On Measuring Personal Perception of Self-Efficacy of Students in Engineering Modeling and Design Courses

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Abstract

One of the primary objectives of engineering education is to develop skills and competencies in engineering students to enable them to design, construct and maintain objects and systems as future engineers. The engineers are expected to undertake design process within the constraints imposed by safety, practicality, and cost criterions. Engineering education needs to maintain its focus on principles of engineering design that include identifying the needs of new developments, conceiving solutions to those needs and delivering the solutions within the applicable constraints. With rapid onset of new technologies and fields of study in engineering, the engineering education also needs to keep up with effective teaching of application, adaptation and creation of mathematical models. An important measure of effectiveness of engineering education is the determination of self-efficacy of students. Engineering self-efficacy refers to a student's personal perception that they can successfully steer through the engineering curriculum and become practicing engineers. An important question is how to measure personal perception of engineering students' self-efficacy. This paper proposes an approach for measuring personal perception of self-efficacy of students in undergraduate engineering modeling and design courses. An instrument is proposed that will be used in undergraduate engineering modeling and design courses at Arkansas Tech University.

Keywords

Personal perception, self-efficacy, modeling and design, engineering curriculum, educational effectiveness.

Introduction

Within engineering education, the need to understand and measure student learning and effectiveness of teaching approaches has been growing. Although, it is important to consider cognitive development of students while designing engineering curriculum, the chief goal remains the skills development and resolve to succeed[1]. To improve effectiveness of engineering education and achieve best outcomes in student learning, it is important to evaluate and clearly understand changes in the student resolve and cognition. With the growing pace of economic development and resulting changes in the industrial world, the engineering design processes are pursued using sophisticated information technology (IT) systems and multi-disciplinary global teams. The product lead times are getting shorter and the traditional engineering design activities are taking place in parallel. Technological transformation through Internet of Things (IOT), robotics, augmented reality, 3-D printing and nanotechnology is having significant impact on society. The focus of product design is on whole life modeling from idea conception and mathematical modeling to decommissioning, recycling and disposal. In an undergraduate engineering curriculum, it is clearly impossible to include all of these developments. The curriculum, however, needs to focus on providing students with solid grounding in engineering fundamentals, and preparing them to work across disciplines throughout their careers.

The emerging engineering technologies and fields use mathematical modeling as the primary form of design[2]. The application, adaptation, and creation of mathematical models are foundational to the engineering profession[3-5]. New interdisciplinary fields, such as nanotechnology, smart grids, renewable energy and automation are heavily based on computationally intensive aspects of science and engineering. Understanding of mathematical models, conventions, and procedures for design of experiments, data collection and simulation is essential to effectively perform in these multi-disciplinary fields.

Traditionally, the effectiveness of undergraduate engineering education is measured through grading and performance on course projects. The course assessments help determine academic achievement in terms of levels of skills and competencies. In addition to measuring academic success, it is also important to measure the self-belief of students to perform with the acquired skills. Self-efficacy enables students to develop their self-belief and optimism in their competence to accomplish tasks and produce expected results. It is an important element in determining their chances of success as future engineers. The present study addresses this aspect by proposing an approach to develop an instrument for measuring student's perception of their self-efficacy in engineering modeling and design courses. The paper also presents an instrument that can be used to conduct pre and post course survey of students to collect data for analysis and draw conclusions for implementation and remedial actions.

What is Self-efficacy?

The definition of self-efficacy is based on considering it as a construct of Bandura's Social Cognitive Theory[6-8]. Bandura has defined self-efficacy as “the beliefs in one’s capabilities to organize and execute the courses of action required to produce given attainments”[7]. These beliefs influence people's feelings, thinking, motivation and behavior. They also influence the way people make choices, the efforts they put into tasks, their resolve when difficulties arise, and their coping skills. Bandura also argued that self-efficacy is not about how many skills people possess but it relates to what they can do with those skills under variety of situations. For undergraduate engineering students to be successful in their degree programs, it is important that they should have skills and competencies essential for engineering profession. They should also have the belief that they will be able to perform with those skills[7]. Bandura identified four major processes that contribute to the self-efficacy beliefs[8]. These include cognitive, motivational, affective and selection processes. More details on these processes can be found in the reference[8].

Bandura also named four sources that can be used to develop self-efficacy. These include mastery experiences, vicarious experiences, verbal persuasion and emotional and physiological states[9]. The mastery experience is related to previous successes that build self-belief. The vicarious experiences come from observation of others completing a task that produces self-confidence to accomplish similar tasks. Verbal persuasions comes from influential people in a person's life such as parents. teachers, managers and coaches who can strengthen self-beliefs. The emotional and physiological state of a human mind also influences judgment of one's self-efficacy such as positive emotions that can increase self-confidence.

Relevance of Self-efficacy to Engineering Education

Self-efficacy is an important factor that contributes to students' academic achievements. Meta-analysis of self-efficacy studies has shown that the contribution of self-efficacy to student academic performance was 14% of the variance[10]. Although, this meta-analysis was based on self efficacy in non-engineering domains, it does highlight importance of self-efficacy as a variable in motivation studies in engineering. There has been considerable research in engineering self-efficacy mostly focused on mathematics and science subjects. Although those courses are part of engineering curriculum, researchers stress the need to study self-efficacy in engineering domain in its distinct context. Researchers have highlighted the need to identify important skills for engineers and strategies to increase self-confidence in the use of those skills[11]. They indicated that engineering students should have strong knowledge of fundamentals. They should also be able to translate theory into practice. Researchers also highlighted that engineering students should develop skills in logical thinking, problem solving and communication[12].

Research has also identified engineering-specific skills that engineering students should possess to become successful engineers. One such skill is the ability to visualize three-dimensional objects in two dimensions, which is called spatial ability[13]. Ability to create and modify products has also been highlighted as an important skill for engineers[14]. One of the most important skill, highlighted by researchers, is engineering design skill. This gives engineers ability to design a system or component to meet given specifications. This skill is essential to prepare engineering students to meet requirements of industrial jobs[15]. The key point is that engineering students should develop these skills while pursuing engineering curriculum. However, it is important that they should also have a belief (self-efficacy) that they can use these skills under various circumstances[7].

Purpose of the Study

We introduce an approach for measuring personal perception of students' self-efficacy in engineering modeling and design courses. An instrument is proposed that can be used by educators in engineering modeling and design courses to assess student perception of self-efficacy. Bandura, A. , " Self-efficacy", In V. S. Ramachaudran (Ed.), Encyclopedia of human behavior ,Vol. 4, Academic Press, New York, 1994, 77-81. that Accreditation Board for Engineering and Technology (ABET) has Engineering Accreditation Commission (EAC) which has laid out Student Learning Outcomes in General Criterion 3. Criterion 3 documents student outcome with respect to engineering modeling and design courses in outcomes 3(a), 3(b), 3(c), 3(e) and 3(k)[16]. These outcomes state that:

- (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 techniques, skills, and modern engineering tools necessary for engineering practice.

These student learning outcomes need to be considered while designing a framework for measuring self efficacy in engineering modeling and design courses. There has been previous efforts to investigate and develop instruments to measure engineering design self-efficacy. Carberry et al.[15] looked at design and validation of a 36-item online instrument which was administered to 202 respondents. Their study, however, was based on an eight-step process specified in the Massachusetts Department of Education (DoE) Science and Technology/Engineering Curriculum Framework[17]. In addition to self-efficacy, they also used the instrument to measure motivation, outcome expectancy and anxiety. Another instrument was based on ten-step engineering design process taken from a textbook used during consists of items based on a ten-step engineering design process taken from course textbook[18]. The present study focuses on a seven step Engineering Design Process (EDP) more suited for undergraduate engineering courses based on project based learning which is given in Fig. 1.

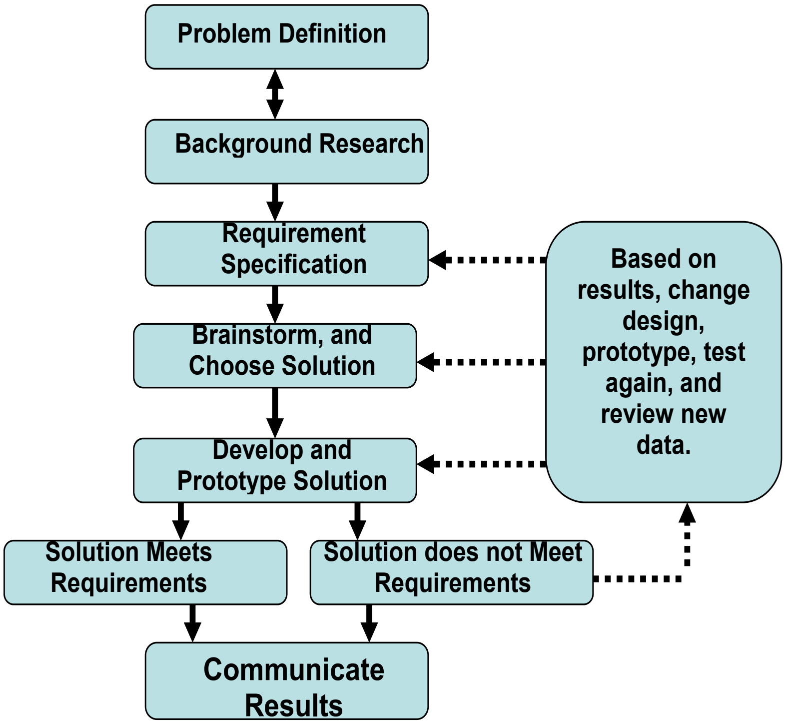

Figure 1 : Engineering Design Process[19].

Proposed Approach and Instrumentation

We propose a hybrid approach which is based on measuring technical self efficacy in terms of skill-specific and task-specific measures. Technical self-efficacy is a concept which was formulated by Baker et al.[14] and covers confidence and belief in one's competence to learn, and apply technical knowledge to success in engineering. To measure skill-specific self-efficacy, students can be given a set of problems and surveyed to rate their self-belief for solving problems[20]. To assess task-specific self-efficacy, students are given verbal descriptions of various tasks and are asked to rate their confidence in accomplishing them. This approach is well-suited to assess student self-efficacy in performing various tasks within the engineering design process[15]. In this study, concept of technical self-efficacy is used as a modeling self-efficacy measure. This measure is used to assess students personal perception of self-efficacy in modeling aspect of engineering modeling and design courses. Our consideration of modeling will be limited to system-level, where components and sub-systems are treated as black boxes. In this black box approach, sub-systems interact with each other through discrete interfaces and are modeled using differential algebraic equations. The focus will be on aspects of modeling which are important in the context of engineering system design.

This modeling self-efficacy measure will be used to assess student learning outcomes through focus on following areas:

- Statistical data modeling skills
- Data analysis skills
- Practical thinking skills
- Understanding of relationship between theory and application.
- Logical thinking skills to transform an analytical model into a working computer model for simulation using a suitable computer-based modeling language.

For engineering students who aspire to become future engineers to meet needs of the industry, understanding and experience of going through various tasks in the EDP given in Fig. 1 is essential. It is important that while designing any self-efficacy measuring instrument for students in an engineering design course, the confidence of students to perform each of the tasks in Fig. 1 is assessed. This aspect has also come up from previous work on engineering design self-efficacy measurements[15,18,21]. Assessing students' confidence in being able to perform the challenging practical tasks during EDP is a very important step in preparing students for jobs as engineers. Any instrument designed for this purpose should also assess students' confidence to perform tasks based on varying level of difficulty. This approach will ensure that self-efficacy measure follows Bandura's guidelines related to "*gradations of challenges*" and " *if the engineering task is easily performable, then everyone would be highly efficacious in engineering*" [22].

The essential elements of a self-efficacy instrument for EDP will measure students' confidence in their ability to accomplish the following:

- Explain their understanding of EDP and various tasks that form part of it.
- Apply steps given in EDP to an engineering problem and solve it.
- Build a prototype following constraints in the specifications by using machining and other manufacturing tools and processes.

- Employ a computer-based design and visualization tool to come up with a three-dimensional model of the prototype.
- Document activities and processes that were undertaken at various stages of EDP from concept to a testable prototype.
- Share their experiences during the design processes and after its completion with their peers and other audiences.
- Distinguish between various possible design options to select the most suitable design.
- Work as part of a diverse team to accomplish a common goal.
- Work under tight time constraints and be able to effectively manage their time for other curriculum related activities.
- Logical thinking skills to transform an analytical model into a working computer model for simulation using a computer-based modeling language.

While formulating above guidelines, consideration has been given to ensure that elements of ABET criteria stated earlier in the paper are included in the design of self-efficacy measuring instrument. An added benefit of this approach is that collected data can be used to determine the success in achieving course learning objectives.

The instrument was designed in accordance with Bandura's guidelines for constructing self-efficacy scales[22]. He highlights that self-efficacy is concerned with "*perceived capability*". Per his guidelines, the items contained in the instrument are phrased in terms of "*can do*" rather than "*will do*". The instrument contains 20 questions that ask students how confident they are in their belief that they have developed a certain ability. These questions can be answered using an eleven-point likert scale to achieve greater variance in the collected data. The scale ranges between "Cannot do at all" at 0 to “Highly certain can do" at 10. The instrument is given in Table 1.

Validation Plan

The proposed approach and instrument are being implemented in the Engineering Modeling and Design Courses (ELEG 3003-Summer 2017) within the curriculum of BS(Electrical Engineering) program at Arkansas Tech University. The course is also taught during the Fall and Spring semesters. The instrument will be used to collect data during those two semesters as well. The collected data will be analyzed to validate the proposed approach and findings will be reported in future. Based on the analysis of collected data, any remedial actions required to improve the self-efficacy of students in engineering modeling and design will also be implemented.

Conclusion

This paper proposes a measuring instrument to assess personal perception of self-efficacy of students in engineering modeling and design courses. Self-efficacy is important for engineering students because it assesses their confidence to use the engineering skills that they possess. The confidence to use the skills that students master during an engineering curriculum is an important quality that is needed to fulfill the engineering jobs. The paper highlights areas in engineering modeling and design courses in which the student self-efficacy can be measured through pre- and post course surveys. The results from the surveys can be analyzed to plan any remedial actions. To help engineering educators, a survey instrument is also proposed that can be used to measure self-efficacy on an eleven-point likert scale. The survey takes into consideration elements highlighted in the student learning outcomes specified by the ABET-EAC. This project is work in progress as it is currently being implemented in an engineering modeling and design course. The results will provide useful data for validation. As engineering modeling and design courses also run during the fall and spring semesters, authors plan to collect more data for analysis and validation of the proposed approach.

Table 1: Instrument to measure 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 thorough 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

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