Measuring Curricular Impact
using an ABET-based Engineering Self-Efficacy Scale

Mark Schar
Stanford University
Stanford, CA USA
mfschar@stanford.edu

Patsy Brackin
Rose-Hulman Institute of Technology
Terre Haute, IN USA
brackin@rose-hulman.edu

K. J. Chew
Stanford University
Stanford, CA USA
kaijunch@stanford.edu

Sheri Sheppard
Stanford University
Stanford, CA USA
sheppard@stanford.edu

Abstract — **This Research to Practice Full Paper outlines the use of an ABET-based engineering self-efficacy scale (ESE-ABET) to successfully measure changes in engineering self-efficacy pre-to-post over a course term. This scale can be used to measure learning progress toward the "instructor's intent" for learning in a class, which will likely be unique to each engineering classroom experience. This scale also shows the differing changes in engineering self-efficacy for groups of students generally underrepresented in engineering education – women, ethnic minorities and first-generation college students. A discussion of the value of having a valid and reliable ABET-based self-efficacy measure is included.**

Keywords — self-efficacy; engineering self-efficacy measures; ABET Criterion 3 - Student Outcomes; curriculum development; curriculum measurement; ABET accreditation

As an instructor develops the teaching plan for a course, it starts with explicit identification of the key learning objectives for that course. This is called the "Instructor's Intent." These learning objectives translate into a syllabus, lecture plans, homework assignments, group projects and exams, all resulting in a grade for the student which should reflect how well the student was able to demonstrate mastery of the original learning objectives.

However, rarely, if ever, does the instructor know if the student grows in learning efficacy. Learning efficacy is *the belief that one is capable of identifying, organizing, initiating, and executing a course of action that will bring about a desired outcome* [1]. As Ambrose states, "to hold a positive expectancy for success, a student must not only believe that doing the assigned work can earn a passing grade, she must also believe that she is capable of doing the work necessary to earn a passing grade." [2, p. 77] The development and growth of learning self-efficacy becomes an important component of personal agency and ultimately drives future motivation and success.

This paper explores the use of an engineering self-efficacy scale, based on the ABET Student Outcome criteria, to measure both changes in student learning self-efficacy over the course of an academic term and changes in self-efficacy relative to the instructor's intent for learning objectives in the classroom experience.

I. Measuring Engineering Efficacy

A. Self-Efficacy as a Predictor of Behavior

In Bandura's model (see Fig. 1), efficacy expectations moderate behavior, and in turn, behavior is moderated by one's expectations of an outcome leading to action toward an outcome [3]. In Bandura's construction, efficacy and efficacy expectations are a necessary precursor to behavior which, in turn, leads to outcomes. Therefore, efficacy is a necessary complement to both learning behaviors and successful learning outcomes. Measuring efficacy, particularly when combined with grade performance analysis offers a more complete picture of the students learning process.

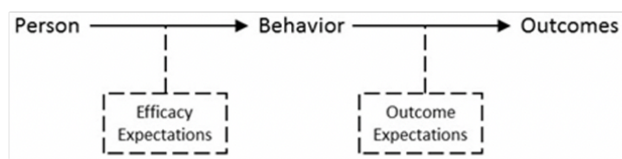

Fig. 1. Bandura's model of efficacy

Efficacy has been shown to be an important predictor for a wide variety of human achievement, from positive academic performance [4] and workplace performance [5], to prosocial behavior[6] and even improved health benefits [7] in a wide variety of cultures and countries worldwide [8]. In the field of engineering education, efficacy has proven a useful indicator of academic major selection, academic performance and career choice [9].

B. Engineering Efficacy Scales and ABET Criteria

The measurement of engineering self-efficacy among engineering students has generally fallen into two broad areas: academic self-efficacy and engineering task self-efficacy. The problem with these measurement scales is that academic self-efficacy does not capture the behaviors specific to engineering and the various measures of engineering task self-efficacy are limited to specific tasks often associated with a single version of engineering study or practice. Recently, a new engineering self-efficacy scale has been developed which is based on ABET criteria , as shown in TABLE I, and has proven to be both valid and reliable [10] and is the measure used in the current paper.

TABLE I. ABET CRITERION 3 – 2017-2018

GENERAL CRITERION 3. STUDENT OUTCOMES:
The program must have documented student outcomes that prepare graduates to attain the program educational objectives.

Code	ABET Label	Description
3.1	solve complex	identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics
3.2	engineering design	apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors
3.3	communicate	communicate effectively with a range of audiences
3.4	ethical solutions	recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts
3.5	team leadership	function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives
3.6	experiment analyze	develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions
3.7	learning strategy	acquire and apply new knowledge as needed, using appropriate learning strategies

ABET was established in 1932 as a non-governmental organization that accredits post-secondary education programs in "applied science, computing, engineering, and engineering technology" [11]. In 2017, ABET reports accrediting over 3,700 programs at over 750 colleges and universities in 30 countries [12]. Input to ABET accreditation criteria is broad based with contributions from over 2,200 volunteer academic and industry professionals from 35-member societies.

One of the ABET assessment criteria is known as ABET Criterion 3 – Student Outcomes. A revised version of this Criterion was released in 2017, as shown in TABLE I. The goal of Criterion 3 is to define student behavioral outcomes that would be “common criteria for all engineering programs,” [13] and the broad and inclusive nature of the ABET definition process helps insure that these criteria, in their totality, are a relevant definition of “engineeringness” for all accredited programs.

C. ABET Certification and ABET Engineering Self-Efficacy

The primary purpose of the ABET criteria is to serve as a standard for formal ABET accreditation which is proof that a collegiate program has met standards essential to produce graduates ready to enter the critical fields of applied science, computing, engineering, and engineering technology” [14]. Program accreditation occurs over a multi-year cycle and requires applicant programs to connect their curricular offerings to the Student Outcome criteria. The use of an ABET-based self-efficacy measure used on a curricular level can be helpful in the accreditation process if the measure can detect changes in self-efficacy and these changes are related to the “instructor’s intent” for that curricular experience.

Previous testing with an ABET-based self-efficacy measure showed that over the short-term (two weeks) there were no statistically significant changes in engineering self-efficacy among engineering students [10] which is good indicator of the temporal stability of the measure. However, to be useful on the curricular or program level, this scale must be able to detect changes in self-efficacy over a longer period such as a class term, an academic year or even a four-year academic career.

II. RESEARCH METHODS

A. Participants

Data collection was conducted at three university/college locations during the fall semester of 2017, resulting in 253 valid responses, as shown in TABLE II. Most of the participants were in their first, second and third years of engineering education (mean 2.4 years), The sample is mostly comprised of biomedical, mechanical and civil engineering majors enrolled in either an introduction to engineering design class or a solid mechanics-type class. The gender split of this sample was 36% female, 39% underrepresented minorities (URM) and 43% first generation college students [1] which are all overrepresented relative to U.S. national percentages for post-secondary engineering students.

TABLE II. PARTICIPANT DEMOGRAPHICS

Location	n	Year	% Female	% URM	% FGC
A	49	1.0	51%	12%	14%
B	76	2.4	57%	20%	14%
C	128	2.9	18%	60%	70%
Total	253	2.4	36%	39%	43%

B. Curricular Experiences and Instructor’s Intent

While the curricular experiences at the three locations were targeted to mechanical and civil engineering students, there were important differences in the curriculum by location. Location A was a first-year level introduction to engineering design, while Locations B and C were typical introduction to mechanics type

[1] For the purposes of this study, underrepresented minority (URM) is defined as any respondent who indicated a Latino/a, African American, Native American or Pacific Islander ethnicity. First Generation College (FGC) is defined as any respondent where both the mother/female guardian and father/male guardian had less post-secondary education than an Associate degree. This is regarded as a broader definition of FGC students [15]–[17].

courses. These differences were also reflected in measures of "instructor's intent."

Location A (49 students) – This one-quarter course is for first year biomedical engineering students and *introduces the engineering design process including problem definition, analysis, alternate solutions, specifications of final solution, and techniques of oral and written communications.*

Location B (76 students) – This one-quarter course is for second and third year students and represents the prototypical *introduction to engineering analysis using the principles of engineering solid mechanics* that *builds on the math and physical reasoning concepts in [physics] to develop skills in evaluation of engineered systems across a variety of fields*.

Location C (128 students) – Similar to Location B, this one semester course is for second and third year students and covers both the *fundamentals of statics and dynamics* including *planar kinematics of rigid bodies and kinetics for planar motion of rigid bodies, including equations of motion and principles of energy and momentum*.

To account for intended differences in curriculum at each location, "instructor's intent" was measured using the same ABET self-efficacy scale used with students. Each instructor was asked to rate their learning intention for their class using the seven ABET Student Outcomes criteria with the prompt "*what was your teaching/learning intent as it relates to each criterion?*" The rating scale was from (100) "*This [criteria] was the sole and singular intent [of the class]"* to (50) "*There was an intention to teach this among other important issues"* to (0) *"No intention, purposeful or incidental."*

The responses from each instructor were ipsatized to make them comparable between locations. The specific technique used was "mean ipsatization" [18]–[20] where an individual score from an instructor was subtracted from the mean of all scores from that instructor and then divided by the mean of all scores from that instructor. This results in a .00 as the mean score for any instructor with positive values indicating above average intent and negative values indicating below average intent. Instructor's intent scores are shown in TABLE III.

TABLE III. INSTRUCTOR'S INTENT – IPSATIZED SCORES

Code	ABET Label	All	Loc. A	Loc. B	Loc. C
3.1	solve complex	.55	-.15	.34	1.47
3.2	engineering design	-.02	.69	.08	-.73
3.3	communicate	-.05	.06	-.02	-.18
3.4	ethical solutions	-.38	-.15	-.11	-.86
3.5	team leadership	.06	.06	.01	.10
3.6	experiment analyze	-.42	-.58	-.51	-.18
3.7	learning strategy	.22	.08	.22	.37

shaded scores are above average

Results show that the instructor at Location A intended to build engineering self-efficacy in the area of ABET Criterion 3.2 *"engineering design."* The instructors at Location B and C had similar intentions to build engineering self-efficacy in the areas of ABET Criterion 3.1 *"solve complex"* and 3.7 *"learning strategy."* This establishes the areas of interest for measurement of changes in engineering self-efficacy over the course of the curricular term by location.

C. Data Collection and Cleaning

The survey and all measures used in the study were reviewed and authorized by the lead research university's institutional review board with concurrence from each location. With the instructors' permission at each site, an on-line survey was administered to students participating in specific classes. There was no compensation for participation beyond a "thank you" candy bar for each member of the class regardless of survey participation. Survey questions were presented in an identical order across all survey administrations and the self-efficacy scale items (i.e., ABET 3.1, 3.2, 3.3, etc.) were randomly presented by participant to prevent order bias. Pre-measurement occurred during the first week of the class term, while post-measurement occurred in the week before the class final exam.

Survey responses were accepted only from self-declared engineering majors. The data across all studies was 95.3% complete. It was determined that missing data was missing completely at random (MCAR) and multivariate imputation by chained equations (MICE) was used with predictive mean matching (PMM) and 5-iterations to complete the data set for analysis [21], [22].

D. ABET Self-Efficacy Scale Construction

The ABET-based self-efficacy scale used in this research was created using Bandura's guidelines [23] for the development of self-efficacy scales. The prompt for this scale was worded to frame the response as confidence in the respondent's ability to accomplish the behavior – *"How confident are you in your ability to ..."* The scale items were drawn directly from the specific ABET Criterion. For example, ABET 3.1 is stated as the ability to *"identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics"* and this became a survey item. Bandura recommends using a 0 to 100 scale for recording responses [23, p. 312] so a slider bar was used that ranged from 0 ("Cannot Do At All) to 100 ("Highly Certain Can Do") with 0 as the initial setting. The individual self-efficacy items were presented in a random order that varied with each participant. A complete description of the reliability and validity of this scale is described in Schar et al. [10] and the survey question used in this research is shown in the APPENDIX.

E. Analysis Procedures

Descriptive analyses were conducted by examining item means, standard deviations, and frequency distribution. The data were normally distributed with skewness and kurtosis within ± 2.0 [24] for all self-efficacy items. Responses pre-and-post were collected by individual and then summarized by group.

For the purposes of significance testing, the sample sizes are large enough to make mean value t-testing and a .05 *p*-value susceptible to Type I error and not rigorous for comparison. Therefore, Cohen's *d* [25], a measure of effect size, is used for comparison of mean difference with $d > .20$ considered a small significant difference, $d > .50$ a medium significant difference and $d > .80$ a large significant difference. For significance testing among Spearman correlations a *p*-value < .05 is considered significant. Data analysis was completed in R v3.4.4 [26].

III. Results

A. Overall Changes in Engineering Self-Efficacy

Measures of pre-to-post changes engineering self-efficacy for each ABET Criteria among all students (n = 253) is shown in TABLE IV.

TABLE IV. Overall Engineering Self-Efficacy Scores Pre-to-Post Measures

Code	**ABET Label** (n = 253)	Pre	Post	Diff	*d* [a]
3.1	solve complex	**63.4**	**72.3**	**8.9**	**.39**
3.2	engineering design	**60.5**	**73.3**	**12.8**	**.59**
3.3	communicate	**72.4**	**76.6**	**4.2**	**.20**
3.4	ethical solutions	**66.4**	**77.2**	**10.8**	**.52**
3.5	team leadership	81.1	83.5	2.4	.15
3.6	experiment analyze	**61.1**	**71.4**	**10.3**	**.45**
3.7	learning strategy	75.7	77.7	2.0	.11
	TOTAL	**68.7**	**75.6**	**6.9**	**.46**
	Female (89)	**67.4**	**74.7**	**7.3**	**.47**
	Male (164)	**69.4**	**76.7**	**7.3**	**.45**
	d	.12	.14		
	URM (98)	**65.0**	**75.2**	**10.2**	**.63**
	≠URM (155)	**71.0**	**76.5**	**5.5**	**.35**
	d	**.36**	.08		
	FGC (107)	**64.2**	**75.1**	**10.9**	**.69**
	≠FGC (146)	**71.9**	**76.6**	**4.7**	**.30**
	d	**.46**	.10		

[a] Cohen's *d*: **bold** is significant
< .20 – no difference, .20 - .49 small difference, .50 - .79 medium, +.80 large

The total mean score for all participants increased from 68.7 (pre) to 75.6 (post), a statistically significant 6.9-point increase (*d* = .46). ABET Criterion 3.2 "engineering design" had the greatest pre-to-post increase from 60.5 to 73.3, a 12.8-point increase (*d* = .59). In pre-measurement, students had the highest engineering self-efficacy scores in ABET Criterion 3.5 *"team leadership,"* and with 3.7 *"learning strategy"* pre-post changes were not significant. Conversely, where students had the lowest pre-measure engineering self-efficacy, changes pre-to post were the largest – ABET Criterion 3.2 *"engineering design"*, 3.6 *"experimentation and analysis"* and 3.1 *"ability to solve complex engineering problems."*

Overall engineering self-efficacy was statistically identical between female and male students both before the course term (*d* = .12) and after the course term (*d* = .14) although both groups experience a significant increase in engineering self-efficacy over the course term (*d* = .47 and .45, respectively). This is consistent with a growing body of literature that shows no difference in engineering self-efficacy by gender or URM status [27]–[30]. Underrepresented minority students started the course term with significantly lower engineering self-efficacy scores than non-URM students (65.0 to 71.0, *d* = .36) and this disadvantage was erased by the end of the course term with both groups experiencing significant gains in engineering self-efficacy (*d* = .63 and .35, respectively) and the gains by URM students were large enough to offset their initial deficiency (75.2 to 76.6, *d* = .08). Similarly, first generation college (FGC) students began the course term with significantly lower engineering self-efficacy scores than non-FGC students (64.2 to 71.9, *d* = .46) and this disadvantage was offset by the end of the course term with both groups experiencing significant gains in engineering self-efficacy (*d* = .69 and .30, respectively) and the gains by FGC students were large enough to offset their initial deficiency relative to non-FGC students (75.1 to 76.6, *d* = .10).

B. Changes in Engineering Self-Efficacy by Location

An important characteristic on this ABET-based engineering self-efficacy scale is its ability to measure changes relative to the instructor's intent and this is evident on a by-location analysis of changes, as shown in TABLE V. Recall, the instructor at Location A identified ABET Criterion 3.2 *"engineering design"* as the most important criteria for this class, as pre-post measures

TABLE V. Engineering Self-Efficacy Scores Pre-to-Post Measures By Location

		Location A					Location B					Location C				
	ABET Label	**Intent**[a]	**Pre**	**Post**	**Diff**	***d*** [b]	**Intent**	**Pre**	**Post**	**Diff**	***d***	**Intent**	**Pre**	**Post**	**Diff**	***d***
3.1	solve complex	-.15	**57.0**	**63.9**	**6.9**	**.28**	.34	**70.7**	**79.9**	**9.3**	**.52**	1.47	**61.5**	**71.0**	**9.5**	**.42**
3.2	engineering design	**.69**	**57.1**	**69.8**	**12.7**	**.54**	.08	**69.8**	**80.1**	**10.4**	**.60**	-.73	**56.2**	**70.6**	**14.3**	**.66**
3.3	communicate	.06	68.2	70.3	2.0	.09	-.02	82.4	84.6	2.3	.15	-.18	**68.1**	**74.4**	**6.3**	**.29**
3.4	ethical solutions	-.15	**63.8**	**70.5**	**6.7**	**.30**	-.11	**74.1**	**82.4**	**8.4**	**.51**	-.86	**62.9**	**76.6**	**13.7**	**.64**
3.5	team leadership	.06	79.0	81.7	2.8	.16	.01	89.5	88.7	-0.9	.08	.10	**77.0**	**81.0**	**4.1**	**.24**
3.6	experiment analyze	-.58	**59.8**	**66.1**	**6.2**	**.24**	-.51	**65.8**	**77.6**	**11.9**	**.64**	-.18	**58.9**	**69.6**	**10.8**	**.46**
3.7	learning strategy	.08	73.2	74.0	0.8	.04	.22	**86.7**	**84.2**	**-2.5**	**.21**	.37	**70.2**	**75.3**	**5.0**	**.26**
	TOTAL		**65.4**	**70.9**	**5.4**	**.32**		**77.0**	**82.5**	**5.5**	**.50**		**65.0**	**74.1**	**9.1**	**.55**

shaded areas represent Instructor's Intent

[b] Instructor's Intent ipsatized scores, [b] Cohen's *d*, **bold** is significant

of engineering self-efficacy of this criterion (57.1 to 69.8, d = .54) showed a significant increase and the largest pre-to-post increase of any criteria. The instructors at Locations B and C identified ABET Criterion 3.1 *"solve complex engineering problems"* and 3.7 *"acquire and apply new learning strategies"* as top learning priorities and both locations showed statistically significant increases in Criterion 3.1 (Location B: 70.7 to 79.9, d = .52 and Location C: 61.5 to 71.0, d = .42) with mixed results on Criterion 3.7. In Location C there was a small but statistically significant increase in engineering self-efficacy on Criterion 3.7 (70.2 to 74.1, d = .26), while in Location B engineering self-efficacy on Criterion 3.7 showed a small but statistically significant decrease (86.7 to 84.2, d = .21). This result at Location B might cause the instructor to review the curriculum to determine if changes might be made to reinforce Criterion 3.7 as a learning objective.

While it is encouraging that positive pre-to-post changes occurred among most of the ABET Criteria identified as important to each instructor, perhaps the biggest surprise was the wider gains in Criterion not targeted by the instructors. For example, at Location A there were gains in Criterion 3.6 "*experiment analyze*" (from 59.8 to 66.1, d = .24) which seems appropriate, if not planned, for an introduction to engineering design class. Similarly, at Location C, while there were significant gains in pre-to-post self-efficacy in the areas of instructor's intent (Criterion 3.1 and 3.7), every criterion of measure showed a statically significant increase. The students at Location C started with the lowest overall measure of engineering self-efficacy (pre 65.0) and finished the term with a significant 9.1-point overall gain in self-efficacy measure. While these results are promising, ascribing changes within elements of self-efficacy to any one course requires caution. Students are involved with several courses, projects and experiences within one course term, so without specific attribution it can be difficult to know exactly where changes in self-efficacy develop. However, the fact that there are overall positive changes remains encouraging.

C. Engineering Self-Efficacy Predicting Grade Performance

Self-efficacy has long been associated with a student's desire to learn and achieve academically. As Zimmerman states, "two decades of research have clearly established the validity of self-efficacy as a predictor of students' motivation and learning" [4, p. 89]. There is less clarity about the role of self-efficacy and actual classroom grade performance. It may be because a student's confidence about academic performance is not closely related to their actual knowledge and performance, similar to the "Kruger-Dunning effect" [31] or, more likely, classroom grade performance is a complicated mix of subject self-efficacy, personal identity, social belonging and feeling of closeness to others in the classroom [32]. This means that self-efficacy is an important, but not the solely determinant, factor in predicting classroom grade performance.

In this study grade performance was measured by converting number and letter grades to a normally distributed percentile by Location using the mean and standard deviation for each Location, signifying that a value of 50 is the 50th percentile (or mean) for a specific Location. This method of comparison is appropriate because it is curriculum content agnostic and, for example, groups the top performing students at one location with the top performing students at the other locations.

TABLE VI. GRADE PERCENTILE CORRELATED WITH ENGINEERING SELF-EFFICACY MEASURES

Measure [a]	All	Female	URM	FGC	URM + FGC
n	253	89	98	107	73
ESE Pre	.07	-.02	.04	.01	-.02
ESE Post	**.17**	.11	**.31**	**.18**	**.26**
ESE Change	.06	.12	**.21**	.12	**.23**

[a] Spearman *rho* correlation, **bold** significant p < .05

The *a priori* assumption is that grade performance will have a positive correlation with engineering self-efficacy ratings pre, post and a net change from pre-to-post. Results from a correlation analysis are shown in TABLE VI.

Grade percentile did have a positive and significant correlation with engineering self-efficacy score post-course term (r = .17, p < .01) and a positive but not significant correlation with engineering self-efficacy scores pre-course term (r = .07, p = ns) and the change pre-to-post (r = .06, p = ns). Grade percentile had a non-significant correlation with gender. Engineering self-efficacy post measure is positively correlated with grade performance among URM and FGC students (URM .31, p < .00 and FGC .18, p < .01), reflecting the significant engineering self-efficacy growth these students experienced over the course. Among students who are both URM and FGC (n = 73), both engineering self-efficacy post and change pre-to-post are significantly correlated with grade performance (.26, p < .00 and .23, p < .00), more so than with students who and not URM or FGC, indicating the importance of growing engineering self-efficacy on improving grade performance.

As mentioned earlier, engineering self-efficacy is only a part of determining overall grade performance. Among all students, linear regression with grade performance as the dependent variable and engineering self-efficacy post and change pre-to-post as the independent variables shows that the engineering self-efficacy explains only about 3% of variance in grade performance (r^2 = .03, F(3, 249) = 3.85, p < .01). However, among URM and FGC students, engineering self-efficacy explains up to 9% of the variance in grade performance (r^2 = .09, F(3, 69) = 3.42, p < .02) making it an important contributor.

IV. DISCUSSION

This ABET-based engineering self-efficacy scale seems to be an effective tool for tracking changes in student self-efficacy relative to the instructor's intent. This scale is capable of detecting changes in engineering student self-efficacy and can serve as an important check for the instructor to confirm that students are benefiting from instruction in the intended ways. The scale also seems to be a meaningful tool in tracking engineering students outside the majority – underrepresented minority students and first-generation college students.

There are many benefits to the use of an ABET-based engineering self-efficacy scale for classroom assessment. The ABET Student Outcome criteria are written to address engineering capability across a spectrum on academic majors, so this one scale can be used broadly to measure changes and growth. The scale itself is relatively short and easy to administer and can be used on a class-by-class basis or to track an entire engineering school cohort level as part of a continuing process. Perhaps the biggest benefit of this scale to an academic program is that regular, periodic use helps prepare the department for ABET accreditation and the data from this scale can be useful evidence for the effectiveness of a program.

There is much to be learned from broader use of the ABET-based engineering self-efficacy scale. It is important to gain experience with this scale in a wider range of academic departments beyond mechanical, civil and biomedical engineering to determine if this scale (and its wording) have resonance in disciplines like chemical, electrical, industrial, aero/astro and software engineering. Beyond further qualification of the scale, it would be helpful to know more about how the role of engineering self-efficacy contributes to classroom performance. For example, some researchers postulate that engineering self-efficacy can be more descriptive of classroom performance if it captures a broader range of classroom experiences like experimental skills, tinkering skills, and design [30]. Other researchers see the role of engineering self-efficacy as a contributing factor to classroom grade performance within a context of social-belonging and academic affirmation [33]. These differences can only be explored through a broader, more comprehensive research process.

Finally, it would be interesting to know more about how engineering self-efficacy develops in engineering students over the course of their academic (and workplace) careers. For example, *do fourth year students have greater engineering self-efficacy than first year students? Does engineering self-efficacy have natural peaks and valleys, meaning is engineering self-efficacy understandably lower at the beginning of a course term (or year) because the material is unknown to the student and higher at the end of a course term (or year) after successful completion? Is engineering self-efficacy largely content based (what has a student learned about engineering?) or is it influenced by instructor's skill in teaching? Are there certain instructors who naturally build engineering self-efficacy in students and how do they do it?* These are just a few of the interesting questions inspired by this study and we hope other researchers will use this scale to answer these and other questions.

Acknowledgment

We would like to thank our research colleague Dr. Bob Rice of UC-Merced who made his class available for this study and provided helpful advice in the process. Also, a heart-felt thank you to the engineering students who have given their time and attention to this project.

References

[1] A. Bandura, *Self-Efficacy: The Exercise of Control*, 1st edition. New York: Worth Publishers, 1997.

[2] S. A. Ambrose, M. W. Bridges, M. DiPietro, M. C. Lovett, and M. K. Norman, *How learning works: Seven research-based principles for smart teaching*. John Wiley & Sons, 2010.

[3] A. Bandura, "Self-Efficacy: Toward a Unifying Theory of Behavioral Change.," *Psychological review*, vol. 84, no. 2, p. 191, 1977.

[4] B. J. Zimmerman, "Self-Efficacy: An Essential Motive to Learn," *Contemporary educational psychology*, vol. 25, no. 1, pp. 82–91, 2000.

[5] A. D. Stajkovic and F. Luthans, "Self-Efficacy and Work-Related Performance: A Meta-Analysis.," *Psychological bulletin*, vol. 124, no. 2, p. 240, 1998.

[6] G. V. Caprara and P. Steca, "Self–Efficacy Beliefs as Determinants of Prosocial Behavior Conducive to Life Satisfaction Across Ages," *Journal of Social and Clinical Psychology*, vol. 24, no. 2, pp. 191–217, Mar. 2005.

[7] A. Bandura, "Health Promotion by Social Cognitive Means," *Health education & behavior*, vol. 31, no. 2, pp. 143–164, 2004.

[8] U. Scholz, B. G. Doña, S. Sud, and R. Schwarzer, "Is General Self-Efficacy a Universal Construct? Psychometric Findings from 25 Countries," *European Journal of Psychological Assessment*, vol. 18, no. 3, pp. 242–251, 2002.

[9] R. W. Lent, S. D. Brown, and K. C. Larkin, "Self-Efficacy in the Prediction of Academic Performance and Perceived Career Options," *Journal of Counseling Psychology*, vol. 33, no. 3, pp. 265–269, 1986.

[10] M. F. Schar, P. Brackin, K. J. Chew, and S. D. Sheppard, "ABET Criterion 3 as a Measure of Engineering Self-Efficacy: Comparing the New Criteria (3.1-7) to the Previous Criteria (3a-k) (In Press)," in *Frontiers in Education Conference*, San Jose, CA, 2018.

[11] "ABET | Constitution," Jun-2017. [Online]. Available: http://www.abet.org/about-abet/governance/board-of-directors/constitution/.

[12] "ABET | History," Jun-2017. [Online]. Available: http://www.abet.org/about-abet/history/.

[13] J. F. Volkwein, L. R. Lattuca, P. Terenzini, L. Strauss, and J. Sukhbaatar, "Engineering Change: A Study of the Impact of EC2000," *International Journal of Engineering Education*, vol. 20, no. 3, pp. 318–328, 2004.

[14] "ABET | Why Accreditation Matters," Jun-2017. [Online]. Available: http://www.abet.org/accreditation/why-abet-accreditation-matters/.

[15] S. Choy, "Students Whose Parents Did Not Go to College: Postsecondary Access, Persistence, and Attainment. Findings from the Condition of Education, 2001.," *Condition of Education - US Department of Education*, Dec. 2001.

[16] R. Auclair *et al.*, *Transitions: Research Paper 2 - First-Generation Students: A Promising Concept*. Montreal,

QC, Canada: The Canada Millennium Scholarship Foundation, 2008.

[17] R. K. Toutkoushian, R. S. Stollberg, and K. A. Slaton, "Talking 'bout My Generation: Defining 'First-Generation Students' in Higher Education Research," in *Association for the Study of Higher Education - 40th Annual Conference*, Denver, CO, 2015.

[18] R. B. Cattell, "Psychological Measurement: Normative, Ipsative, Interactive.," *Psychological Review*, vol. 51, no. 5, p. 292, 1944.

[19] H. Baron, "Strengths and Limitations of Ipsative Measurement," *Journal of Occupational and Organizational Psychology*, vol. 69, no. 1, pp. 49–56, 1996.

[20] W. Chan, "Analyzing Ipsative Data in Psychological Research," *Behaviormetrika*, vol. 30, no. 1, pp. 99–121, 2003.

[21] C. A. Manly and R. S. Wells, "Reporting the Use of Multiple Imputation for Missing Data in Higher Education Research," *Research in Higher Education*, vol. 56, no. 4, pp. 397–409, 2015.

[22] S. van Buuren and K. Groothuis-Oudshoorn, "mice: Multivariate Imputation by Chained Equations in R," *Journal of Statistical Software*, vol. 45, no. 3, pp. 1–67, Dec. 2011.

[23] A. Bandura, "Guide for Constructing Self-Efficacy Scales," in *Self-efficacy beliefs of adolescents*, vol. 5, F. Pajares and T. C. Urdan, Eds. Information Age Publishing, 2006, pp. 307–337.

[24] D. R. Krathwohl, *Methods of Educational and Social Science Research: The Logic of Methods*, 3rd ed. Waveland Press, 2009.

[25] J. Cohen, "A power primer.," *Psychological bulletin*, vol. 112, no. 1, p. 155, 1992.

[26] R Core Team, *R: A Language and Environment for Statistical Computing*. Vienna, Austria: R Foundation for Statistical Computing, 2018.

[27] J. P. Concannon and L. H. Barrow, "A Cross-Sectional Study of Engineering Students' Self-Efficacy by Gender, Ethnicity, Year, and Transfer Status," *Journal of Science Education and Technology*, vol. 18, no. 2, pp. 163–172, 2009.

[28] J. P. Concannon and L. H. Barrow, "Men's and Women's Intentions to Persist in Undergraduate Engineering Degree Programs," *Journal of Science Education and Technology*, vol. 19, no. 2, pp. 133–145, 2010.

[29] R. W. Lent, M. J. Miller, P. E. Smith, B. A. Watford, K. Hui, and R. H. Lim, "Social Cognitive Model of Adjustment to Engineering Majors: Longitudinal Test Across Gender and Race/Ethnicity," *Journal of Vocational Behavior*, vol. 86, pp. 77–85, 2015.

[30] N. A. Mamaril, E. L. Usher, C. R. Li, D. R. Economy, and M. S. Kennedy, "Measuring Undergraduate Students' Engineering Self-Efficacy: A Validation Study," *J. Eng. Educ.*, vol. 105, no. 2, pp. 366–395, Apr. 2016.

[31] J. Kruger and D. Dunning, "Unskilled and Unaware of It: How Difficulties in Recognizing One's Own Incompetence Lead to Inflated Self-Assessments.," *Journal of Personality and Social Psychology*, vol. 77, no. 6, p. 1121, 1999.

[32] M. F. Schar *et al.*, "Classroom Belonging and Student Performance in the Introductory Engineering Classroom," in *American Society for Engineering Education - First-Year Programs: Paying Attention to Retention*, Columbus, OH, 2017.

[33] G. M. Walton, C. Logel, J. M. Peach, S. J. Spencer, and M. P. Zanna, "Two Brief Interventions to Mitigate a 'Chilly Climate' Transform Women's Experience, Relationships, and Achievement in Engineering," *Journal of Educational Psychology*, vol. 107, no. 2, p. 468, 2015.

APPENDIX

Below is a list of activities. Please think about how **confident** you are in your ability to do these activities. Move the slider bar to the position that describes your level of confidence.

How **confident** are you in your ability to ...?

- identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics
- apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors
- communicate effectively with a range of audiences
- recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts
- function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives
- develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions
- acquire and apply new knowledge as needed, using appropriate learning strategies

Scale: Slider bar 0-100, set at 0 with (0) "Cannot Do at All", (50) Moderately Can Do, (100) Highly Certain Can Do