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# Measuring Engineering Design Self-Efficacy

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ADAM R. CARBERRY AND HEE-SUN LEE  
*Tufts University*

MATTHEW W. OHLAND  
*Purdue University*

## BACKGROUND

Self-concept can influence how an individual learns, but is often overlooked when assessing student learning in engineering.

## PURPOSE (HYPOTHESIS)

To validate an instrument designed to measure individuals' self-concepts toward engineering design tasks, three research questions were investigated: (a) how well the items in the instrument represent the engineering design process in eliciting the task-specific self-concepts of self-efficacy, motivation, outcome expectancy, and anxiety, (b) how well the instrument predicts differences in the self-efficacy held by individuals with a range of engineering experiences, and (c) how well the responses to the instrument align with the relationships conceptualized in self-efficacy theory.

## DESIGN/METHOD

A 36-item online instrument was developed and administered to 202 respondents. Three types of validity evidence were obtained for (a) representativeness of multi-step engineering design processes in eliciting self-efficacy, (b) the instrument's ability to differentiate groups of individuals with different levels of

engineering experience, and (c) relationships between self-efficacy, motivation, outcome expectancy, and anxiety as predicted by self-efficacy theory.

## RESULTS

Results indicate that the instrument can reliably identify individuals' engineering design self-efficacy ( $\alpha = 0.967$ ), motivation ( $\alpha = 0.955$ ), outcome expectancy ( $\alpha = 0.967$ ), and anxiety ( $\alpha = 0.940$ ). One-way ANOVA identified statistical differences in self-efficacy between high, intermediate, and low experience groups at the  $p < 0.05$  level. Self-efficacy was also shown to be correlated to motivation (0.779), outcome expectancy (0.919), and anxiety ( $-0.593$ ) at the  $p < 0.01$  level.

## CONCLUSIONS

The study showed that the instrument was capable of identifying individuals' self-concepts specific to the engineering design tasks.

## KEYWORDS

assessment, engineering design, self-efficacy

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## I. INTRODUCTION

There is a growing need within engineering education to understand more completely how students learn and how to effectively teach them. While cognitive gains are an important outcome of engineering education, students need to have both the will and the skill to succeed (Pintrich and De Groot, 1990). An evaluation of changes to both will and cognition is needed to understand how student learning can be facilitated or hindered in engineering education.

This paper addresses the need to analyze will through the development and validation of an instrument measuring task-specific self-concepts. A task-specific self-concept is any variable concerning the understanding an individual has of him or herself for a given task. Understanding of self is what leads to the desire, or lack thereof, to perform a given task. Four task-specific self-concepts were investigated—self-efficacy, motivation, outcome expectancy, and anxiety—with self-efficacy as the central focus. Self-efficacy refers to an individuals' judgment of their capability to organize and execute courses of action for a given task (Bandura, 1986; 1997). According to self-efficacy theory, the level of self-efficacy for a given task is influenced by other task-specific self-concepts including motivation, outcome expectancy, and anxiety or self-doubt toward the task (Pintrich and Schunk, 2002).

For the domain of engineering, the effect of self-efficacy on learning can be more pronounced because of the frequent uses of design tasks as part of an engineering learning experience. Engineering design tasks in this study refer to the applied or practical component of engineering, which consists of several processes used in devising a system, a component, or a protocol to meet an identified need. The importance of design tasks as part of engineering education relates directly to preparing students for industrial demands (Auyang, 2004; Duderstadt, 2008; Grinter, 1994; Society for the Promotion of Engineering Education, 1930). While some engineering fields do not necessarily demand hands-on design task ability, the use of design tasks, and hence engineering design knowledge, is recommended by ABET (the U.S. accreditation body for computing, engineering, and technology).

The engineering design self-efficacy instrument development and validation were guided by three research questions:

1. How well do the items in the instrument represent the engineering design task in eliciting the task-specific self-concepts of self-efficacy, motivation, outcome expectancy, and anxiety?
2. How well does the instrument predict differences in the self-efficacy held by individuals with a range of engineering experiences?

3. How well are responses to the instrument aligned with the relationships among the task-specific self-concepts as conceptualized in self-efficacy theory?

In the following sections, we will describe how each research question was addressed through the development and validation of the engineering design self-efficacy instrument. We first define three sources of validity evidence and connect them to previous research conducted on task-specific self-efficacy related to engineering. We then describe each source of validity to formulate each research question, describe participants based on their engineering experience, and construct a theoretical framework. Finally, we present results regarding each research question and discuss limitations and potential future uses of the instrument.

## II. SOURCES OF VALIDITY EVIDENCE

Validation is an evaluation of how adequately an instrument measures what it is intended to measure so that inferences and actions resulting from the data on the instrument can be justified (Messick, 1989; Moskal, Leydens, and Pavelich, 2002). The development of the engineering design self-efficacy instrument was guided by three sources of validity evidence recommended by the measurement community (American Educational Research Association, American Psychological Association, and National Council on Measurement in Education, 1999): content, criterion, and construct validity.

### A. Content Validity

Content validity concerns the extent to which a measurement adequately samples a specific domain represented in an instrument (Carminer and Zeller, 1979; Messick, 1989; Moskal, Leydens, and Pavelich, 2002). Content validity can be difficult to obtain because prediction of ability, attitudinal, and affective variables cannot be directly observed (Wilson, 2005). This makes adequate sampling of the intended domain difficult. Two examples of content validity regarding engineering-related self-efficacy were found in the literature. Baker, Krause, and Purzer (2008) constructed two scales to represent expert views and options of two open-ended questions about tinkering and technical skills. Using the responses of these questions, they were able to develop tinkering and technical self-efficacy scales. Quade (2003) reviewed literature, interviews of computer science graduates, and analysis of the skill set required for an introductory computer science course to represent the computer science domain. Using these sources of content, she was able to develop a computer science self-efficacy scale for first-year computer science majors. Both instruments used content validity as a way to validate the appropriateness of items used in the instrument to represent specific domains. In this study, content validity is used to show how well the developed items adequately represent the engineering design domain in eliciting task-specific self-concepts.

### B. Criterion-Related Validity

Criterion-related validity concerns the ability of an instrument to predict an externally related criterion (Carminer and Zeller, 1979; Messick, 1989; Moskal, Leydens, and Pavelich, 2002). The use of criterion-related validity is mainly to correlate scores obtained from an instrument with a current or future event defined as a relevant criterion. Identifying a relevant criterion to the latent or hidden

variable an instrument attempts to measure is challenging. One self-efficacy study that employed criterion-related validity was Quade's (2003) computer science self-efficacy study. The selected criterion was whether students passed the introductory computer science course. The assumption was that students with high computer science self-efficacy coming into the class were more likely to pass the course than those who came into the course with low computer science self-efficacy. Using this criterion, Quade (2003) validated the computer science self-efficacy instrument. In this study, the external relevant criterion for engineering design self-efficacy is an individuals' experience in engineering. Engineering experience was chosen as a relevant criterion based on self-efficacy theory described in the next section.

### C. Construct Validity

Construct validity concerns how well an instrument is designed to measure theoretically identified relationships between latent variables (Carminer and Zeller, 1979; Messick, 1989; Moskal, Leydens, and Pavelich, 2002). Common use of construct validity is to counteract a situation lacking a clear domain or an adequate criterion (Cronbach and Meehl, 1955). For example, many self-efficacy studies base their entire validation evidence on Bandura's four sources of self-efficacy. According to Bandura's Self-Efficacy Theory (1986; 1997), self-efficacy is shaped by 1) performance accomplishments or mastery experiences, 2) vicarious experiences, 3) verbal or social persuasions, and 4) physiological states. These four sources affect individuals' performance by mediating the goals they set for themselves, the amount of effort they expend, their persistence, and resilience to failures (Bandura, 1994). Two such studies employing construct validity in this fashion include Richardson (2008) and Hutchinson, Follman, and Bodner (2006). Richardson (2008) conducted a study on tinkering self-efficacy, which framed two self-report instruments within Bandura's sources of self-efficacy. Hutchinson and her colleagues (2006) used Bandura's sources of self-efficacy to develop an instrument to analyze factors influencing the self-efficacy beliefs of first-year engineering students in terms of overall academic efficacy and engineering milestone efficacy. Both instruments used Bandura's self-efficacy theory to analyze the extent to which their instrument was connected appropriately to the theory.

Construct validity can be investigated for how it is linked to other sources of validity evidence. For example, Quade's (2003) computer science self-efficacy study used construct validity in conjunction with content and criterion-related validity. In her study, a panel of experts analyzed how each item is related to Bandura's sources of self-efficacy. For this study, a similar approach was taken; however, unlike the other three construct validated studies described, this study uses self-efficacy theory as a basis for establishing relationships among four task-specific self-concepts—self-efficacy, motivation, outcome expectancy, and anxiety.

Self-efficacy is often connected to outcome expectancy and causal attribution. Outcome expectancy is an individual's beliefs about the contingency between behavior and an anticipated outcome (Pintrich and Schunk, 1996). According to expectancy-value theory, expectation for success combined with actual successes raises an individual's desire to perform a given activity (Atkinson, 1957; Atkinson and Feather, 1966; Atkinson and Raynor, 1974), resulting in increased self-efficacy. Contemporary versions of expectancy-value theory further separate expectancy and value into differing motives for achievement. Eccles and Wigfield (Eccles, 1983; 1993;

Wigfield, 1994; Wigfield and Eccles, 2000) characterize *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) (Pintrich and Schunk, 2002). Self-efficacy affects both expectancy and value by influencing what endeavors are undertaken in accordance with perceived capability and expectancy for success. Therefore, 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 causes of low levels of self-efficacy.

Self-efficacy beliefs also influence causal attributions toward success and failure. Self-efficacy contributes to the relationship between attributions and motivation, which influences subsequent performance expectancies (Bandura, 1995; Schunk, 1991, 1994; Weiner, 1986). Judgments based on past successes and failures affect whether that experience warrants future engagement (Vogt, 2003). An individual's self-efficacy relates to the underlying reasons for why success or failure resulted in a subsequent effort level. For instance, success due to luck rarely leads to a belief that warrants future similar actions. People who regard themselves as having high self-efficacy attribute their failures to insufficient effort. Those who regard themselves as having low self-efficacy attribute their failures to low ability (Pintrich and Schunk, 1996).

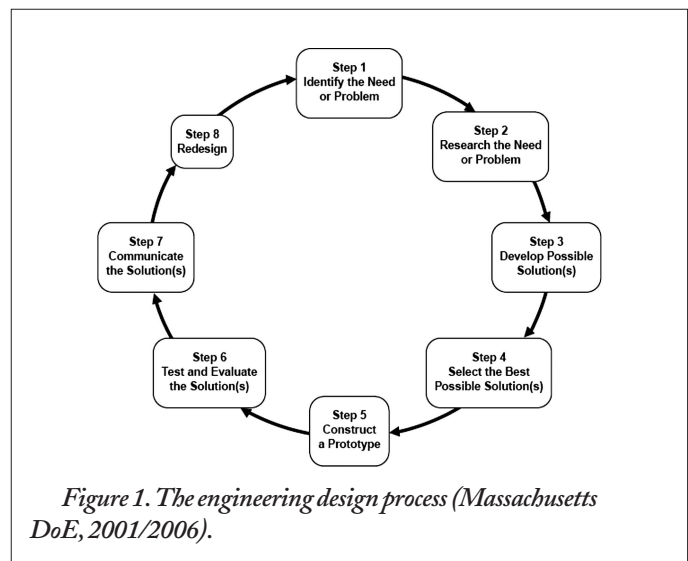
In sum, these three sources of validity evidence together can strengthen the quality of the engineering design self-efficacy instrument. These validation considerations can provide a full analysis of the instrument in terms of representativeness of the domain of interest, connection to criterion regarding engineering experience, and theoretical relationships.

### III. RESEARCH METHODS

#### A. Instrument Design

A 36-item online instrument was developed and tested for content, construct, and criterion validity. Content validity concerns the representation of the engineering design process. The engineering design process is the activity that governs all engineering design. Within the process are important steps for efficient and effective engineering design; however, there is no consensus on what exactly constitutes the engineering design process. Similarity across various models exists in that the engineering design process is not simply sequential, but rather an iterative process that loops (Ball and Ormerod, 1995; Ennis and Gyeszly, 1991). Specific terms for steps, the order of the steps, and the available pathways through the models vary from one model to another.

For this study, the model referenced is an eight-step process proposed in the Massachusetts Department of Education (DoE) Science and Technology/Engineering Curriculum Framework (Figure 1) (Massachusetts DoE, 2001/2006). Massachusetts was the first state to officially integrate engineering content into their state standards. Such standards have been and continue to be very influential in affecting many levels of education throughout the United States. The Massachusetts Department of Education model was developed with substantial expertise from several groups,



including the Massachusetts Technology Education/Engineering Collaborative (MassTEC), the Technology Education Association of Massachusetts Inc. (TEAM), and professional engineers, university faculty, and Massachusetts' practitioners (led by Ioannis Miaoulis, President and Director of Museum of Science, Boston). The steps provided in the model are aligned with others, providing conceptual (though not semantic) equivalence across expert opinion as to what comprises the engineering design process.

This model was used to develop items to represent the engineering design task. The model conceptually aligns with other recognized models differing only based on the exact words or phrases used and the way in which the looping nature is depicted or drawn (note: the sequential or cyclic nature of the model is not addressed in the methods and analysis chosen for the study). Using the chosen model, a nine-item scale was developed for each task-specific self-concept. The first item reports the respondent's self-conception toward *conducting engineering design* (item one of Figure 2). This item represents a respondent's engineering design (ED) score. The remaining eight items represent each step (subdimensions) of the chosen engineering design process—*identify a design need, research a design need, develop design solutions, select the best possible design, construct a prototype, test and evaluate a design, communicate a design, and redesign* (items two through nine of Figure 2). Exclusion of any one subdimension would cause the instrument to fail on fully representing the engineering design domain as defined by our chosen engineering design process. An average of these eight items represents a respondent's engineering design process (EDP) score. Overall, the nine items regarding engineering design and each step of the engineering design process ensure that the engineering design domain is fully represented.

Criterion-related validity was addressed using respondent engineering experience. The assumption was made that individuals with more engineering experience are more likely to have higher engineering design self-efficacy than those with less engineering experience. Participants self-reported their engineering experience by choosing one of the five categories provided: *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*. The evidence supports that the

Rate your degree of (FILL IN TASK-SPECIFIC SELF-CONCEPT OF INTEREST) to perform the following tasks by recording a number from 0 to 100. (0 = low; 50 = moderate; 100 = high)

	0	10	20	30	40	50	60	70	80	90	100
conduct engineering design	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
identify a design need	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
research a design need	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
develop design solutions	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
select the best possible design	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
construct a prototype	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
evaluate and test a design	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
communicate a design	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
redesign	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Figure 2. Generic scale used to represent the engineering design domain.

instrument has criterion validity if individuals with varying degrees of engineering experience can be differentiated as presumed.

Construct validity was addressed by determining how the task-specific self-concepts relate to how the theory predicts. Hypothesized responses were developed for each group using the theoretical relationships of motivation, outcome expectancy, and anxiety drawn from self-efficacy and expectancy-value theory.

The resulting instrument (Appendix) measured the four task-specific self-concepts, including self-efficacy (measured as confidence) (Bandura, 1997, p. 382), on a scale consisting of nine Likert-type items scored on a 100-point range with ten-unit intervals. A 0 to 100 response format was used because it is a stronger predictor of performance than a five-interval Likert scale (Pajares, Hartley, and Valiante, 2001) based on an individual's common understanding of being typically scored in school on a 100-point scale.

Additional, demographic information pertaining to age, education, profession, and engineering experience was gathered to develop criteria for engineering experience. Gender information was not collected from the greater population to maintain engineering experience as the guiding criterion; however, gender's known influence on the self-efficacy of engineering students (Besterfield-Sacre, Moreno, Shuman, and Atman, 2001; Felder et al., 1995; Hackett et al., 1992; Schaefer, Epperson, and Nauta, 1997; Schmidt et al., 2001) made it a validity concern. Gender information was therefore gathered from a small subset of the population consisting of undergraduate and graduate engineering students ( $N = 64$ ) in to investigate if items for task-specific self-concepts function differently between male and female groups.

## B. Participants

Three hundred and sixty-seven individuals responded to an e-mail soliciting them to test the engineering design self-efficacy instrument. One hundred and thirty-seven responses were excluded because the respondents did not complete the entire instrument. Twenty-eight responses were excluded because the respondents rated each item with the same score across a given task-specific self-concept (although this could be their actual beliefs, the chance of the respondent trying to quickly complete the instrument warrants their removal). The remaining 202 respondents ranged in age from 21–62

years old ( $M = 26.69 \pm 8.15$ ). The overall population of respondents consisted of individuals with diverse engineering experiences: 12 engineering or engineering education professors, 26 engineers, 7 engineering education graduate students, 28 engineering graduate students, 60 engineering undergraduate students, 32 non-engineers with science backgrounds and 37 non-engineers without science backgrounds. Variability in engineering expertise was deliberately sought within the sample to ensure variability in the engineering design self-efficacy groups as well as to identify the extremes. Gender information was collected for only a subset ( $N = 64$ ) of the student population. Among the subset of students who provided gender information 26 (18 undergraduate and 8 graduate) were female and 38 (25 undergraduate and 13 graduate) were male.

## C. Data Collection and Analysis

Data were collected using an online surveying tool. The survey took respondents an average of five minutes to complete. Individuals were solicited to participate in the survey through e-mail listings available to the researchers. A subset of engineering students at a small private institution was later solicited to test the instrument specifically on its intended population and to conduct an analysis of gender influence on the survey responses. Results from the survey were then pooled for further analysis. The Statistical Package for the Social Sciences (SPSS) was used to calculate correlations and reliability coefficients, conduct factor analysis, and analysis of variance (ANOVA).

Using the respondents' self-reported engineering experience, each respondent was classified as having high, intermediate, or low task-specific self-efficacy. An individual who has high self-efficacy toward a task is confident about their abilities, is motivated by the task, seeks and expects success, and has little to no anxiety toward the task; while an individual who has low self-efficacy toward a task has no confidence in their abilities, is unmotivated by the task, expects failure, and has a high level of anxiety toward the task (Pintrich and Schunk, 1996). Between the extremes are respondents who cannot be classified under either. These individuals who fall between the high and low self-efficacy were identified as having intermediate self-efficacy. An individual who has intermediate self-efficacy toward a task is moderately confident in his or her abilities, is motivated by



the task, but unsure of the possibility of success, and has slight to moderate anxiety toward the task.

## IV. RESULTS

### A. How Well do the Items in the Instrument Represent the Engineering Design Task in Eliciting the Task-Specific Self-Concepts of Self-Efficacy, Motivation, Outcome Expectancy, and Anxiety?

The representativeness of engineering design by the engineering design process steps was tested in three steps. The first step was to test the inter-item reliability among the eight individual engineering design process steps—items two through nine of the self-efficacy, motivation, outcome expectancy, and anxiety scales—for each of the four task-specific self-concepts. Each set of items for a given task-specific self-concept was analyzed separately. The Cronbach's  $\alpha$  values for self-efficacy (0.967), motivation (0.955), outcome expectancy (0.967), and anxiety (0.940) showed a high reliability among the eight steps for a given task-specific self-concept. A subset of engineering students was additionally tested to ensure that the reliability of the instrument was not affected by a respondent's gender. Relatively similar Cronbach's  $\alpha$  values seen in Table 1 for females, males, and the overall subset ensure that gender does not affect the overall reliability of the instrument. These high reliability coefficients among the eight engineering design steps for the gender and non-gendered analysis show overall agreement of individuals across the eight steps for each of the four task-specific self-concepts.

High inter-item reliabilities suggested that the observed items were capable of being reduced to fewer factors through factor analysis. Exploratory factor analysis was used to identify the number of factors present among the eight steps of the engineering design process for each of the four task-specific self-concepts (items two through nine in Figure 2 for questions one through four in the Appendix). Factor analysis for each task-specific self-concept revealed one factor per task-specific self-concept determined using only factors with eigenvalues greater than one (Rummel, 1970). These factors were labeled the *engineering design process (EDP)* (one per task-specific self-concept). An EDP factor score, therefore, refers to a calibrated average of the eight individual engineering design process steps (items two through nine in Figure 2) for each separate task-specific self-concept. Additionally, confirmatory factor analysis was used for each individual step of the engineering design process across the four task-specific self-concepts (for example, a respondent's 'identify a need' score for each of the four task-specific self-concepts) to ensure item consistency. Factor analysis of each

individual step also revealed one factor per item determined using only factors with eigenvalues greater than one. Each factor was labeled using the identical name of the step—*identify a design need, research a design need, develop design solutions, select the best possible design, construct a prototype, test and evaluate a design, communicate a design, and redesign*.

The final step was conducted to check the extent to which the new EDP factor scores for each of the four task-specific self-concepts represented overall engineering design (ED). ED scores were obtained from the first item of the scale referring to *conduct engineering design* (item one in Figure 2 for questions one through four in the Appendix). Pearson correlations for self-efficacy (0.890), motivation (0.882), outcome expectancy (0.888), and anxiety (0.791) were all significantly correlated ( $p \leq 0.01$ ) suggesting that responses were consistent between ED scores and EDP factor scores.

These results indicate that the engineering design process steps obtained from the Massachusetts Science and Technology/Engineering Curriculum Framework consistently and reliably represent engineering design in measuring all four task-specific self-concepts. The possibility exists for the instrument to be modified to ask respondents to rank their self-efficacy, motivation, outcome expectancy, and anxiety only toward engineering design. The use of the factored score across eight items to measure each task-specific self-concept is more beneficial in statistical analyses because of the increased variations among subjects.

### B. How Well does the Instrument Predict Differences in the Self-Efficacy Held by Individuals with a Range of Engineering Experience?

Engineering experience was tested as a criterion by hypothesizing that individuals with high levels of engineering experience should have overall high levels of engineering design self-efficacy, while individuals with low levels of engineering experience should have low levels of engineering design self-efficacy. Participants were first grouped based on their engineering self-identifications. Each engineering self-identification was confirmed by matching each individual's responses to questions about their undergraduate degree and current profession (if applicable). Respondents were regrouped into the three levels of engineering design self-efficacy—high self-efficacy, intermediate self-efficacy, and low self-efficacy—based on their engineering experience. The following groups resulted:

*High Self-Efficacy (N = 73)*—respondents with engineering degrees and firsthand engineering experience (professors of engineering and engineering education, engineers, engineering and engineering education graduate students)

	Females (n = 26)	Males (n = 38)	Overall (n = 64)
Self-Efficacy	0.963	0.905	0.934
Motivation	0.885	0.878	0.879
Outcome Expectancy	0.940	0.857	0.906
Anxiety	0.929	0.955	0.950

Table 1. Gender-specific reliability analysis of the four task-specific self-concepts.

*Intermediate Self-Efficacy* ( $N = 92$ )—current learners of engineering (engineering undergraduate students and non-engineers with science backgrounds)

*Low Self-Efficacy* ( $N = 37$ )—non-engineers with little to no engineering experience (non-engineers without a science background)

A one-way ANOVA was conducted to compare mean ED scores on self-efficacy, motivation, outcome expectancy, and anxiety toward engineering design for the three groups. There were statistically significant effects on all four task-specific self-concepts at the  $\rho < 0.05$  level for the three groups [ $F_{\text{self-efficacy}}(2,199) = 79.16, \rho < 0.001$ ;  $F_{\text{motivation}}(2,199) = 71.73, \rho < 0.001$ ;  $F_{\text{expectancy}}(2,199) = 77.91, \rho < 0.001$ ;  $F_{\text{anxiety}}(2,199) = 8.76, \rho < 0.001$ ]. Post hoc comparisons using the Tukey HSD test indicate that the mean scores for self-efficacy, motivation, outcome expectancy, and anxiety (Table 2) were significantly different ( $\rho \leq 0.001$ ) among all three groups with two exceptions: 1) the High Self-Efficacy and Intermediate Self-Efficacy groups were significant ( $\rho = 0.042$ ) for anxiety and 2) the Intermediate Self-Efficacy and Low Self-Efficacy groups were not significant for anxiety ( $\rho = 0.055$ ).

A one-way ANOVA was also conducted to compare mean EDP scores for self-efficacy, motivation, outcome expectancy, and anxiety for the three groups. Again, statistically significant differences existed for all four task-specific self-concepts at the  $\rho < 0.05$  level among the three groups [ $F_{\text{self-efficacy}}(2,199) = 63.84, \rho < 0.001$ ;  $F_{\text{motivation}}(2,199) = 51.13, \rho < 0.001$ ;  $F_{\text{expectancy}}(2,199) = 57.15, \rho < 0.001$ ;  $F_{\text{anxiety}}(2,199) = 11.47, \rho < 0.001$ ]. Post hoc comparisons using the Tukey HSD test indicated that the mean scores for self-efficacy, motivation, outcome expectancy, and anxiety (Table 3) were significantly different ( $\rho \leq 0.001$ ) for all three groups with two exceptions: 1) the High Self-Efficacy and Intermediate Self-Efficacy groups were significant ( $\rho = 0.003$ ) for anxiety and 2) the Intermediate Self-Efficacy and Low Self-Efficacy groups were not significant for anxiety ( $\rho = 0.117$ ).

Taken together, these criterion results suggest that self-efficacy, motivation, outcome expectancy, and anxiety toward engineering design match an individual's level of engineering design self-efficacy. ED and EDP scores for self-efficacy, motivation, and expectancy displayed decreasing average scores as engineering experience decreases. Conversely, ED and EDP scores for anxiety increase as engineering experience decreases.

### C. How Well are Responses to the Instrument Aligned with the Relationships Among the Task-Specific Self-Concepts as Conceptualized in Self-Efficacy Theory?

Correlations between self-efficacy with motivation, outcome expectancy, and anxiety were calculated to investigate relationships among the four task-specific concepts. Motivation, expectancy, and anxiety were all significantly correlated ( $\rho \leq 0.01$ ) to self-efficacy confirming theoretical predictions. Motivation (0.779) and outcome expectancy (0.919) were positively correlated to self-efficacy. This does not imply 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 ( $-0.593$ ) was negatively correlated to self-efficacy. Anxiety's lower magnitude correlation to self-efficacy suggests that high self-efficacy and extensive engineering experience do not necessarily eliminate anxiety completely.

## V. DISCUSSION

The results of this study demonstrate three important findings about measuring engineering design self-efficacy. First, the engineering design process steps used in this study can represent engineering design when measuring task-specific self-concepts such as self-efficacy, motivation, outcome expectancy, and anxiety. The Massachusetts DoE model was chosen based on concurrent validity with other similar engineering design process models. Because there is no consensus on an engineering design process, other engineering

Group	Self-Efficacy		Motivation		Expectancy		Anxiety	
	M	SD	M	SD	M	SD	M	SD
High	80.14	17.04	81.64	17.80	78.77	15.09	38.77	30.23
Intermediate	54.35	25.95	63.48	29.07	53.70	26.38	49.46	25.31
Low	21.89	26.34	21.35	26.05	21.89	25.80	62.16	30.20

Table 2. Mean ED scores with standard deviations for experience analysis.

Group	Self-Efficacy		Motivation		Expectancy		Anxiety	
	M	SD	M	SD	M	SD	M	SD
High	82.47	12.44	78.66	14.22	80.05	11.34	31.47	21.71
Intermediate	60.50	22.63	65.65	23.46	60.12	23.43	43.49	22.61
Low	36.96	26.34	35.47	26.22	36.39	26.20	52.33	25.31

Table 3. Mean EDP scores with standard deviations for experience analysis.

design process models could be tested using the same methods to investigate their content validity. The steps should factor load on one factor and correlate well to an overall engineering design item.

Second, engineering design self-efficacy is highly dependent on engineering experiences. This is evident in significant differences in task-specific self-concepts among high, intermediate, and low engineering experience groups. According to Bandura's sources of self-efficacy, individuals can build their self-efficacy through engineering experience. Opportunities for mastery experiences, vicarious experiences, social persuasion, or positive and negative physiological states within engineering design may not naturally occur unless the individual has had some sort of experience. The possibility does exist for negative experiences, but then those individuals are likely not to persist in engineering.

Finally, motivation, outcome expectancy, and anxiety were shown to relate to self-efficacy toward engineering design. High correlations between self-efficacy and the other three task-specific self-concepts confirm the theoretical connections in this study. This means that the instrument accurately represents the theory postulates.

Overall, the instrument has been validated as a general engineering design instrument. Of interest for further validation of the engineering design self-efficacy instrument would be comparing differences between genders and among engineering disciplines and experiences, student classes, students who transferred into an undergraduate engineering program, and engineering graduate students pursuing design-related research versus those pursuing technical research. The instrument could also be extended to include more task-specific self-concepts such as task incentive and attribution to failure to further establish construct validity.

## VI. CONCLUSIONS

The instrument tested in this study can provide a tool for educators to gather information about engineering design self-efficacy. The results indicate that the developed instrument validly and reliably measures an individual's self-efficacy toward engineering design. The potential uses of the engineering design self-efficacy instrument include an analysis of student change in will or drive over a given period of time, identifying students that need additional classroom support, and as a base for grouping students specifically for design projects. In general, knowing an individual's self-efficacy serves as a useful complement to their cognitive gains. Understanding how self-efficacy affects student learning can facilitate the development of intervention strategies to improve learning. Further research is needed to identify various task-specific self-concepts and to investigate how these relate to cognitive learning outcomes in engineering education. These relationships can be measured and understood better if and only if more instruments are developed. The more instruments there are aimed to analyze student will, the more precisely engineering educators will be able to assess the effects of conative outcomes on learning.

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## AUTHORS' BIOGRAPHIES

Adam R. Carberry is a doctoral candidate in Engineering Education in the Tufts University Math, Science, Technology, and Engineering Education program. He holds an M.S. in Chemistry from Tufts University and a B.S. in Material Science Engineering with a minor in Chemistry from Alfred University. He is currently working at the Tufts University Center for Engineering Education and Outreach as a research assistant and manager of the Student Teacher Outreach Mentorship Program (STOMP).

*Address:* Tufts University Center for Engineering Education and Outreach, 474 Boston Ave., Curtis Hall, Medford, MA, 02155; telephone: (+1) 617.627.5888; fax: (+1) 617.627.4760; e-mail: adam.carberry@tufts.edu.

Hee-Sun Lee is an assistant professor in the Education Department at Tufts University. She earned her Ph.D. degree in Science Education and an M.S. degree in Physics from the University of Michigan, Ann Arbor. She is currently affiliated with the Technology Enhanced Learning in Science Center at the University of California, Berkeley, and the Wright Center for Science Education at Tufts University.

*Address:* Tufts University, Department of Education, Paige Hall, Medford, MA, 02155; telephone: (+1) 617.627.6356; fax: (+1) 617.627.3901; e-mail: heesun.lee@tufts.edu.

Matthew W. Ohland is an associate professor of Engineering Education at Purdue University. He holds a Ph.D. in Civil Engineering from the University of Florida and M.S. degrees in Mechanical Engineering and Materials Engineering from Rensselaer Polytechnic Institute and in Engineering and Religion from Swarthmore College. He was previously Associate Professor of General Engineering at Clemson University. As a National Science Foundation Postdoctoral Fellow, he was the Assistant Director of the Southeastern University and College Coalition for Engineering Education. He is past President of Tau Beta Pi, has been recognized with best paper awards in multiple conferences and the *Journal of Engineering Education*, and has received teaching awards from both Clemson and Purdue.

*Address:* School of Engineering Education, Purdue University, Neil Armstrong Hall of Engineering, Room 1305, 701 West Stadium Avenue, West Lafayette, IN, 47907; telephone: (+1) 765.496.1316; fax: (+1) 765.494.5819; e-mail: ohland@purdue.edu.



## APPENDIX

### Engineering Design Self-Efficacy Instrument

DIRECTIONS: *Please fill in the following background information as it best applies to you.*

Date (MM/DD/YYYY): \_\_\_\_\_

Birthday (MM/DD/YYYY): \_\_\_\_\_

Gender: \_\_\_\_\_

Current Profession: \_\_\_\_\_

Major in college (choose one):

- ☐ Arts and Humanities (art, 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

DIRECTIONS: *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.*

*(Note: When administered, each question is accompanied by the 9-items seen in Figure 2.)*

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)
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)
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)
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)