MEASURING ENGINEERING DESIGN

SELF-EFFICACY

A qualifying paper

submitted by

Adam R. Carberry

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Advisor: Dr. Hee-Sun Lee

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INTRODUCTION

There is a growing need within engineering education to understand more completely what influences student achievement. Traditional engineering assessments focus solely on cognitive measurement. Full attention paid to cognitive gains overlooks underlying factors that will be referred to in this paper as *conative measures*. When conative measures are neglected, an educator is supplied with an incomplete report of student progress. Students need to have both the will and the skill to succeed (Pintrich & De Groot, 1990), so assessment of total student achievement should include an analysis of both cognition and connation.

The purpose of this study is to take an initial step in the measurement of conative measures, by documenting the development and validation of a new instrument to assess engineering design self-efficacy. Self-efficacy is a motivational construct regarding an individual's belief or judgment of their capability to organize and execute courses of action for a given domain-specific task (Bandura, 1986, 1997). Self-efficacy influences behaviors in accordance with perceived abilities for a specific task. The task of interest for this study will be engineering design. Engineering design is the process used to devise a system, component, or process to meet a need. The concept was chosen because of its importance in the field of engineering (Auyang, 2004).

Instrument development was guided by three forms of validation recommended by the measurement community (AERA, APA, & NCME, 1999): content, criterion-related, and construct validity. Each validity type addresses a specific research question:

1. *How well do the developed items represent the engineering design domain?* (content validity)

2. *How well does the instrument predict differences in self-efficacy held by subjects with a range of engineering experience?* (criterion-related validity)

3. *How well do responses to the instrument connect to constructs of the theoretical framework adopted in this study?* (construct validity)

In the following paper I will discuss how each question was addressed in the development of the engineering design self-efficacy instrument. The paper begins by defining each validity type to establish the need 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. The three forms of validity are used to define the engineering design domain, group respondents based on engineering experience, and construct a theoretical framework to predict expected results. Testing of the instrument is then performed to confirm the three forms of validation. The paper concludes with a discussion of the results and future work with the new instrument.

VALIDATION

Validation is an evaluation of how well empirical evidence and theoretical rationales adequately and appropriately assess given inferences and actions (Messick, 1989). Numerous types of validation exist for use in social science research. Content, criterion-related, and construct validity concepts are most commonly used.

Content Validity

Content validity is an evaluation of the extent to which a measurement represents all facets of a specific domain (Carminer & Zeller, 1979; Messick, 1989). According to

Carminer and Zeller, achieving content validation is a multi-step process. First, the full domain of the content relevant to the particular measurement situation must be specified. This is accomplished by exploring the available literature to develop an understanding of the domain and its dimensions. Second, the test must carefully specify the appropriate sampling procedures that will ensure representativeness of the domain. Finally, testable items are formed to reflect associated meaning with each dimension or subdimension of the domain. What emerges from this process is a test that adequately reflects the domain of content that is to be measured by the items.

The process is considerably complex when dealing with latent concepts common in social science research (Wilson, 2005). The difficulty relates to adequate sampling of the domain the instrument is designed to present. This consequentially creates an issue in the assurance of representativeness of a particular item; however, studies of engineering-based self-efficacy have employed content validity.

Baker, Krause, and Purzer (2008) 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. Answers with a similar meaning or theme were counted to establish the most frequently mentioned statements. Similarly themed statements from the expert answers were used to develop thirty 5-point Likert-type items – zero (not descriptive of me) to five (very descriptive of me) – for each scale. Questions were worded both positively and negatively. Both scales were shown to be highly reliable using Spearman-Brown reliability coefficients ($r_{tinkering} = 0.87$ and $r_{technical} = 0.80$). Additional factor analysis of each scale further demonstrated the content validity of the scales. Three factors were identified for both tinkering and technical self-efficacy. Knowledge & experience, creativity & curiosity, and knowledge & skills accounted for 44% of the tinkering scale variance. Technical knowledge, understanding theory & models, and systems & how things work accounted for 41% of the technical scale variance. The authors note that the original scale configurations need revision and further validation before broader use can commence.

Quade (2003) 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 generate thirty-five items, which were validated to ensure representativeness of the domain. Of the thirty-five items, twenty-one were developed into 6-point Likert-type items – one (strong agreement) to six (strong disagreement). All items were positively worded. Factor analysis was used to further content validate the scale. Six factors were extracted: student problem-solving confidence, computer troubleshooting confidence, career encouragement, satisfaction with college major, career exploration, and course anxiety. Reliability of this instrument was done by calculating inter-item variances (0.012, 0.008, 0.020, 0.020, 0.004, 0.000, 0.000 respectively) as well as Cronbach's alpha (0.792, 0.807, 0.736, 0.828, 0.613, and 0.636 respectively) for each of the six factors. Additional forms of validity were also established for instrument (see *Construct* and *Criterion-Related Validity* sections below).

Criterion-Related Validity

Criterion-related validity is a measure of prediction accuracy related to a component of the test's external structure (Carminer & Zeller, 1979; Messick, 1989). Correspondence between a test and the criterion of interest is usually indicated by the size of the correlation between test performance and performance on the criterion variable. According to Carminer and Zeller, there are two possible ways to conduct criterion-related validity: concurrent and predictive. Concurrent criterion-related validity is when a correlation of a measure and the criterion are conducted at the same point in time. Predictive criterion-related validity is when an assessment of a future criterion correlation is conducted with the relevant measure. Both employ the same logic, with the difference concerning the existence of the criterion variable.

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 contexts, relevant criterion variables do no exist. This makes obtaining criterion-related validity difficult to obtain with no criteria against which the measure can be reasonably evaluated. One self-efficacy study that uses criterion-related validity is Quade's (2003) computer science self-efficacy study. Criterion-related validity was used to further validate what had already been validated through content validity (see *Content Validity* section above). 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. The participants were grouped into *success* and *no success* groups. Respondents for each group were determined by the final grade received in the introductory computer science course (*success* = final grade of A or B; *no success* = final grade of C, D, or F). Significant differences in total factor score ($\underline{z}$ = -3.162, p = 0.002) were identified between the *success* and *no success* groups identifying a distinct relationship between student success and computer science self-efficacy.

Construct Validity

Construct validity is an evaluation of how well a certain measure relates to a theoretical network concerning the construct being measured (Carminer & Zeller, 1979; Messick, 1989). Construct validity is used when a consensus of accepted and adequate criterion or universe of content is lacking (Cronbach & Meehl, 1955). This is primarily the case for social science concepts like self-efficacy. According to Carminer and Zeller, achieving construct validation is a three-step process. First, a theoretical relationship needs to be specified between the constructs of interest. The theoretical network establishes a basis for generating theoretical predictions to be tested. Construct validity would be impossible to obtain without a theoretical network surrounding the concept. Second, the theoretical predictions are tested to determine the empirical relationship between the measured concepts. Finally, the empirical evidence is interpreted to determine how it clarifies the construct validity of the particular measure. Pieces of evidence are produced each time the empirical evidence supports the theoretical prediction. Subsequent positive predictions involving diverse, theoretically related variables build construct validation. Patterns of consistent findings between different researchers using different theoretical structures further construct validate the concept. Negative pieces of evidence can infer one of four conclusions: 1) the indicator does not measure what it purports to measure, 2) the theoretical framework used to generate the empirical prediction is incorrect, 3) the method or procedure used to test the theoretically derived hypotheses is faulty or inappropriate, or 4) there is a lack of construct validity or reliability for another variable(s) in the analysis.

Understanding how to measure self-efficacy requires an investigation of self-efficacy theory. According to Bandura (1986, 1997), 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. The four sources combine to create an overall self-efficacy for a given task. Each source has the potential of impacting self-efficacy toward engineering.

Mastery experiences are the most effective way to induce a strong sense of self-efficacy. Mastery experiences within engineering are typically firsthand opportunities to perform a given task. For example, when an individual constructs a model bridge, they internally establish data points based around the project. These data points can include success of the final project, ease of solving the problem, and how much iteration was required. Based on these data points, an individual will develop their bridge building ability. Overall positive results, like a first iteration successful bridge, should create a positive level of self-efficacy toward building; negative results, like a bridge that consistently fails, can undermine self-efficacy. Early successes or failures do not guarantee a certain level of self-efficacy. Difficulties can provide opportunities to overcome failure and raise self-efficacy. Easy successes lead to expected success and easy discouragement in the face of adversity. Whether positive or negative, mastery experiences afford learners an opportunity to reflect and produce a self-perception of capability on future similar activities.

Vicarious experiences are observations of social models as they succeed or fail. Social models contribute to self-efficacy when the model is deemed to be of similar ability to oneself or the model is perceived to be a master. When the model is gauged to be of similar ability, the learner can vicariously assume that they are capable of producing a similar result when performing the same task. For example, when one honors student sees another honors student pass an exam, the observing student can believe they too can pass the exam based on the previous student's success. The experience of viewing another individual of similar ability as being successful can develop a belief that vicariously they too will inevitably succeed; vice versa seeing that same individual fail could lead to the belief that they too would fail. When the model is perceived to be a master, the vicarious experience can provide models towards which individuals to aspire to. This would be the basis for how a master-apprentice or teacher-student relationship works.

A third source of self-efficacy comes in the form of verbal or social persuasions. Persuasions in engineering from important referents can supply a boost in self-efficacy. For example, when a project manager verbally encourages a member of the team of his or her capabilities, the individual is reassured of their ability by someone with inside knowledge of the situation. Persuasion can also lead to a negative impact. For example, when a teacher pushes students prematurely into a situation they are not ready for. In either case, the potency of the persuasion depends on the credibility, trustworthiness, and expertise of the persuader.

The final source of efficacy is an individual's judgment of their personal physiological states. Emotional and physical reactions, including joy, excitement, stress, tension, and fatigue, are interpreted by the body as signs of prowess toward good performance or vulnerability to poor performance. For example, if an individual is in a despondent mood, self-efficacy can be diminished, affecting performance. It is the individual's perceptions of these physiological states that determine whether they will enhance performance or debilitate it.

Most self-efficacy studies use the four sources of self-efficacy to establish construct validation of their measures. Richardson (2008) conducted a study on tinkering self-efficacy framed by Bandura's sources of self-efficacy. Students in a freshman engineering design course were given two self-report instruments. The first instrument focused on prior tinkering experiences (mastery experiences). The instrument consisted of seven 5-point Likert-type items – 1 (never) to 5 (always) – closely related to tasks encountered in the course[1]. A second instrument was constructed focusing on tinkering involvement. The instrument consisted of eleven Likert-type items guided by tinkering behaviors and Bandura's other three sources of self-efficacy. The reliabilities of the two instruments were $\alpha = 0.84$ and $\alpha = 0.77$ respectively. Correlations were calculated to examine the relationship between sources of tinkering self-efficacy and tinkering behaviors. General results concluded that with more tinkering experience there is more tinkering involvement ($r = 0.312$). This suggests that increased tinkering experience results in less avoidance or abandonment of tinkering tasks and more openness to approach new tinkering tasks. Additional correlations provided an indication that a

[1] Incorporation of tasks encountered in the course appears to be a rudimentary form of content validity minimally applied while creating the instrument.

relationship also exists between tinkering behavior and the other four sources of self-efficacy. The study would be enhanced with the development of three other instruments dedicated to the other three sources of self-efficacy. Four separate instruments would allow for a clearer identification of the impact of each self-efficacy source as seen with the prior tinkering experience instrument.

Hutchinson *et al.* (Hutchinson, Follman, & Bodner, 2006), and later in Hutchinson's Ph.D. dissertation (2007), also used Bandura's sources of self-efficacy to construct 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. Students taking a first-year engineering course titled *Engineering Problem Solving and Computer Tools* were given an extensive engineering efficacy instrument comprised of both fixed response items and open-ended items. Each item focused on eliciting two separate self-efficacy constructs: overall academic efficacy and engineering milestone efficacy. Validation of the items used to determine self-efficacy was done vicariously by comprising items from two established tools: Self-Efficacy for Academic Milestones (Lent, Brown, & Larkin, 1986) and Patterns of Adaptive Learning (Midgley et al., 2000); however, validation of the results was conducted by using construct validity. Results of the study identified nine emerging categories affecting students' responses. These categories included understanding or learning of the material, drive or motivation toward success, teaming issues, computing abilities, the availability of help & ability to access it, issues surrounding doing assignments, student problem-solving abilities, enjoyment, interest & satisfaction associated with the course and its material, and grades earned in the course. Each category, except drive and motivation, was classified within one of Bandura's sources of self-efficacy. Mastery experiences were indicated as the most influential source of efficacy beliefs.

Quade's (2003) study of computer science self-efficacy used construct validity in conjunction with content and criterion-related validity (see *Content* and *Criterion-Related Validity* sections). After thirty-five items were generated based on content validity, the items were further validated using construct validity. Each of the items was analyzed by a panel of experts instructed to consider how each item relates to Bandura's antecedents of perceived self-efficacy. Of the thirty-five items, twenty-one were theoretically supported by self-efficacy theory. Relationships were later confirmed by matching the six factors – determined by factor analysis – to the antecedents.

RESEARCH METHODS

Instrument Design

An online instrument was constructed with the intent to satisfy content, construct, and criterion-related validity. Content validity 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)[2]. 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,

[2] Figure 1 is one of many engineering design processes. 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.

develop design solutions, select the best possible design, construct a prototype, test and 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.

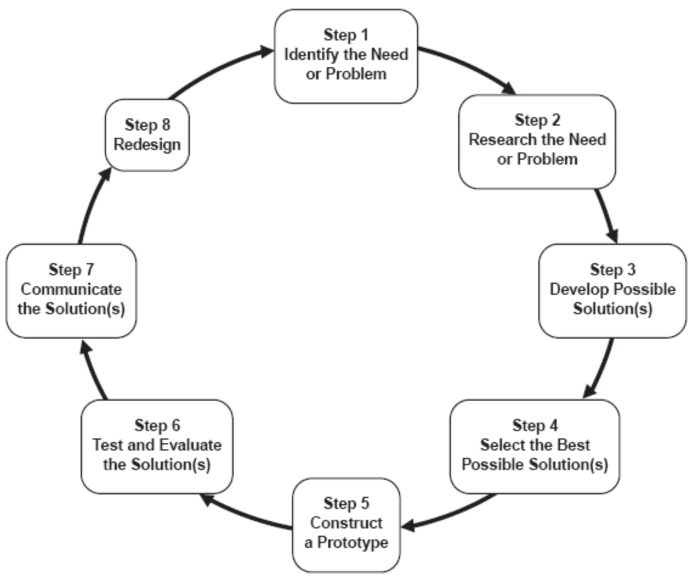

Figure 1: The engineering design process (Massachusetts, 2001/2006).

Criterion-related validity 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 becomes 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 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 (Bandura, 1997). The impact of beliefs is driven by the mediating role self-efficacy plays on the mechanisms influencing cognitive motivation (Bandura, 1977; Pintrich & De Groot, 1990; Pintrich & Schunk, 1996). 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 (Bandura, 1994). Individuals who harbor doubts about their capabilities when faced with obstacles quickly give up. Those who are highly efficacious about their capabilities exert greater effort when they fail to master the challenge.

Two cognitive motivators often correlated with self-efficacy are outcome expectancy and casual attribution. Outcome expectations are beliefs about the contingency between a person's behavior and the anticipated outcome (Pintrich & Schunk, 1996). 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 (Atkinson, 1957; Atkinson & Feather, 1966; Atkinson & Raynor, 1974). Expectancy-value theory draws on an individual's level of aspiration (Lewin, Dembo, Festinger, & Sears, 1944). 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 (Eccles, 1983, 1993; Wigfield, 1994; Wigfield & Eccles, 2000) 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) (Pintrich & Schunk, 2002). Self-efficacy impacts both expectancy and value by determining which endeavors are undertaken in accordance with perceived capability and expectancy for success.

Self-efficacy beliefs also influence causal attributions toward success and failure. Self-efficacy forms a relationship between attributions and motivation impacting subsequent performance expectancies (Bandura, 1995; Schunk, 1991, 1994; Weiner, 1986). Judgments established by past successes and failures influence whether that experience warrants future engagement (Vogt, 2003). Self-efficacy considers deeply the underlying reason for why success or failure resulted in relation to effort level. For instance, attributing success to luck does not result in a personal belief that warrants future similar actions. People who regard themselves as highly efficacious attribute their failures to insufficient effort. Those who regard themselves as inefficacious attribute their failures to low ability (Pintrich & Schunk, 1996).

A summary of the theoretical connections was conducted by using a construct map (Figure 2)[3]. A construct map is a visual representation of a construct and its theoretical connections. Construct maps organize multiple factors to form different possible respondents and ranges of item responses (Wilson, 2005). For the engineering design self-efficacy scale, respondents were first established by setting the extremes at highly efficacious and inefficacious toward engineering design. Responses were developed for each extreme using the theoretical effects of motivation, outcome expectancy, task value, attribution, and anxiety drawn from self-efficacy and expectancy-value theory. An individual who is highly efficacious toward a task is confident about their abilities, attributes failures to insufficient effort, is internally motivated by the task, seeks and expects success, and has little to no anxiety toward the task; while an individual who is inefficacious toward a task has no confidence in their abilities, attributes failures to a lack of knowledge, is unmotivated or externally motivated by the task, expects failure, and has a high level of anxiety toward the task (Pintrich & Schunk, 1996). Between the extremes exist respondents who are neither highly efficacious nor inefficacious toward engineering design. These individuals who fall between the two extremes are identified as intermediately efficacious. An individual who is intermediately efficacious toward a task is confident in their abilities, attributes failures to a lack of experience, knowledge, and/or low ability, is motivated by the task but unsure of the possibility of success, and has slight to moderate anxiety toward the task.

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[3] Figure 1 represents the final iteration of the construct map. Multiple iterations were used during the development process to fine-tune the respondents and responses.

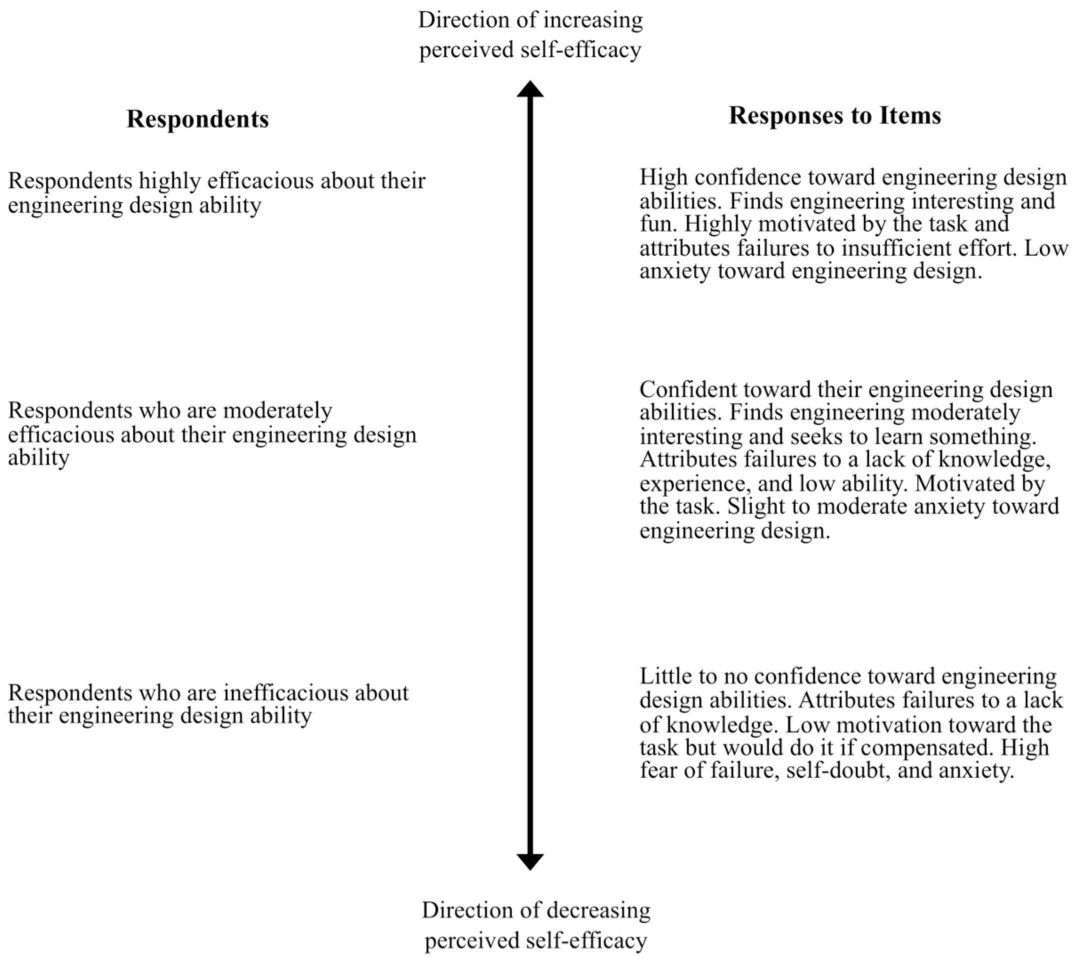

Figure 2: Construct map representing the theoretical ranges of self-efficacy.

The final instrument consists of four self-identifying questions and six scales (Appendix I). Each of the six scales corresponds to one of the constructs present in the construct map. Confidence, motivation, expectancy for success, and anxiety scales were 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 (Pajares, Hartley, & Valiante, 2001). 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. 100-point response questions were not appropriate for the remaining two constructs – task incentive and attribution to failure. To analyze these constructs, rank-order questions with four possible choices were used – four overall data points per question.

These choices for question type were made based on three arguments. First, fixed response items are ordinal in nature supplying the researcher with ranks. Rankings are appropriate because self-efficacy is by nature a respondent's judgment or ranking of their confidence. Second, the outcome space for fixed response items is fixed resulting in an ease of scoring. Responses require no additional coding other than the respondents' answers. Coding of the data by the respondents themselves not only serves the purposes of the researcher, but also maintains that self-efficacy be collected as self-reported data. Self-efficacy should not be determined by anyone other than the respondent.

Subjects

156 respondents were solicited through email to test the engineering design self-efficacy instrument. Respondents ranged in age from twenty-one to sixty-two years old. The sex of each respondent was kept anonymous. The overall population consisted of individuals with diverse engineering experiences. Figure 3 shows the engineering identifications self-selected by each respondent. Variable engineering expertise was deliberately obtained within the test population in order to witness each possible engineering design self-efficacy group discussed in later sections.

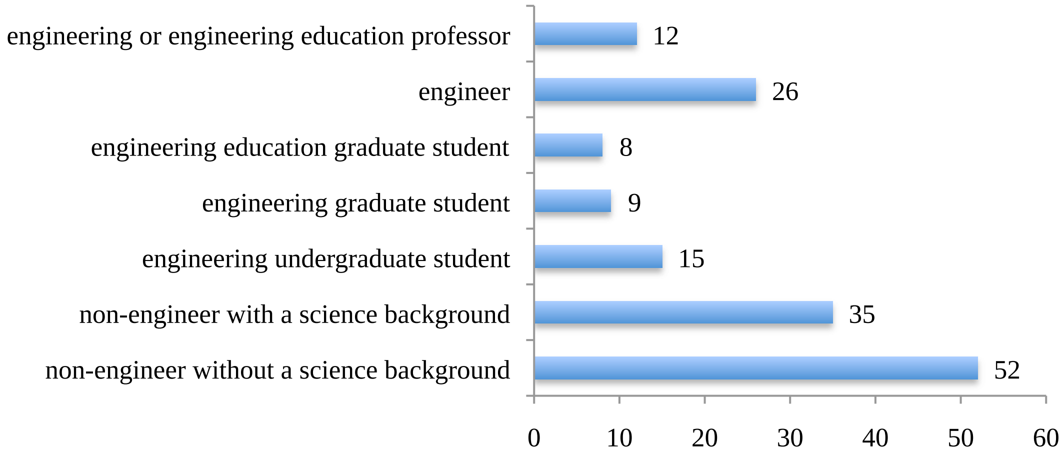

Figure 3: Respondent engineering self-identifications.

Data Collection

Data was collected using the online surveying tool called Survey Monkey[4]. The survey took each respondent on average approximately five minutes. Individuals randomly solicited to participate in the survey were given one week's time to complete the survey. Results from the survey were then pooled into a spreadsheet for further analysis using the statistical software, Statistical Package for the Social Sciences (SPSS). SPSS was used to calculate correlations and reliability coefficients, conduct factor analysis and rank-sum tests, and determine significance levels. The results of the data analysis can be seen in the following section.

DATA ANALYSIS & RESULTS

Content Validity

Establishing a relationship between engineering design and the engineering design process steps was tested in a three-step process. The first step was to test the

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[4] www.surveymonkey.com

reliability between the eight individual engineering design process items – 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 the confidence, motivation, outcome expectancy, and anxiety scales). Each set of items for a given construct was analyzed separately. The Cronbach's α values seen in Table I show a high reliability between each step for a given construct. These high reliability coefficients among the eight engineering design steps show overall agreement of an individual across the steps in each of the four self-efficacy constructs.

Table I: Reliability between the 8 steps of the engineering design process.

Construct	**Cronbach's α**
Confidence	0.980
Motivation	0.971
Outcome Expectancy	0.982
Anxiety	0.954

The second step was to perform factor analysis on the 32 Likert-type items across the four scales (items 2-9 of the confidence, motivation, overall expectancy, and anxiety scales seen in Appendix I). Factor analysis was used to identify the number of components present amongst all the items, amongst each item across scales, and the eight steps for one scale. Exploratory factor analysis was first performed on all 32 items of the confidence, motivation, expectancy for success, and anxiety scales to determine the overall correlation throughout the instrument. Factor analysis identified the presence of three factors: 1) engineering design confidence, motivation, & outcome expectancy (all items from the confidence, motivation, and outcome expectancy scales), 2) engineering design anxiety (all items from the anxiety scale), and 3) construction and communication ("construct a prototype" and "communicate a design" items from all four scales). Factors were determined using only factors with eigenvalues greater than 1 (Rummel, 1970). Overall factor analysis of the instrument suggests that the anxiety scale be removed to allow for the instrument to load on one component. The third factor is immaterial because it does not account for any additional variance. Removal of the third component would leave two remaining components, which is not ideal. If anxiety were removed, what would remain is a pure factor instrument consisting of the confidence, motivation, and outcome expectancy scales.

The total number of respondents did not meet the necessary capacity; so additional confirmatory factor analysis was conducted for each item and each construct. Item factor analysis was conducted on each individual step of the engineering design process. For example, factor analysis for “identify a need” was conducted by analyzing item 2 from scale 1, 2, 3, and 4. The factor analysis of each item revealed one factor per item determined using only factors with eigenvalues greater than 1. Each factor was labeled using the identical name of the item. Construct factor analysis was conducted on each set of items for a given scale. For example, factor analysis for confidence was conducted by analyzing items 2-9 of scale 1. The factor analysis for each construct revealed one factor per construct determined using only factors with eigenvalues greater than 1. This factor was labeled the engineering design process (EDP). An EDP score, therefore, refers to a calculated average of the eight individual engineering design process steps (items 2-9) for each separate construct.

The final step performed a check of reliability to determine the extent to which the new EDP factors represent overall engineering design (ED). ED scores were obtained from the first item of the confidence, motivation, outcome expectancy, and anxiety scales. These items directly refer to beliefs toward engineering design. For example, the ED score for confidence is obtained from item 1 of scale 1 seen in Appendix I. The Cronbach's α values seen in Table II suggest that respondents rated each factor consistently.

These results conclude that the engineering design process steps 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: Reliability between ED and the one factor EDP scores.

Construct	**Cronbach's α**
Confidence	0.954
Motivation	0.943
Outcome Expectancy	0.956
Anxiety	0.905

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 (Figure 3). 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 – highly efficacious, intermediately efficacious, and inefficacious – determined by the construct map (Figure 2). Respondents were clustered based on two criteria: 1) average engineering design (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 - highly efficacious; Group 2 - intermediately efficacious; and Group 3 - inefficacious (Figure 4).

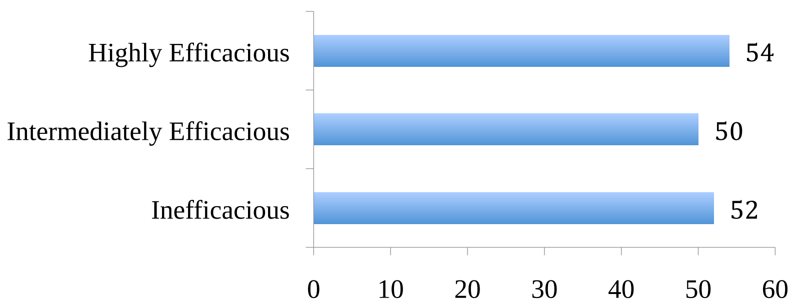

Figure 4: Efficacy groups based on engineering experience.

Highly efficacious respondents were individuals with engineering degrees and firsthand engineering experience (professors of engineering and engineering education, engineers, engineering and engineering education graduate students). Intermediately efficacious respondents were current learners of engineering (engineering undergraduate students and non-engineers with science backgrounds). Inefficacious 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 [$F_{confidence}(2,153) = 87.00$, $\rho < 0.001$);

$F_{motivation}(2,153) = 81.48$, $\rho < 0.001$); $F_{expectancy}(2,153) = 15.83$, $\rho < 0.001$); $F_{anxiety}(2,153) = 89.61$, $\rho < 0.001$)]. 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 two exceptions; Group 1 and Group 2 were significant to the $\rho = 0.004$ for anxiety, and Group 2 and Group 3 were nearly significant for anxiety ($\rho = 0.057$).

Table III: Mean (M) ED scores with standard deviations (SD).

	Confidence		**Motivation**		**Outcome Expectancy**		**Anxiety**	
Group	**M**	**SD**	**M**	**SD**	**M**	**SD**	**M**	**SD**
1	81.30	17.38	82.04	18.77	80.19	16.08	34.44	28.99
2	43.92	28.92	46.47	31.93	41.96	28.36	52.94	27.66
3	18.63	26.16	17.84	25.48	18.43	25.88	66.27	30.72

A one-way between subjects ANOVA was also conducted to compare the effects of confidence, motivation, outcome expectancy, and anxiety toward the eight steps of the engineering design process (EDP scores were used) for the three self-efficacy groups. Again, significant effects from all four constructs at the $\rho < 0.05$ level for the three self-efficacy groups [$F_{confidence}(2,153) = 87.00$, $\rho < 0.001$); $F_{motivation}(2,153) = 81.48$, $\rho < 0.001$); $F_{expectancy}(2,153) = 15.83$, $\rho < 0.001$); $F_{anxiety}(2,153) = 89.61$, $\rho < 0.001$)]. Post hoc comparisons using the Tukey HSD test indicated that the mean scores for confidence, motivation, outcome expectancy, and anxiety (Table IV) were significantly different ($\rho \leq 0.001$) for each of the three groups with one exception; Group 2 and Group 3 were significant at the $\rho = 0.029$ for anxiety.

Table IV: Mean (M) EDP scores with standard deviations (SD).

	Confidence		Motivation		Outcome Expectancy		Anxiety	
Group	**M**	**SD**	**M**	**SD**	**M**	**SD**	**M**	**SD**
1	83.31	13.11	79.24	15.01	80.76	12.47	28.40	17.87
2	52.53	25.80	51.99	27.29	49.95	26.61	46.52	23.79
3	29.96	28.03	28.25	27.93	28.95	28.49	53.87	28.45

Taken together, 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 and EDP scores for confidence, motivation, and expectancy displayed decreasing average scores as engineering experience decreases. Conversely, ED and EDP scores for anxiety increase as engineering experience decreases. The scores validate that levels of engineering expertise match particular performances on the instrument.

Construct Validity

Validation of the scale is complete when a final evaluation is conducted to ensure that the scales are theoretically connected with relevant sub-constructs. Construct validity for the Likert-type measured empirical indicators – motivation, outcome expectancy, and anxiety – was achieved by using correlations. Correlations between the variables were calculated (Table V) to illustrate their impact on one another. Each construct was significantly correlated 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.

Table V: Pearson correlations between self-efficacy and motivation, outcome expectancy & anxiety.

Construct	**Pearson Correlation**
Motivation	0.880**
Outcome Expectancy	0.964**
Anxiety	-0.637**

** $\rho \leq 0.01$

Construct validity of the two rank-order questions – task value and attribution – was done using two tests. First, each choice was treated as an individual variable to be correlated with self-efficacy (Table VI & VII). Correlations between self-efficacy and incentive choices showed all four choices to be significantly correlated. The variables “you find it interesting and/or fun” and “to learn something (acquire a skill)” were positively correlated. This result assumes that those who find engineering design interesting or hope to learn something are more likely to be efficacious toward engineering design. The other two variables, “compensation (money or a class grade)” and “just to get it done if required” were negatively correlated. This result assumes that those who perform engineering design for compensation or just to get it done are more likely to be inefficacious toward engineering design. Each of the correlations is relatively close to zero, which translates to a minimal effect.

Table VI: Pearson correlations between self-efficacy and task incentive.

Variable	**Pearson Correlation**
You find it interesting and/or fun	0.314**
To learn something (acquire a skill)	0.173*
Compensation (money or a class grade)	-0.328**
Just to get it done if required	-0.236**

** $\rho \leq 0.01$ * $\rho \leq 0.05$

Correlations between attribution to failure choices and self-efficacy found three of four variables to be significant. The variable “insufficient effort” was positively correlated. This result assumes that those claiming insufficient effort as their reason for failure are more likely to be efficacious toward engineering design. Attributing failure to “lack of knowledge” or “low ability” were both negatively correlated with self-efficacy. These results assume that those claiming a lack of knowledge or low ability as their reason for failure are more likely to be inefficacious toward engineering design. The three correlations did not deviate extensively from zero, which translates to a minimal effect. The final variable, “lack of experience”, did not show a significant correlation to engineering design self-efficacy. This means that there is no significant difference in individuals with high or low self-efficacy for those attributing failure on an engineering design task to lack of experience.

Table VII: Pearson correlations between self-efficacy and attribution to failure.

Variable	**Pearson Correlation**
insufficient effort	0.383**
lack of experience	0.048
lack of knowledge	-0.400**
low ability	-0.169*

** $\rho \leq 0.01$ * $\rho \leq 0.05$

A second analysis of task incentive and attribution to failure was performed to test the significance between the categorically ranked variables and the continuous variable of self-efficacy. This analysis was performed using a Kruskal-Wallis Rank-Sum Test of the three efficacy groups. For task incentive, two of four variables were significantly linked to a particular efficacy group. “You find it interesting and/or fun” was significantly linked ($\rho \leq 0.01$) to Group 1 (highly efficacious) and “compensation (money or a class grade)” was significantly linked ($\rho \leq 0.01$) to Group 3 (inefficacious). These links can be similarly translated to the correlations in that those who find engineering design interesting are more likely to be efficacious toward engineering design, while those performing engineering design for the sole purpose of compensation are more likely to be inefficacious toward engineering design.

For attribution to failure, two of four variables were also significantly linked to a given efficacy group. “Insufficient effort” was significantly linked ($\rho \leq 0.05$) to Group 1 and “lack of knowledge” was significantly linked ($\rho \leq 0.001$) to Group 3. Again, these links can be similarly translated to the correlations in that those who attribute failure to insufficient effort are more likely to be efficacious toward engineering design, while those who attribute failure to a lack of knowledge would be more likely to be inefficacious toward engineering design.

DISCUSSION

The results of this study clearly indicate three distinct findings about measuring 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 was used similarly to how Baker, Krause, & Purzer used expert views and options and how Quade used reviewed literature, interviews of graduates, and class requirements. Other engineering design process models do exist. The current instrument should be cross-referenced with other models before implementation across the country.

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 possibility does exist for negative experiences, but then those individuals would not persist in engineering.

Finally, the sub-constructs of motivation, outcome expectancy, anxiety, task value, and attribution to failure are good indicators of self-efficacy toward engineering design. This was clearly predicted by self-efficacy theory and expectancy-value theory; however, some results suggest that alterations to the instrument be made to improve the overall effectiveness. Factor analysis suggests that the anxiety scale be altered or removed from the instrument. Removal of anxiety as a measured construct would result in a pure factor instrument.

Rank-sum analysis suggests that alternative ways to measure task incentive and attribution to failure should be considered. The nature of these two constructs made it difficult to measure them in a similar fashion to the other constructs. Correlation and rank-sum analysis failed to identify variables for the intermediately efficacious respondents. The possibility exists that engineering learners are driven by incentives and attribute failures to reasons not available in the current instrument. Improvements are necessary for the task value and attribution analysis to improve these correlations and identify incentives and attributions for the intermediate group. It is suggested that the task incentive and attribution to failure questions be reexamined in an open-ended fashion or completely removed from the instrument. Using an open-ended approach could provide the questions with the most prevalent answers given by actual respondents. The questions could later be refashioned into a rank-sum questions informed by respondent information. The inclusion or removal of the task value and attribution to failure scales should be determined based on the theories the instrument posits to predict in the future.

Future implementation of this instrument would be enhanced by these suggestions. Additionally, the instrument could also be enhances with the inclusion of a qualitative component. The instrument could be supported with supplementary interviews about engineering design or observations of students conducting an engineering design task. The current future plan for the instrument is to use the engineering design self-efficacy measurement as one data point triangulated with conceptual understandings of engineering design and epistemological beliefs of engineering. The dynamic interplay between these three sources of information can be analyzed qualitatively and quantitatively to predict success in engineering design.

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 (Ponton, Edmister, Ukeiley, & Seiner, 2001) and improve the retention of women and minorities (Besterfield-Sacre, Moreno, Shuman, & Atman, 2001; Felder, Felder, Mauney, Hamrin, & Dietz, 1995; Hackett, Betz, Casas, & Rocha-Singh, 1992; Schaefers, Epperson, & Nauta, 1997; Schmidt, Lent, Schmidt, Mead, & Bigio, 2001).

In the results of this study, a new and validated engineering design self-efficacy instrument has been fabricated. The three validation procedures used provided reassurance that engineering design was suitably represented, respondents were appropriately identified and grouped, and self-efficacy was theoretically linked.

Content validity addressed the representation of engineering design. Factor analysis and reliability data of the engineering design process steps were used to show that engineering design was suitably represented. The underlying variable controlling these eight items is the engineering design process.

Criterion-related validity was used to appropriately group respondents. Respondents were easily grouped into efficacy groups by using their varying degrees of engineering experience. Average scores for engineering self-identification groups presented clear overall differences.

Construct validity analyzed the theoretical connections used in constructing the instrument. Correlation data between self-efficacy and its sub-constructs ensured a theoretical connection with motivation, outcome expectancy, and anxiety. Motivation and outcome expectancy results were positively correlated to self-efficacy, while anxiety results were negatively correlated to self-efficacy.

A combination of correlations and rank-sum analyses for task value and attribution linked choices to specific efficacy groups. Experienced engineering designers were more apt to perform engineering design for pleasure and attributed failure to insufficient effort, while respondents with little to no experience were more likely to do engineering design for superficial reasons (money or credit) and attribute failure to a lack of knowledge and low ability. Correlation and rank-sum analysis failed to identify variables for the intermediately efficacious respondents.

Overall, the new engineering design self-efficacy instrument is a viable tool capable of supplying an educator with information about student beliefs to complement what they know about student academic achievement.

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APPENDIX I: 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. Rank the following choices form 1-4 in order of what would be your incentive to participate and complete an engineering design task (4 = highest incentive to do the task; 1 = the least incentive).

	1 = lowest	2	3	4 = highest
You find it interesting and/or fun				
To learn something (acquire a skill)				
Compensation (money or a class grade)				
Just to get it done if required				

5. Rank the following possible reasons from 1-4 for why you might be unsuccessful in solving an engineering design problem (4 = the most likely reason for failure; 1 = the least likely reason).

	1 = least likely	2	3	4 = most likely
insufficient effort				
lack of experience				
lack of knowledge				
low ability				

6. 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											