18-25 years. Majority of participants were familiar with using technology, and preferred hands-on classroom activities as learning style. Table 1 summarizes students' descriptive statistics.

Table 1: Descriptive Statistics

	Level	Counts	Total	Proportion	p
Gender	Male	74	80	0.925	< .001
	Female	6	80	0.075	< .001
Age	18-21	46	81	0.568	0.266
	22-25	23	81	0.284	< .001
	26-30	6	81	0.074	< .001
	31-40	5	81	0.062	< .001
	41 and above	1	81	0.012	< .001
Major	Electrical Engineering	41	81	0.506	1.000
	Electrical Engineering (Computer Engineering Option)	14	81	0.173	< .001
	Mechanical Engineering	26	81	0.321	0.002
Learning Styles	Lectures/Discussions: Listening to lectures or podcast, discussing	8	78	0.103	< .001
	Books/Related Written Material: Reading texts or notes	3	78	0.038	< .001
	Video/Movies/Media	4	78	0.051	< .001
	Hands-on activities: Hands-on, creativity, model building, note-taking, and experimentation	34	78	0.436	0.308
	Collaborative Group Work: Experiential learning, role-play, physical involvement in learning	1	78	0.013	< .001
	Mixed method between some or all of the above	28	78	0.359	0.017

Note. Proportions tested against value: 0.5.

Research question 1:

Does the use of project-based learning effect the self-efficacy and course scores of male and female students differently?

To address this question, we conducted one-way between subject's ANOVA to compare the effect of project-based learning strategy on male and female engineering students' self-efficacy and course scores.

The investigators checked the ANOVA assumption of equal variances using Levene's Test (homoscedasticity). The result of Levene's test revealed that homogeneity of variance assumption was met for both variables: course scores($p = .259$) and self-efficacy ($p = .758$).The result of ANOVA showed that there was no significant difference in the effect of PBL on male and female students' self-efficacy and course scores at the $p<.05$, Course Grade[$F(1, 54) = 2.938$, $p = .092$], students' self-efficacy [$F(1, 72) = 3.271$, $p = .075$]. Taken together, these results suggest that the effect of project-based learning strategy was the same on male and female students' self-efficacy and course scores. Specifically, our results suggest that the project-based learning strategy improved equally the male and female engineering students' self-efficacy and course scores. Tables 2, 3 and 4 summarize the ANOVA results.

Table 2
Descriptive for A one-way between subject's ANOVA

		N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean: Lower Bound	95% Confidence Interval for Mean: Upper Bound	Minimum	Maximum
Course Grade	Male	53	73.25	13.485	1.852	69.53	76.96	48	100
	Female	3	59.67	9.074	5.239	37.13	82.21	53	70
	Total	56	72.52	13.581	1.815	68.88	76.15	48	100
Students' self-efficacy	Male	70	1595.86	298.739	35.706	1524.63	1667.09	0	2000
	Female	4	1317.50	314.152	157.076	817.61	1817.39	920	1620
	Total	74	1580.81	304.018	35.341	1510.38	1651.25	0	2000

Table 4
A one-way between subject's ANOVA

				Sum of Squares	df	Mean Square	F	Sig.
Course Grade	Between Groups	(Combined)		523.504	1	523.504	2.938	.092
		Linear Term	Unweighted	523.504	1	523.504	2.938	.092
			Weighted	523.504	1	523.504	2.938	.092
	Within Groups			9620.478	54	178.157		
	Total			10143.982	55			
Students' self-efficacy	Between Groups	(Combined)		293177.780	1	293177.780	3.271	.075
		Linear Term	Unweighted	293177.780	1	293177.780	3.271	.075
			Weighted	293177.780	1	293177.780	3.271	.075
	Within Groups			6453973.571	72	89638.522		
	Total			6747151.351	73			

Note. *Level is significant at p < .05*

Table 3
Test of Homogeneity of Variances

	Levene's Statistic	df1	df2	Sig.
Course Grade	1.303	1	54	.259
Students' self-efficacy	.096	1	72	.758

Note. *Level is significant at p < .05*

Research question 2:

Is there a relationship between students' self-efficacy and course grades in a course utilizing PBL strategy?

To answer this question, we computed a Pearson correlation coefficient to assess the relationship between students' self-efficacy and their course grades in a course utilizing project-based learning strategy. The analysis shows that there was a strong and positive correlation between students' self-efficacy (M = 1582.67, SD = 302.38) and their course grades (M = 72.23, SD = 13.636), r = .28, p = < .05, n = 57 &75. Tables 5 and 6 summarize the correlation results.

Table 5
Descriptive Statistics

	Mean	Std. Deviation	N
Course Grade	72.23	13.636	57
Students' self-efficacy	1582.67	302.384	75

Table 6
Correlations

		Course Grade	Students' self-efficacy
Course Grade	Pearson Correlation	1	.281*
	Sig. (2-tailed)		.034
	Sum of Squares and Cross-products	10412.035	47627.895
	Covariance	185.929	850.498
	N	57	57
Students' self-efficacy	Pearson Correlation	.281*	1
	Sig. (2-tailed)	.034	
	Sum of Squares and Cross-products	47627.895	6766266.667
	Covariance	850.498	91436.036
	N	57	75

Note. *Correlation is significant at the 0.05 level (2-tailed).*

Conclusion

In this paper, we have focused on gaining a deeper understanding of the impact of hands-on project based learning on self-efficacy and course scores of male and female students in engineering modeling and design courses at ATU. We analyzed the data to determine the difference in impact of PBL on male and female students' self-efficacy and course scores. The results indicate that PBL strategy is equally effective for both male and female students. We observed improvement in both male and female students' self-efficacy and course scores when PBL strategy was employed. We have also analyzed the data to understand the relationship between students' self-efficacy and course grades. The analysis shows there is strong correlation between students' self-efficacy and course grades. Specifically, when PBL was employed the self-efficacy and course grades of the students improved.

The presented results are from a longitudinal study being conducted to analyze the factors contributing and impacting self-efficacy of students in engineering modeling and design courses. This subject is very important for engineering students, especially female students to improve diversity in project teams and to achieve the goal of increased diversity in engineering profession. The study has helped us understand and analyze factors that can predict student performance in the course based on their confidence and self-efficacy. These factors link the student performance in engineering modeling and design to logical thinking, communication, and problem-solving skills. We plan to continue this study over the next semesters by collecting data from students, and conducting deeper analysis to gain further insights into pedagogy and student performance in engineering modeling and design.

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