125 YEARS AT THE HEART OF ENGINEERING EDUCATION
ASEE
2018 ASEE ANNUAL CONFERENCE & EXPOSITION
JUNE 24–27, 2018
SALT PALACE CONVENTION CENTER
SALT LAKE CITY, UT

Paper ID #22397

# A Study on Measuring Self-efficacy in Engineering Modeling and Design Courses

**Dr. Muhammad Safeer Khan, Arkansas Tech University**

Muhammad Khan received Ph. D. degree in Electrical and Computer Engineering from the University of North Carolina at Charlotte, Charlotte, NC, USA in 2013. He is an Assistant Professor in the Department of Electrical Engineering at Arkansas Tech University (ATU). His research interests include signal processing for audio and acoustics, Wireless Communications, Internet of Things applications, non-destructive evaluation, engineering and integrated STEM education and K-12 and higher education collaboration. Dr. Khan is a faculty counselor for ATU IEEE Student Branch and is also Vice-Chair for IEEE Arkansas River Valley section. He is also active member of Arkansas Academy of Science and ASEE.

**Dr. Nansong Wu, Arkansas Tech University**

Nansong Wu received M.S. and Ph.D. degrees in Electrical and Computer Engineering from Florida International University, Miami, FL, USA, in 2008 and 2012. He is an assistant professor in the Department of Electrical Engineering, Arkansas Tech University. Previously, he was a faculty member in the Department of Electrical and Computer Engineering, Florida International University. His research interests include high-performance embedded systems, image processing, wireless communication, and IoT applications.

**Dr. Mohamed Ibrahim, Arkansas Tech University**

Mohamed Ibrahim, PhD Associate Professor of Curriculum and Instruction College of Education Arkansas Tech University (479) 964-0583 ext. 2452

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## Abstract

Preparing future engineers to model and design engineering systems is one of the primary objectives of engineering education. Rapid advances in technologies such as high performance computing, rapid prototyping through additive manufacturing, robotics, automation, nanotechnology and instrumentation have increased the complexity of engineering systems. The engineering design process involves knowledge of multiple domains of engineering and collaborative work among multi-disciplinary teams. The design process is also complicated by the safety, practicality and cost constraints. In light of these challenges, the engineering education needs to maintain its focus on principles of engineering design that can effectively prepare engineering graduates to meet the challenges posed by rapid technological growth in engineering and manufacturing technologies. The effectiveness of engineering education in modeling and design courses, traditionally, is measured through quizzes, exams and course projects that are aimed at measuring level of developed skills. For engineering students to be successful, it is not only essential that they possess required skills and competencies but should also have the belief that they will be able to perform with those skills. This self-belief in one's ability to perform assigned tasks for attainment of a specified objective has been described as "self-efficacy" construct in terms of Bandura's Social Cognitive Theory. An important research question is how to measure the developed self-confidence of engineering students in modeling and design courses. To address this question, present study proposes development of a self-efficacy measure. The proposed measure has been used to collect pre and post course data on self-efficacy through student surveys in engineering modeling and design courses at Arkansas Tech University. The collected data is analyzed with Statistical Package for the Social Sciences (SPSS). The data analysis involves computation of correlations and reliability coefficients, t-tests and analysis of variance (ANOVA).

## Introduction

Designing objects and systems to meet the demands of society is one of the primary tasks of engineers. In light of technological developments and emerging fields of study, mathematical modeling is increasingly being used as a primary form of the design [1]. The engineers are expected to apply, adapt and create mathematical models as part of engineering design process. They are also expected to work in multi-disciplinary teams, communicate effectively with diverse audiences and engage in system design activities to solve emerging technological challenges. Importance of engineering profession and engineering education in modern society can be realized by examining the list of 14 grand challenges for engineering produced by the National Academy of Engineering (NAE) [2]. These challenges highlight the major issues facing the society in the twenty-first century, and engineers are playing a crucial role to realize solutions for all of them. In order to prepare the future engineers to meet these challenges, the engineering education needs to keep its focus on providing problem-solving opportunities to students through collaboration across disciplines and experiencing team-work.

The process of engineering and technological design is dependent on generation and analysis of mathematical models [3]. Engineers use modeling to understand the response of a process during the design of a system. To develop mathematical models as a first step, engineers perform system response prediction through representational modeling using drawings, renditions and simulations that incorporate important assumptions on operating conditions. The developed mathematical characterization helps engineers predict the response of technological solution through experiments on prototypes before large scale development and deployment. The representational and mathematical modeling approaches need software programming skills and expertise in the use of simulation software. This process of system response prediction using modeling and simulation as a tool is an important element of engineering design process [4].

Having highlighted the importance of modeling and simulation for engineers to be successful in their profession, there is a need to define engineering design. Engineering design is an approach the engineers use to solve problems and includes determining the best way to make a device or process that serves a particular purpose [5]. Engineering design process has a number of distinctive attributes: it is purposeful; it is driven; it is systematic, iterative and creative. Design is also dependent on specifications and constraints and also involves social and collaborative skills as engineers work on design activities in multidisciplinary teams and require effective communication skills to communicate with clients [6].

The importance of skills in modeling and design for engineers raises an important question with respect to effectiveness of engineering education at the undergraduate level. The question is: How to measure the effectiveness of engineering education in courses on modeling and design? The traditional methods to measure the effectiveness of courses on modeling and design is based on quizzes, assignments, exams and projects. These assessment techniques measure academic achievement of students. Another important aspect of measuring effectiveness of engineering modeling and design courses is to determine the perceived self-efficacy of students. Self-efficacy is related to the self-belief and optimism of students in their abilities to accomplish responsibilities and produce expected outcomes. This is directly related to their success as future engineers.

The purpose of present study is to address the measurement of perceived self-efficacy of students in engineering modeling and design courses. We have proposed an instrument to measure self-efficacy of students in [7]. The proposed instrument was used to collect data from students in engineering modeling and design course at Arkansas Tech University (ATU). The collected data, through pre and post course surveys, is analyzed using statistical analysis techniques. We present results and deductions from data analysis that can help improve pedagogy in engineering modeling and design courses.

## Self-Efficacy Construct

The self-efficacy construct presented in this paper is based on Albert Bandura's formulation presented in [8]. Bandura has defined self-efficacy as "people's beliefs about their capabilities to produce designated levels of performance that exercise influence over events that affect their lives". Belief in one's self-efficacy guides their feelings, thoughts, motivation and behavior. There are four major processes that produce these diverse effects: cognitive, motivational, affective and selection processes. A strong perception of self-efficacy results in enhanced achievements. The self-efficacy construct relates to sense of self-confidence. People with higher level of self-confidence in their capabilities take difficult tasks as challenges that they need to overcome. The self-confidence in one's capabilities leads individuals to set challenging goals and have commitment to overcome them. Bandura has identified four sources that contribute to enhancing the perception of self-efficacy: (a) enactive mastery experiences (actual performances); (b) observation of others (vicarious experiences); (c) social persuasion, both verbal and otherwise; and (d) ‘physiological and affective states from which people partly judge their capableness, strength, and vulnerability to dysfunction’ [9-10].

An important aspect of self-efficacy is that it relates to judgment of one's capabilities in a particular domain [11]. This leads to the conclusion that high self-efficacy in one domain is not necessarily related to high efficacy in another domain. As an example, an engineering student may have high self-efficacy in electronic circuit design, but that same student may have low self-efficacy in modeling electrical machines. Bandura has concluded that the design of measures of perceived self-efficacy should take into account 'domains of functioning' and 'gradations of tasks within those domains’ [9]. Historically in educational research, perception of self-efficacy is measured using surveys that ask participants to rate the strength of their belief in their ability to accomplish requisite tasks [11]. The surveys are constructed to assess ability to perform specific tasks within the domain of functioning being analyzed. Collected data through such surveys helps researchers to perform predictive analysis.

## Self-efficacy and Engineering Education

Previous research on self-efficacy in engineering education have highlighted that engineer's success in their profession is dependent not only on their achievement and ability but also on their perceived self-beliefs [12-13]. Researchers have also concluded that students’ self-efficacy is a significant contributing factor to their persistence and achievement [14]. For undergraduate engineering students to successfully accomplish their degree program objectives, they must possess required skills and competencies along with a strong self-belief to perform with those skills. A meta-analysis of self-efficacy studies in non-engineering disciplines has highlighted that self-efficacy accounted for an average of 14% of the variance in students’ academic performance and approximately 12% of the variance in their academic persistence [15]. Based on the results of meta-analysis, researchers have explored self-efficacy in engineering domains by developing measures of self-efficacy in mathematics and sciences. Although mathematics and science are part of the general engineering curriculum, researchers in engineering education have emphasized the need to study engineering as a distinct context to capture unique experiences specific to this domain [16].

Review of literature on engineering self-efficacy indicates gaps in three areas that need to be addressed for effective measurement of self-efficacy in engineering courses. Previous self-efficacy measures were used to measure self-efficacy in engineering courses but only a few were in line with Bandura's definition and his guidelines [17]. Some of the studies also had conceptual and practical shortcomings as the developed measures reflected on general self-confidence and did not address the concept of self-efficacy. As highlighted in [18], historically developed measures also do not adequately cover the engineering domain and therefore may not accurately predict academic achievement. To date, to the best of our knowledge no study has examined the measurement of self-efficacy in engineering modeling and design courses. Considering that engineering modeling and design are key skills and are essential to the success of future engineers as highlighted before, this study builds on a measure for self-efficacy in engineering modeling and design courses proposed in [7]. We use the proposed measure to collect data from students, analyze it and present the findings. This work is also part of a longitudinal study and the student surveys will be done during future engineering modeling and design courses to collect more data and get better insights for predictive analysis.

## Objectives of the Study

The objective of present study is to develop an approach to measure perceived self-efficacy of students in engineering modeling and design courses. We have developed an instrument that can be used to assess perceived self-efficacy. The instrument is given in Appendix 1. The Engineering Accreditation Commission (EAC) of the Accreditation Board for Engineering and Technology (ABET) has listed learning outcomes for engineering programs in general criterion 3 given in [19]. The student learning outcomes in engineering modeling and design courses have been addressed in outcomes 3(a), 3(b), 3(c), 3(e) and 3(k). These include:

- (3a) An ability to apply knowledge of mathematics, science, and engineering.
- (3b) An ability to design and conduct experiments, as well as to analyze and interpret data
- (3c) An ability to design a system, component, or process to meet desired needs
- (3e) An ability to identify, formulate, and solve engineering problems
- (3k) An ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

The design of self-efficacy measure was guided by the student learning outcomes. Previous work on developing a measure of self efficacy in engineering design led to the formulation of a 36-item online instrument given to 202 respondents [20]. That study was based on a design process specified by the Massachusetts Department of Education (DoE) Science and Technology/Engineering Curriculum Framework [21]. The instrument was used to measure level of motivation, outcome expectancy and anxiety in undergraduate engineering students. Another instrument was also developed that used a ten-step engineering design process taken from a course textbook [22]. Our approach presented in this study is based on a seven step Engineering Design Process (EDP) given in Fig. 1 [23, 7]. The proposed model of EDP is relevant for project based learning approach in undergraduate engineering courses.

## Design of Experiment

Our study employed a within-subjects design to assess the perception of self-efficacy of students in engineering modeling and design courses at ATU. The participants were 25 undergraduate engineering students (a mix of Mechanical and Electrical Engineering (EE), junior standing) enrolled

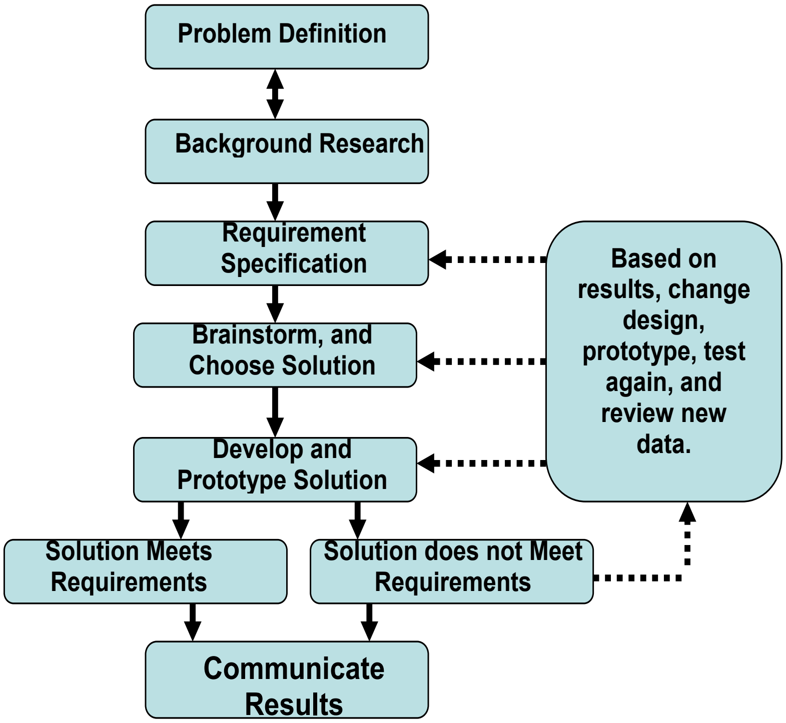

Figure 1 : Engineering Design Process [23, 7].

in Engineering Modeling and Design Course (ELEG 3003) during Fall 2017. ELEG 3003 is the first course, focused on engineering modeling and design within the BS(EE) curriculum and is offered in the first semester of the third year. This course is followed by ELEG 4202 (Engineering Design) during the second semester of third year. The students register for ELEG 4191 (Electrical Design Project-I) and ELEG 4192 (Electrical Design Project-II) during the two semesters of final year. ELEG 3003 covers reduction of engineering systems to mathematical models; methods of analysis using MATLAB® and Simulink®; interpretation of numerical results; and optimization of design variables. The examples in the course are drawn from various engineering disciplines. The student learning outcomes for this course corresponding to ABET criterion 3 are given below:

- Understand how to use MATLAB as programming language (b, k).
- Able to build system model through analysis of data (b, e).
- Able to do advanced plotting in two and three dimensions (b).
- Perform statistical analysis on the data and use probability and interpolation (b, e).
- Proficient in solving system models in differential equation form and related calculus problems using numerical analysis techniques (a, e).
- Understand system model building and simulation using SIMULINK (e, k).
- Able to design basic engineering systems using CAD software (Autodesk Inventor) (c).

The topics covered during the course correspond to achieve the student learning outcomes. During the course students also do short projects using MATLAB/Simulink and Autodesk Inventor. The essential elements of engineering design process are emphasized at the beginning of the course and students are advised to follow those during the system design process while doing the projects.

During this study the participating students were all male with an average reported age between 22-27 years (Standard Deviation (SD) = 1.517 years). The instrumentations to collect data from students consisted of the following items:

- **Demographic Survey:** A 9-question demographic survey was given to the students. This survey was designed to collect information on students' demographic makeup. Questions were designed to solicit participants' gender, age range, years in college, major, racial/ethnic identity, learning style preference, comfort level of working with computer, comfort with technology in teaching and learning, and range of grade point average.
- **Self-Efficacy Survey:** A 20-question 11-level Likert scale questionnaire was given to students to assess their perceived self-efficacy based on Bandura' measure [11]. The 11-point scale ranged between "Cannot do at all" at zero to “Highly certain can do" at 10. Students were asked about their degree of confidence to successfully complete a task related to engineering modeling and design activities. This survey was given at the beginning and end of the course.

The collected data from pre and post course self-efficacy surveys was averaged across 20 items. For the pre-assessment, the statistical analysis revealed a mean $(\mu)$ of 49.50, standard deviation $(\sigma)$ of 4.82 and range of 18.0. For the post-assessment, the mean $(\mu)$ , standard deviation $(\sigma)$ and range were 63.93, 2.60 and 9.6 respectively. We also calculated the intra-class correlation coefficients to evaluate the consistency of the ratings. The Cronbach’s alpha was computed to measure reliability and internal consistency of the reliability estimate. The theoretical value of alpha ranges between zero to 1, since it is the ratio of two variances. For the collected data in this study, the Cronbach’s alpha value was 0.89, which indicated good internal consistency of the reliability estimates.

## Data Analysis and Results

As a first step to compare the self-efficacy scores from pre and post course surveys, the aggregates of total scores are computed for each student from both surveys. The results show the relationship between the self-efficacy at the start of the course to that at the end of the course. The change or improvement in self-efficacy can be readily observed from plot given in Fig. 2.

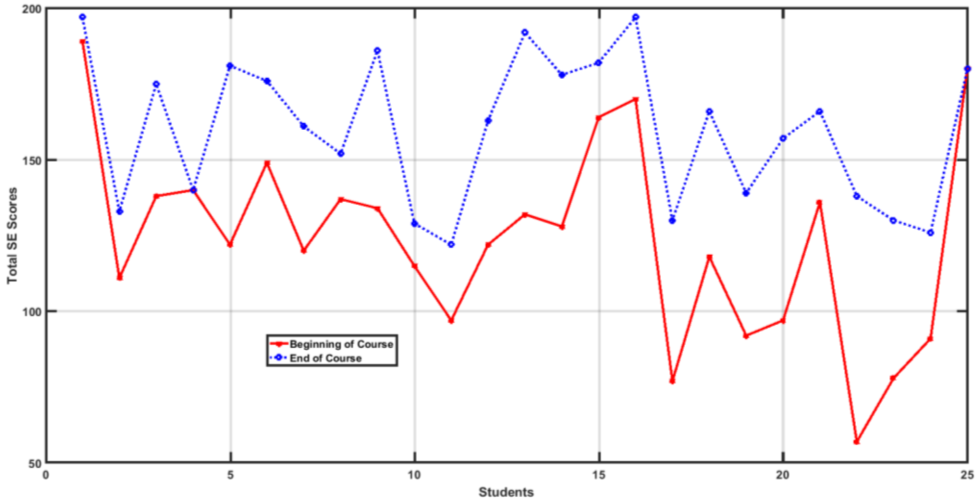

Figure 2 : Comparison of pre and post course self-efficacy survey data.

In order to further analyze the data to assess whether there was statistically significant difference between self-efficacy observations before and after the engineering modeling and design course, we test the null hypothesis that true mean difference between the observations from students is 0, using paired-samples t-test procedure as follows:

- Calculate the difference between the corresponding observations in the data set.
- Compute the mean of the difference between observations ($\mu$).
- Compute the standard deviation of the difference ($\sigma$) and use that to calculate mean standard error (M$SE$) i.e. $MSE(\mu) = \frac{\sigma}{\sqrt{N}}$.
- Calculate the t-statistic given by $t = \frac{\mu}{MSE(\mu)}$. If the null hypothesis is true the $t$-statistic will follow a $t$-distribution with *N-1* degrees of freedom (*df*).

The values of t-statistic are compared with the $t_{N-1}$ distribution to obtain a $p$-value for the paired t-test. This value gives the probability of observing the test results assuming that null hypothesis is true. For our study, the cutoff $p$-value for statistical significance is 0.001, which ensures 99.9% confidence in the results.

Table I: Paired Sample t-test results

| The Mean scores and standard deviations for the paired-samples t-test results of students' self-efficacy before and after the engineering modeling and design course | | | | | | | | |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| | Paired Differences | | | | | | | |
| | Mean ($\mu$) | Std. Deviation ($\sigma$) | Std. Error of the Mean (M$SE(\mu)$) | 95% Confidence Interval of the Difference | | $t$ | df | Sig. |
| | | | | Lower | Upper | | | |
| After - Before | 360.8 | 96.39 | 19.27 | 321.01 | 400.58 | 18.71 | 24 | .000 |
| ***Note:*** Significant at $p < 0.001$ level | | | | | | | | |

The analysis showed that there were significant differences in the students' self-efficacy mean scores at the end of the course ($\mu$=1,598.4, $\sigma$ =65.04) compared to the start of course ($\mu$ =1,237.6, $\sigma$ =120.63); $t(24)$= 18.72, $p$ = 0.001. These results suggest that the engineering modeling and design course had statistically significant positive effect on engineering students' self-efficacy. Table I summarizes the paired-samples t-test results. While analyzing the data, we also wanted to look at the effect of students' academic achievements on their self-efficacy. During the demographic survey, students were asked to provide a range of their grade point average (GPA). The range choices in the survey for students were: 2.0 - 2.5; 2.5 - 2.8, 2.8 - 3.0; 3.0 - 3.2 ; 3.2 - 3.4 ; 3.4 - 3.6; 3.6 - 3.8 and 3.8 - 4.0. The number of students in each category is given in Table II. To observe the effect of students' GPA on their self-efficacy, collected data was analyzed using One-way analysis of variance (ANOVA). One-way ANOVA provides results to determine any statistically significant differences between the means of two or more independent samples. This approach was, therefore, suited to analyze effect of students' academic achievements on their self-efficacy in engineering modeling and design courses.

One-way ANOVA results provide an F-statistic and a p-value that can be obtained from F-distribution. The collected data had a sample size of 25 and so we have 24 degrees of freedom (df) within groups. Between the groups the data was analyzed with respect to 8 GPA ranges (7 degrees of freedom). The results of analysis show that the F-statistic and p-value are F (7,24) = 0.457 and p = 0.852. Table III summarizes the results of one-way ANOVA. The box plot of results from one-way ANOVA is also given in Fig. 3. The results indicate the self-efficacy of students equally improved regardless of their starting GPAs in the course. The improvement in self-efficacy also enhanced the students' academic achievement. As part of this study, we have collected data to analyze the effect of improvement in self-efficacy on students' academic grades. The authors will continue to collect more data from students in future courses as well. The analysis of effect of self-efficacy on students' academic grades in the course will be presented based on analysis from a larger dataset in future.

Table II: Student's GPA Ranges in Engineering Modeling and Design Course

| Students' GPA Ranges | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| No of Students | 2.0-2.5 | 2.5-2.8 | 2.8-3.0 | 3.0-3.2 | 3.2-3.4 | 3.4-3.6 | 3.6-3.8 | 3.8-4.0 |
| | 1 | 1 | 3 | 4 | 5 | 3 | 6 | 2 |

Table III: One Way ANOVA Results - Self-Efficacy with Students' GPA.

| Self-Efficacy Scores | Sum of Squares Error | Degrees of Freedom (df) | Mean Square Error | F | Significance |
|---|---|---|---|---|---|
| Between Groups | 16,083 | 7 | 2,297.5 | 0.457 | 0.852 |
| Within Groups | 85,453 | 17 | 5,026.7 | - | - |
| Total | 1,01,536 | 24 | - | - | - |

## Conclusion

This paper reports the results of a study to measure and analyze self-efficacy of students in engineering modeling and design courses. The authors have developed an instrument in line with the requirements highlighted in [11]. The instrument was used to survey the students at the beginning and end of course to collect data on their perceived self-efficacy. The instrument comprises 20 questions that require responses on an 11-point Likert scale between 0 to 10. The data was collected from 25 students in Engineering Modeling and Design Course (ELEG 3003) at ATU. A demographic survey of students was also conducted as part of the study. The collected data was analyzed to observe the effect of the course on students' self-efficacy. The analysis reveals that self-efficacy of students improved over the duration of the course. Data on students' GPA was also collected through the demographic survey. GPA data was analyzed to observe its effect on self-efficacy using One-way ANOVA. The results revealed that self-efficacy of students improved for all students irrespective of their starting GPAs in the course. The authors have also collected data on end-of course student grades to analyze the effect of self-efficacy on actual academic accomplishment (final course letter grade) of the students. We would like to collect more data from future courses and develop this project into a longitudinal study. The results from analysis of additional collected data will be presented in future.

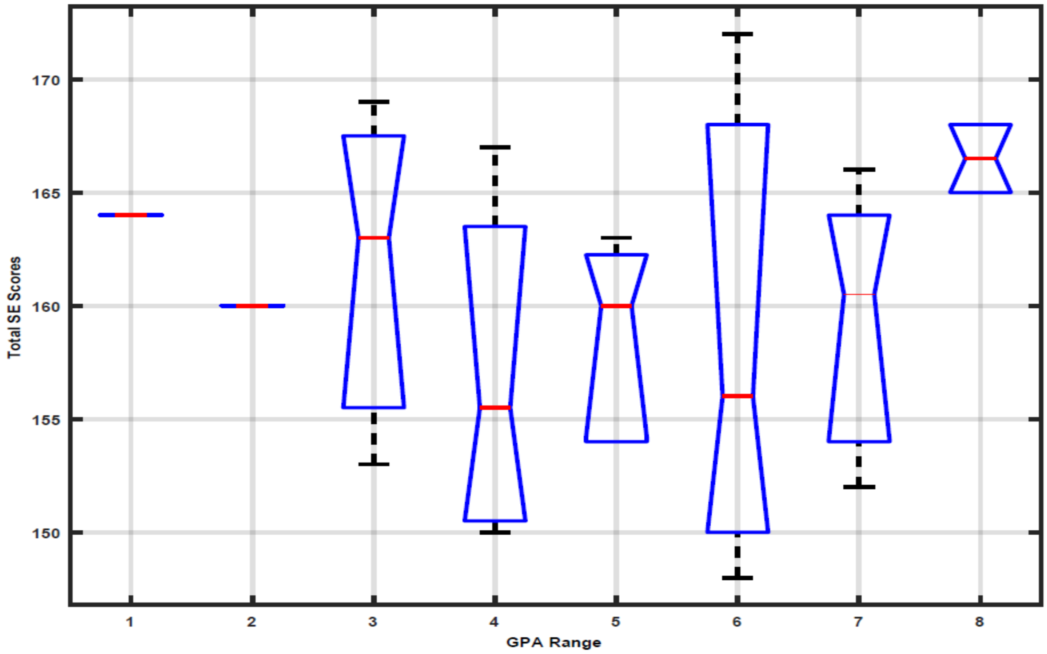

Figure 3: Box plot of results from One-way ANOVA.

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## Appendix 1

## Instrument for measuring self-efficacy in Engineering Modeling and Design Courses

| For each of the statements below, circle the degree of confidence you have to successfully complete that task, where: 0 = Cannot do at all, and 10 = Highly certain can do. | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Statements** | **Student Responses** | | | | | | | | | | |
| 1. I can develop a statistical model of an engineering process. | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| 2. I can analyze data with a modeling and simulation software . | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| 3. I can think logically to come up with a solution to an engineering problem. | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| 4. I can relate the theory I study in classroom to practical situations. | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| 5. I can work well with my hands | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| 6. I can identify if a problem needs an engineering solution. | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| 7. I can do through research on a problem to find out if any solutions already exist. | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| 8. I can think practically to find a solution to an engineering problem. | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| 9. I can select a best design if there are multiple design options available. | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| 10. I can effectively communicate to my peers about my engineering design experience. | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| 11. I can effectively communicate to wider audience about EDP. | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 12. I can work in a team with my peers | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| 13. I can redesign a prototype if it does not perform according to specifications during testing. | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| 14. I can operate engineering tools and common workshop machinery (drill, milling, lathe etc.) | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| 15. I can document my progress as I go through the EDP. | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| 16. I can work under tight time constraints. | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| 17. I can cope with stressful situations due to my work. | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| 18. I can transform an analytical model into working code to run on a simulation software. | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| 19. I can develop test methods to check if a prototype meets the specifications. | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| 20. I have what it takes to be successful in engineering modeling and design course. | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |