AC 2009-206: DEVELOPING AN INSTRUMENT TO MEASURE ENGINEERING DESIGN SELF-EFFICACY

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Developing an Instrument to Measure Engineering Design Self-Efficacy: A Pilot Study

Keywords: self-efficacy, engineering design

Abstract

The following pilot study is an investigation of how to develop an instrument that measures students' self-efficacy regarding engineering design. 36 items were developed and tested using three types of validity evidence. First, the content of the instrument was tested to ensure that the full domain (each subdimension) of the engineering design process was represented. Second, the instrument was tested for whether responses to the instrument could identify groups with various levels of engineering design experience. Finally, theoretical connections between motivation, expectancy for success, and anxiety were tested to determine their appropriateness in the measurement of self-efficacy. Results confirmed an accurate reading of engineering design self-efficacy for 82 volunteer respondents with diverse engineering expertise.

Introduction

Self-efficacy is a motivational construct regarding an individual's belief or judgment in their capability to organize and execute courses of action for a given domain-specific task.[1, 2] An individual's self-efficacy plays a crucial role in their ability to conduct a particular task; however, self-efficacy toward engineering concepts is rarely analyzed. Information about engineering student levels of self-efficacy on engineering tasks can be useful for educators to plan and structure engineering courses.

The following paper describes an exploratory pilot study conducted to inform the development of an instrument designed to identify self-efficacy toward engineering design. Engineering design, or the process used to devise a system, component, or process to meet a desired need, was chosen as the focus because of its importance in the field of engineering.[3]

Instrument development was guided by three questions:

1. *How should the engineering design domain be represented?*
2. *Does the instrument predict differences in self-efficacy held by subjects with a range of engineering experience?*
3. *Does the instrument predict relationships among constructs adopted in this study?*

These questions are explored through three forms of validity evidence[4]: content, criterion-related, and construct. The paper begins by defining each validity type to establish the necessity for each validation step. Previous research in the realm of engineering-based self-efficacy is woven throughout the validation sections as an integrated literature review. The background information is then used to guide the development of the instrument. Preliminary results of the instrument confirm the three forms of validation. The paper concludes with a discussion of the results and future development of the instrument.

Instrument Design

The development of the instrument was guided by the three most commonly used types of validation employed in social science research: content, criterion-related, and construct.

Content Validity

Content validity is an evaluation of the extent to which a measurement represents all facets of a specific domain.[5, 6] Conducting content validity is considerably complex when dealing with latent concepts like self-efficacy.[7] The difficulty relates to adequate sampling of the domain that the instrument is designed to represent. This causes an issue of assuring representativeness of a particular item. Even so, content validity has been employed in previous studies looking at engineering-related self-efficacy. Baker, Krause, and Purzer [8] used content validity effectively in the development of separate tinkering and technical self-efficacy scales. The two scales were constructed based on expert views and options of two open-ended questions about tinkering and technical skills. Expert answers were used to represent the domain.

Quade [9] also used content validation in the development of a computer science self-efficacy scale for first-year computer science majors. Three sources were used to establish the computer science domain: reviewed literature, interviews of computer science graduates, and analysis of the skill set required for an introductory computer science course. The three sources were used to ensure representativeness of the domain.

Content validity for the engineering design self-efficacy instrument was addressed by determining how to represent the engineering design domain. A direct way to analyze engineering design is to measure self-efficacy toward each step of the engineering design process (Figure 1).* Within the process are important steps that guide efficient and effective engineering design. The chosen engineering design process model conceptualized by the Massachusetts Department of Education insinuates that eight items representing each step (subdimensions of engineering design) – identify a design need, research a design need, develop design solutions, select the best possible design, construct a prototype, test and

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* The engineering design process depicted in Figure 2 is one of many versions that have been formulated. The choice to use the Massachusetts Department of Education model for this study was made on the basis that the study was conducted in Massachusetts and because the state of Massachusetts has instituted science and technology/engineering into its state standards.

evaluate a design, communicate a design, and redesign – be included for each construct scale. The scale would fail to fully represent engineering design if any of the steps were excluded. A ninth item was additionally added to query respondents directly about conducting engineering design. The additional item can be used for further content validation. Each item must be validated to ensure representativeness of engineering design.

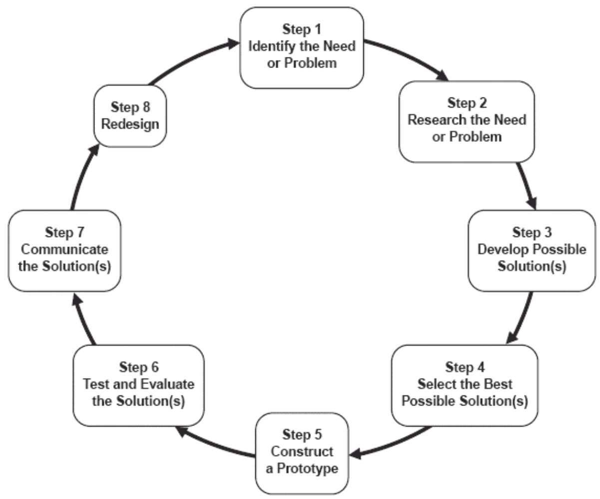

Figure 1: The engineering design process.[10]

Criterion-Related Validity

Criterion-related validity is a measure of prediction accuracy related to a component of the test's external structure.[5, 6] Criterion-related validity is used mostly to correlate scores obtained on a given test with performance on a particular criterion or set of relevant criteria. In most social science research, identifying a relevant criterion to the latent variable an instrument attempts to measure is challenging. One self-efficacy study that employed criterion-related validity is Quade's [9] computer science self-efficacy study previously mentioned. The criterion of interest was whether students passed the introductory computer science course. The assumption was that students who pass the course are more likely to have higher computer science self-efficacy than those who fail the course.

Criterion-related validity for the engineering design self-efficacy instrument was addressed by selecting a criterion to measure that sufficiently relates to engineering design. The assumption is made that individuals with more engineering experience are more likely to have higher engineering design self-efficacy than those with less engineering experience. The criterion of interest is engineering experience. Participants can subsequently be grouped based on a self-identification of engineering experience. The instrument is criterion validated if individuals with varying degrees of engineering experience score as suspected.

Construct Validity

Construct validity is an evaluation of how well a certain measure relates to a theoretical network concerning the construct being measured.[5, 6] Construct validity is used when a consensus of accepted and adequate criterion or universe of content is lacking.[11] This is primarily the case for social science concepts like self-efficacy. The majority of engineering-based self-efficacy studies build their theoretical framework from Bandura's self-efficacy theory. According to Bandura [1, 2], four sources of information – listed in decreasing influence and importance – shape self-efficacy: 1) performance accomplishments or mastery experiences, 2) vicarious experiences, 3) verbal or social persuasions, and 4) physiological states. Richardson [12] conducted a study on tinkering self-efficacy, which framed two self-report instruments within Bandura's sources of self-efficacy.

Hutchinson *et al.* [13], and later in Hutchinson's Ph.D. dissertation [14], also used Bandura's sources of self-efficacy to construct and validate an engineering-related self-efficacy scale. In her study she developed a measure to analyze factors influencing the self-efficacy beliefs of first-year engineering students in terms of overall academic efficacy and engineering milestone efficacy.

Quade's [9] study, in addition to content and criterion-related validity, used construct validity to analyze computer science self-efficacy. Each item developed in accordance to previous validity considerations, was analyzed by a panel of experts instructed to consider how each item relates to Bandura's antecedents of perceived self-efficacy.

Construct validity for the engineering design self-efficacy instrument was addressed by establishing an appropriate theoretical framework. Self-efficacy theory tells us that what is believed has a greater influence on motivation than what is objectively true.[1] The impact of beliefs is driven by the mediating role self-efficacy plays on the mechanisms influencing cognitive motivation.[15-17] Self-efficacy beliefs contribute to motivation through the goals people set, how much effort they expend, how long they persist, and their resilience to failures.[18] Individuals who harbor doubts about their capabilities when faced with obstacles quickly give up. Those who are have high self-efficacy about their capabilities exert greater effort when they fail to master the challenge.

A cognitive motivator often correlated with self-efficacy is outcome expectancy. Outcome expectations are beliefs about the contingency between a person's behavior and the anticipated outcome.[17] Self-efficacy's correlation with outcome expectancy is similar to expectancy for success discussed in expectancy-value theory. Expectancy-value theory is a theory specifically derived to connect achievement motivation with the perceived task value or incentive associated with the likely outcome of an activity.[19-21] Expectancy-value theory draws on an individual's level of aspiration.[22] Expectation for success combined with actual successes raises an individual's desire to perform a given activity. This in turn increases their level of aspiration and often their self-efficacy. The possibility exists for an individual to have high efficacy beliefs, but low outcome expectations. Fear of failure (anxiety) and actual failures are the typical culprits for lower levels of aspiration and self-efficacy.

Contemporary versions of expectancy-value theory separate expectancy and value into differing motives for achievement. Eccles and Wigfield [23-26] highlight *expectancy* as whether one can accomplish the task (expectancy for success), while *value* deciphers why such a task should be undertaken based on attainment value (importance of doing the task well for oneself), intrinsic value (interest and enjoyment in performing the task), utility value (perceived usefulness of the task toward future goals), and cost belief (perceived negatives of doing the task toward what could have been done instead).[27] Self-efficacy impacts both expectancy and value by determining which endeavors are undertaken in accordance with perceived capability and expectancy for success.

A summary of the theoretical connections can be seen in Table I. This summary is the foundation upon which the instrument scales and items were designed.

Table I: Theoretical ranges of self-efficacy.

Group	Confidence	Motivation	Anxiety
High Self-Efficacy	High	High	Little to No
Intermediate Self-Efficacy	Medium	Medium	Medium
Low Self-Efficacy	Low	Low	High

Research Methods

Using the three validation sources, a pilot instrument was developed consisting of four self-identifying questions and four scales (Appendix I). Each of the four scales corresponds to a construct of interest to the measurement of self-efficacy (confidence, motivation, expectancy for success, and anxiety). Each scale was measured on a 100-point range with 10-unit intervals. A 0-100 response format was used as it is a stronger predictor of performance than a 5-interval Likert scale.[28] Each 100-point scale consisted of items pertaining to individual engineering design steps plus an overall engineering design question – nine overall data points per question.

Subjects

82 respondents were solicited through email to pilot test the engineering design self-efficacy instrument. Respondents ranged in age from nineteen to fifty-eight years old. The sex of each respondent was kept anonymous. The overall population consisted of individuals with diverse engineering experiences. Figure 2 shows the engineering identifications self-selected by each respondent.

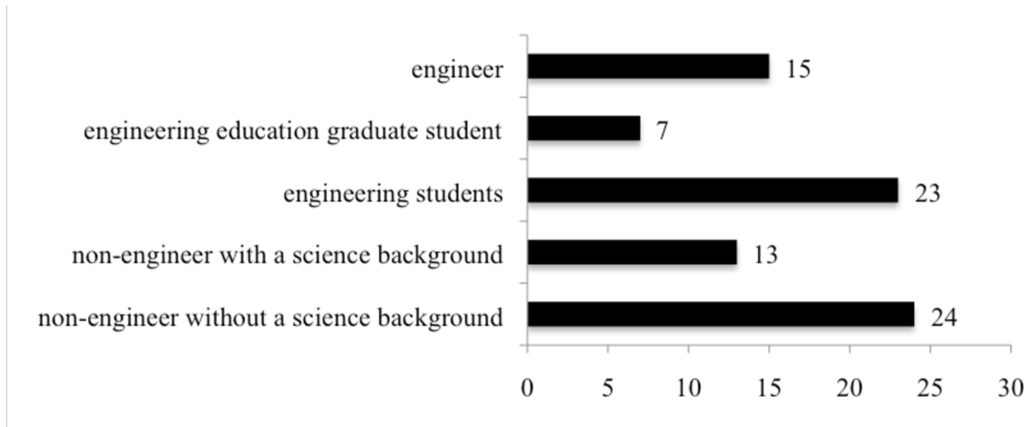

Figure 2: Respondent engineering self-identifications.

Results
Content Validity

A relationship between engineering design and the engineering design process steps was tested in a two-step process. The first step was to test if the thirty-two items regarding the eight steps of the engineering design process – identify a design need, research a design need, develop design solutions, select the best possible design, construct a prototype, evaluate & test a design, communicate a design, and redesign (items 2-9 of all four scales seen in Appendix I) – relate to self-efficacy. Exploratory factor analysis utilizing Varimax rotation and an inspection of the scree plot was used to identify the number of factors present amongst the thirty-two items. Factor analysis identified the presence of one overall factor accounting for 60.24 percent of the total variance. Factors were determined using only factors with eigenvalues greater than 1.[29] The instrument can be defined as a pure factor instrument with an overall Cronbach's α reliability of 0.948.

The second step investigates the correlation between the thirty-two items regarding the eight steps of the engineering design process and the four additional items pertaining to engineering design (ED) (item 1 of all four scales seen in Appendix I). Pearson correlations were calculated between the ED item and each individual step for all four constructs (Table II). Each step of the engineering design process was significantly correlated to engineering design to $\rho \leq 0.01$.

These results conclude that the engineering design process steps defined by the Massachusetts Department of Education adequately represent engineering design. The possibility exists for the instrument to be modified to ask respondents to rank their confidence, motivation, outcome expectancy, and anxiety only toward engineering design. This is not recommended, as an overall outcome reliant on one item could affect the reliability of the instrument.

Table II: Correlations between ED and the engineering design process steps.

	ED Confidence	ED Motivation	ED Expectancy	ED Anxiety
identify a design need	0.871	0.755	0.813	0.720
research a design need	0.765	0.667	0.795	0.721
develop design solutions	0.887	0.897	0.878	0.791
select the best possible design	0.811	0.785	0.747	0.721
construct a prototype	0.864	0.757	0.874	0.778
evaluate & test a design	0.845	0.723	0.872	0.675
communicate a design	0.773	0.697	0.763	0.585
redesign	0.887	0.839	0.920	0.739

Criterion-Related Validity

A criterion-related evaluation was conducted to ensure that the scale adequately represents groups with different levels of engineering expertise. A group with high levels of engineering experience is expected to have higher levels of self-efficacy. Participants were first grouped based on engineering self-identifications. Each engineering self-identification was confirmed by matching each respondent's responses to questions about their undergraduate degree and current profession. Respondents were further grouped to fit each self-identified engineering group into the three levels of engineering design self-efficacy – high self-efficacy, intermediate self-efficacy, and low self-efficacy – determined by Table I. Respondents were clustered based on two criteria: 1) average ED scores – the value recorded for each construct when asked to rate their confidence, motivation, outcome expectancy, or anxiety when "conducting engineering design" – and 2) responses to background questions regarding their engineering experience. Three groups were formed: Group 1 – high self-efficacy (n = 22); Group 2 – intermediate self-efficacy (n = 36); and Group 3 – low self-efficacy (n = 24).

High self-efficacy respondents were individuals with engineering degrees and firsthand engineering experience (engineers and engineering education graduate students). Intermediate self-efficacy respondents were current learners of engineering (engineering students and non-engineers with science backgrounds). Low self-efficacy respondents were non-engineers with little to no engineering experience (non-engineers without a science background).

A one-way between subjects ANOVA was conducted to compare the effects of confidence, motivation, outcome expectancy, and anxiety toward engineering design on the three self-efficacy groups. There was a significant effect from all four constructs at the $\rho < 0.05$ level for the three self-efficacy groups [$F_{confidence}(2,81) = 75.10$, $\rho < 0.001$); $F_{motivation}(2,81) = 47.45$, $\rho < 0.001$); $F_{expectancy}(2,81) = 67.88$, $\rho < 0.001$); $F_{anxiety}(2,81) = 6.78$, $\rho < 0.01$)]. Post hoc comparisons using the Tukey HSD test indicated that the mean scores for confidence, motivation, outcome expectancy, and anxiety (Table III) were significantly different ($\rho \leq 0.001$) for each of the three groups with three exceptions; Group 1 and Group 2 were significant to $\rho = 0.007$ for motivation, Group 1 and 2 were significant to the $\rho = 0.032$ for anxiety, and Group 2 and Group 3 were not significant for anxiety ($\rho = 0.330$).

Table III: Mean ED scores with standard deviations.

	Confidence		Motivation		Outcome Expectancy		Anxiety	
Group	**M**	**SD**	**M**	**SD**	**M**	**SD**	**M**	**SD**
1	86.82	14.60	89.09	15.71	85.00	13.72	23.64	24.41
2	60.28	25.58	67.50	29.89	63.61	24.98	46.39	32.70
3	10.00	21.06	18.75	25.25	13.33	22.39	58.75	38.93

These criterion results suggest that confidence, motivation, outcome expectancy, and anxiety toward engineering design play a significant role in determining an individual's level of engineering design self-efficacy. ED scores for confidence, motivation, and expectancy displayed decreasing average scores as engineering experience decreases. Conversely, ED scores for anxiety increase as engineering experience decreases. The scores validate that levels of engineering expertise match particular performances on the instrument, but respondents should be further separated to obtain better post hoc comparisons between Group 1 and 2.

Construct Validity

The final construct evaluation was conducted to ensure that the scales are theoretically connected with relevant sub-constructs. Construct validity motivation, outcome expectancy, and anxiety were achieved by using correlations. Correlations between the variables were calculated to illustrate their impact on one another. Motivation (0.807), outcome expectancy (0.864), and anxiety (-0.469) were all significantly correlated ($\rho \leq 0.01$) to self-efficacy confirming theoretical predictions. Motivation and outcome expectancy results were positively correlated to self-efficacy. This does not conclude that individuals with low self-efficacy toward engineering design could not be motivated or successful in engineering, but with their current knowledge and beliefs they would not be inclined. Conversely, anxiety results were negatively correlated to self-efficacy. Anxiety's lower magnitude correlation to self-efficacy suggests that high self-efficacy and extensive engineering experience does not necessarily eliminate anxiety completely. The nature of how engineering affects the world and the consequences for poor performance can make the most mastered engineer a bit anxious.

Discussion

The results of this study clearly indicate three distinct findings about the instrument designed to measure engineering design self-efficacy. First, the engineering design process steps are an appropriate way to represent engineering design when measuring self-efficacy. The Massachusetts Department of Education model for the engineering design process represents the domain well.

Second, engineering design self-efficacy is highly dependent on engineering experiences. This is evident in how the respondents were grouped. Individuals placed into specific efficacy groups based on experience are not surprising when framed by Bandura's sources of self-efficacy. Opportunities for mastery experiences, vicarious experiences, social persuasion, or psychological states within engineering design most often won't occur unless the individual has had some sort of experience. The one-way ANOVA results suggest post hoc that the three efficacy groups need further refining. Additional engineering self-identifications may alleviate this problem. For example, splitting up graduate engineering students and undergraduate engineering students.

Finally, the sub-constructs of motivation, outcome expectancy, and anxiety are indicators of self-efficacy toward engineering design. This was clearly predicted by self-efficacy theory and expectancy-value theory. Anxiety results suggest that special accommodations should be made when only one construct is negatively correlated. Fashioning the instrument into two pages so that anxiety is separated from the positively correlated constructs may result in a more accurate measurement of anxiety. A larger population may also assist in differentiating the anxiety levels of the efficacy groups.

Additionally, the instrument could also be enhances with the inclusion of two more constructs: task value (or incentive) and attribution to failure. These two constructs are theoretically linked to self-efficacy, however are not easily assessed using a Likert-type question. A different type of question format would have to be used if these two constructs were to be included.

Conclusions

Self-efficacy is an emerging construct in the field of engineering. Knowing an individuals self-efficacy and understanding how it affects their learning expands what can be identified solely through academic achievement. Establishing clearer learner understandings of self-efficacy in engineering contexts has many benefits that can hopefully reduce barriers prohibiting entry into the profession [30] and improve the retention of women and minorities.[31-35]

This study was a first step in the development and validation of an engineering design self-efficacy instrument. The three validation procedures provided evidence that the Massachusetts Department of Education model suitably represented engineering design, respondents can be identified and clustered into efficacy groups based on engineering expertise, and self-efficacy theory pertains to the domain of engineering design.

We believe that further development of this instrument should provide the engineering education community with valuable and reliable instrument to assess student self-efficacy beliefs.

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Appendix I: Pilot Engineering Design Self-Efficacy Instrument

Engineering Design Self-efficacy Instrument

Background – Please fill in the following background information as it best applies to you.

Date (MM/DD/YYYY): ________________

Birthday (MM/DD/YYYY): ________________

Current Profession: ____________________________________

Major in college (choose one):

- Arts and Humanities 9art, language, pre-law, etc…)
- Social Sciences (psychology, political science, sociology, history, etc…)
- Education
- Business
- Engineering
- Science, Technology, or Math
- Not Applicable
- Other: ____

Choose the category describes you best.

- Professor of Engineering or Engineering Education
- Engineer
- Engineering Student (Graduate)
- Engineering Student (Undergraduate)
- Engineering Education Student
- Non-Engineer with a Science Background
- Non-Engineer without a Science Background

Self-efficacy Questions – Please answer all of the following questions fully by selecting the answer that best represents your beliefs and judgment of your current abilities. Answer each question in terms of who you are and what you know today about the given tasks.

1. Rate your degree of confidence (i.e. belief in your current ability) to perform the following tasks by recording a number from 0 to 100.)
   0 = cannot do at all; 50 = moderately can do; 100 = highly certain can do)

	0	10	20	30	40	50	60	70	80	90	100
conduct engineering design											
identify a design need											
research a design need											
develop design solutions											
select the best possible design											
construct a prototype											
evaluate and test a design											
communicate a design											
redesign											

2. Rate how motivated you would be to perform the following tasks by recording a number from 0 to 100.
(0 = not motivated; 50 = moderately motivated; 100 = highly motivated)

	0	10	20	30	40	50	60	70	80	90	100
conduct engineering design											
identify a design need											
research a design need											
develop design solutions											
select the best possible design											
construct a prototype											
evaluate and test a design											
communicate a design											
redesign											

3. Rate how successful you would be in performing the following tasks by recording a number from 0 to 100.
(0 = cannot expect success at all; 50 = moderately expect success; 100 = highly certain of success)

	0	10	20	30	40	50	60	70	80	90	100
conduct engineering design											
identify a design need											
research a design need											
develop design solutions											
select the best possible design											
construct a prototype											
evaluate and test a design											
communicate a design											
redesign											

4. Rate your degree of anxiety (how apprehensive you would be) in performing the following tasks by recording a number from 0 to 100.
(0 = not anxious at all; 50 = moderately anxious; 100 = highly anxious)

	0	10	20	30	40	50	60	70	80	90	100
conduct engineering design											
identify a design need											
research a design need											
develop design solutions											
select the best possible design											
construct a prototype											
evaluate and test a design											
communicate a design											
redesign											