

Design Practica as Authentic Assessments in First-year Engineering Design Courses

Christopher McComb, Catherine Berdanier, Jessica Menold

The Pennsylvania State University, mccomb@psu.edu, cberdanier@psu.edu, jessmenold@psu.edu

Abstract - This paper describes the design and evaluation of a novel assessment for first-year engineering design courses that is rooted in an authentic design challenge. This approach modifies the traditional written-exam approach typically found in engineering courses, which is inherently inauthentic and cannot easily capture the exploratory nature of engineering design. Our assessment improves alignment with common learning objectives found in first-year engineering design courses and additionally prepares students for the type of case study interviews that are increasingly common for entry-level engineering jobs. To evaluate our assessment, 50 first-year students completed the engineering design self-efficacy instrument once before beginning the assessment and a second time approximately 48 hours later upon completion of a reflection assignment. In addition, students retrospectively reported their perceived change in self-efficacy during the assessment. Analysis shows that students perceived a large retrospective increase in skill level, despite only a small increase in directly measured self-efficacy. These results are analyzed in light of the Dunning-Kruger effect and we posit that the assessment helps to align students' self-efficacy with their actual skill level. Increased alignment of self-efficacy with skill level may minimize student frustration when encountering challenging tasks in the future, potentially increasing retention of engineering students as well as facilitating the development of lifelong learning attitudes.

Index Terms – assessment, design challenge, self-efficacy

INTRODUCTION

Most engineering programs “bookend” design competencies for engineering students, requiring them to engage with open-ended design principles at the beginning and end of their undergraduate degree programs. The rationale for most programs to introduce design in the first year has been validated by numerous engineering education and engineering design researchers. For example, first-year engineering programs can introduce tools (physical tools, software tools) that students will be required to use in subsequent courses; develop student comfort with reflection [1], [2] creativity [3]–[5] and ambiguity in solving ill-structured problems [6]–[8]; introduce the design process [9], [10]; and serves to socialize engineering students in the

habits of mind and professional expectations of engineering as a career and discipline [11], [12]. Some programs also use these courses to foster engineering ethics, writing and communication skills, teamwork competencies, and to develop community and engineering identity within students to aid in retention of engineering students [13]–[15]. In other words, first-year engineering design students are typically gaining other competencies beside academic objectives (the *what* part of engineering) in addition to learning *how* competencies are enacted within the engineering discipline.

While all engineering programs may structure their first year and design experiences differently [14], engineering education and design literature concurs that the emphasis on authentic and experiential learning is important for lasting learning. Moreover, a students' ability to articulate problem-solving skills and constrain ill-structured problems may be useful in successfully navigating case study interviews, which are increasingly common for entry-level engineering positions. These interviews ask students to work authentic problems to enlighten a candidate's process and mastery of technical competencies. If harnessed properly, first-year engineering design courses and assessments can prepare students for these types of interview situations.

However, with the increasing complexity of open-ended and competency-based design assessments comes a difficulty in assessment in the engineering design classroom. While in the workplace, assessment results in either the hiring or non-hiring of candidates, in the classroom, the incorporation of authentic design problems require more involved assessment for engineering design learning objectives, and the quantification of these skills for a reported grade. Furthermore, the classroom is intended to build non-technical skills and attributes as well, further confounding the assessment.

Assessment mechanisms for design education have been discussed in literature. For example, Crismond and Adams' [9] Informed Design Teaching and Learning Matrix is as an assessment tool for design thinking in authentic design teaching environments. Sarkar and Chakrabarti [16] developed a method for assessing design creativity in authentic design settings. Yildirim, Shuman, & Besterfield-Sacre [17] employed model-eliciting activities as assessments of undergraduate engineering students' problem-solving capabilities. Despite these studies, it is still difficult for educators to implement authentic summative

assessments for first-year students in design classrooms. Thus, many educators employ more authentic tasks for formative assessments and projects, but not for summative assessment.

While assessing students' engineering design process, first year engineering students are also developing the affective and regulatory competencies required for engineering success, such as self-efficacy in design, in math, and in engineering overall. Self-efficacy is skill-specific confidence in one's ability to succeed in spite of difficulty [18], [19] and scales have been developed in a myriad of fields. With respect to engineering design in particular, Carberry, Lee, and Ohland [20] validated a scale for design self-efficacy that measures student's self-efficacy, motivation, outcome expectancy, and anxiety across the breadth of activities involved in the design process. The correlation between skill and self-efficacy in first-year engineering design courses is typically studied outside of an assessment context; however, we posit that self-efficacy measures embedded within open-ended design challenges can add insight into the development of students' skills, both as perceived by the students and as assessed by engineering instructors.

To investigate this proposition, this paper presents an assessment for open-ended design challenges developed at [Institution blinded for review] and the evaluation of the assessment instrument. The objective of this paper is to both discuss the assessment mechanism and present our observations of a misalignment between student perceived skill level with their measured design self-efficacy.

METHODS

I. Design of Assessment

The assessment was designed to engage students in an authentic design task. The assessment was broken into two pieces, an in-class team design activity and an out-of class individual reflection. Designers rarely work alone in industry [21]–[23], thus it was critical to incorporate collaborative design in the authentic assessment. Student teams were asked to design a product or service that would aid in water conservation efforts specifically for residents Cape Town, South Africa. Students were instructed that their solution should extend the residents' current water supply as long as possible. Researchers in engineering design emphasize the need for empathic educational experiences [24] and incorporating global perspectives into engineering curricula [25], [26]. As such the design challenge focused on designing a product with social impact for a real-life crisis. Students were also instructed to use the design processes, methods, and tools taught in class to develop a solution. At the conclusion of the in-class activity students were told they had 48 hours to submit an individual reflection about the design challenge. The reflection asked students to consider the design process used on their team, discuss any gaps in this process, and analyze decisions made during the design process. Reflecting in this way encourages meta-cognition which is positively correlated with desirable

learning outcomes [27]. Students were assessed based on their in-class contributions to the design team, their knowledge and application of the design process, and their individual reflections.

II. Data Collection

Data was collected through a pre-assessment survey, completed in class prior to the beginning of the assessment, and a post-assessment survey, completed after students submitted their reflection, approximately 48 hours after the in-class portion of the assessment). The pre-assessment survey queried age, gender, race/ethnicity, preparation (free response, coded here as a binary response). In addition, this survey included the engineering design self-efficacy instrument developed by Carberry et al. [20]. This instrument asks participants to rate their confidence in their ability to complete each of nine common tasks associated with engineering design on a scale from 0 to 100.

The post-experiment survey presented the students with the engineering design self-efficacy tool once again. In addition, students were asked to report a differential version of the engineering design self-efficacy instrument that asked students to rate the change in their degree of confidence for each of the nine engineering design tasks. This made it possible to determine students' perceived change in self-efficacy. Several additional free response questions designed to collect information about motivation were also asked, but those responses are not analyzed in this paper.

III. Participating Students

The assessment developed here was evaluated through deployment in two sections of an introductory engineering design course at [Institution blinded for review] as a mid-semester assessment. A total of 50 students completed the assessment and associated data collection instruments. Demographics of the participating students are summarized in Figure 1.

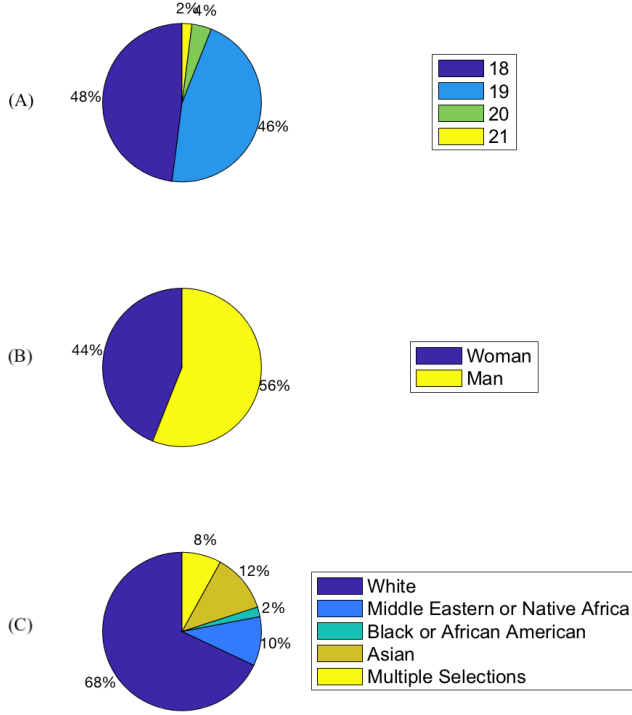


FIGURE 1
DEMOGRAPHICS OF PARTICIPATING STUDENTS WITH RESPECT TO (A) AGE, (B) GENDER, AND (C) RACE/ETHNICITY.

IV. Analysis

The majority of the analysis performed in this paper are based on three metrics: pre-assessment self-efficacy (E_{pre}), post-assessment self-efficacy (E_{post}), and perceived change in self-efficacy (d_{self}). Based on the pre and post measures, a computed change in self-efficacy can be resolved:

$$d_{comp} = E_{post} - E_{pre}. \quad (1)$$

Further, a measure of initial overconfidence (assessed retrospectively) can be computed by taking the difference between the perceived and computed changes in self-efficacy:

$$c = d_{self} - d_{comp}. \quad (2)$$

In essences, this measures the degree to which the initial confidence measure is inflated by assuming that the post-assessment self-efficacy is a better assessment of self-efficacy grounded in a recent experiential application of relevant skills. The pre-assessment self-efficacy, less the overconfidence, resolves the true pre-assessment skill level:

$$t = E_{pre} - c. \quad (3)$$

Several regression analyses are reported here that analyze the underlying factors that might have contributed to post-assessment self-efficacy, retrospective overconfidence, and perceived change in self-efficacy.

Every regression utilizes an all-possible subsets approach, in which model selection is performed by assessing the information content of all possible subsets of variables [28] using the Akaike information criterion [29] as a basis for comparison. This regression tool was utilized to produce linear regression models for post-assessment engineering design self-efficacy, retrospective overconfidence, and perceived change in engineering design self-efficacy. Predictor variables initially provided to the modeling tool were age, gender (binary here since only two genders were reported), preparation (binary), race/ethnicity (binary as minority and non-minority), and pre-assessment self-efficacy (continuous).

RESULTS

Figure 2 compares the pre-assessment and post-assessment engineering design self-efficacy. A two-tailed paired t-test was conducted to understand what if any significant differences between pre and post engineering design self-efficacy scores existed. A significant difference between pre and post engineering design self-efficacy was observed, $t(49) = -2.5270$, $p = 0.0148$; specifically, engineering design self-efficacy was significantly higher after the assessment.

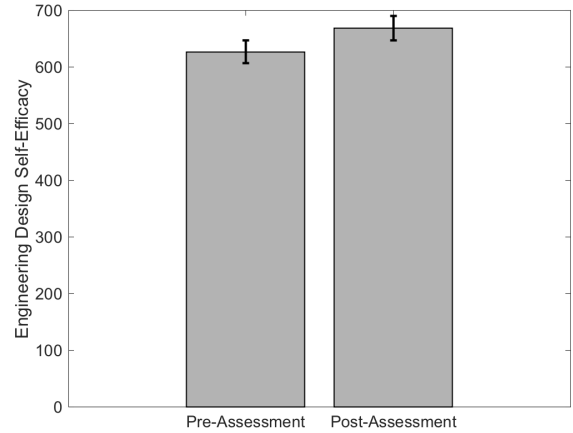


FIGURE 2
COMPARISON OF PRE-ASSESSMENT AND POST-ASSESSMENT ENGINEERING DESIGN SELF-EFFICACY. ERROR BARS INDICATE ± 1 STANDARD ERROR.

The measured change in self-efficacy that is shown implicitly in Figure 2 is computed and shown directly in Figure 3 alongside the perceived change in self-efficacy directly reported by students. A two-tailed paired t-test was conducted to understand what if any significant differences existed between perceived and computed changes in engineering design self-efficacy. A significant difference was observed, $t(49) = -4.6884$, $p < 0.001$; specifically, the perceived change in engineering design self-efficacy was significantly higher than the computed change in engineering design self-efficacy. In total, 92% of students reported a perceived increase in engineering design self-efficacy and 72% of students experienced a computed increase in self-efficacy. The sign of the computed change and perceived change matched for 72% of students.

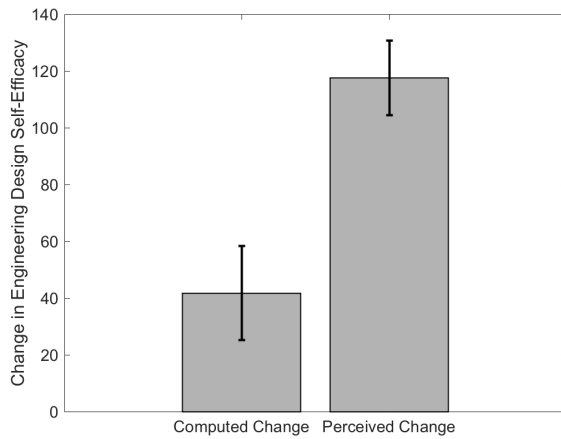


FIGURE 3

COMPARISON OF COMPUTED (BASED ON PRE- AND POST-ASSESSMENT MEASURES) AND PERCEIVED (RETROSPECTIVELY IN POST-ASSESSMENT SURVEY) CHANGE IN ENGINEERING DESIGN SELF-EFFICACY. ERROR BARS INDICATE ± 1 STANDARD ERROR.

Figure 4 again shows pre- and post-assessment measures of engineering design self-efficacy. However, the pre-assessment measure is broken into two components: retrospective overconfidence (computed with Equation 2) and true pre-assessment skill level (computed with Equation 3). Overconfidence accounts for 12.1% of pre-assessment self-efficacy, and significantly increases the retrospective assessment of true skill level, $t(49) = -4.6884$, $p < 0.001$.

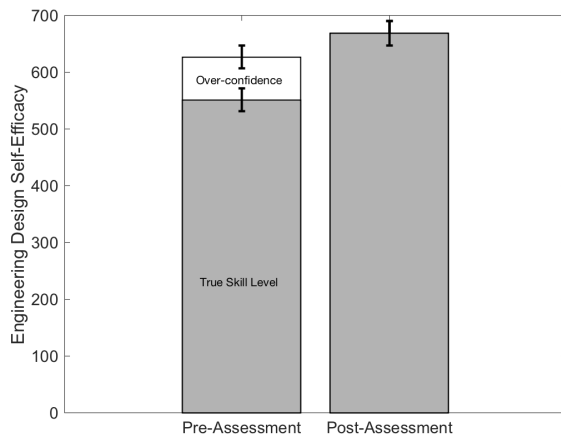


FIGURE 4

COMPARISON OF PRE-ASSESSMENT AND POST-ASSESSMENT ENGINEERING DESIGN SELF-EFFICACY. PRE-ASSESSMENT SELF-EFFICACY IS BROKEN INTO OVER-CONFIDENCE AND RETROSPECTIVE SKILL LEVEL. ERROR BARS INDICATE ± 1 STANDARD ERROR.

For the post-assessment self-efficacy model, the automatic linear modeling tool indicated predictors pre-assessment self-efficacy, gender, and preparation. The linear regression model with these predictors was statistically significant, $F(3, 42) = 97.99$, $p < 0.001$. The model explained 86.6% (Adjusted R^2) of the variance in post-assessment self-efficacy. All predictor variables were significant. Students who identified as women were more likely report higher

levels of engineering design self-efficacy after the assessment. Additionally, students who had not prepared were more likely to report higher levels of engineering design self-efficacy after the assessment. Finally, students with high levels of engineering design self-efficacy prior to the assessment reported higher levels of engineering design self-efficacy after the assessment.

TABLE I
LINEAR REGRESSION MODEL FOR POST-ASSESSMENT ENGINEERING DESIGN SELF-EFFICACY.

Model Term	Estimate	S.E.	t	Sig.
Intercept	153.39	36.51	4.20	< 0.001
Gender (woman)	31.74	14.94	2.12	0.039
Preparation (true)	-62.39	15.08	-4.14	< 0.001
Pre-assessment self-efficacy	0.86	0.05	16.14	< 0.001

For the overconfidence model, the automatic linear modeling tool indicated only pre-assessment self-efficacy as a predictor. The linear regression model with this predictor was statistically significant, $F(1, 44) = 4.82$, $p = 0.033$. The model explained 7.82% (Adjusted R^2) of the variance in overconfidence. The single predictor was statistically significant: high levels of engineering design self-efficacy pre-assessment significantly predicted higher levels of overconfidence. Intuitively this makes sense, as higher pre-assessment scores in engineering design self-efficacy are more likely to be subject to overconfidence.

TABLE II
LINEAR REGRESSION MODEL FOR RETROSPECTIVE OVERCONFIDENCE.

Model Term	Estimate	S.E.	t	Sig.
Intercept	-44.16	55.13	-0.80	0.427
Pre-assessment self-efficacy	0.19	0.09	2.19	0.034

For the perceived change in self-efficacy model, the automatic linear modeling tool indicated predictors of age, gender, and preparation. The linear regression model with these predictors was statistically significant, $F(4, 41) = 6.53$, $p = 0.001$. The model explained 26.9% (Adjusted R^2) of the variance in the perceived change in self-efficacy. All predictor variables were statistically significant except for race/ethnicity. Older students were likely to report lower changes in perceived engineering design self-efficacy. Again, students who prepared in some way were likely to report lower changes in engineering design self-efficacy. Finally, women were more likely to report larger changes in engineering design self-efficacy. The same effect was observed for minority students, but it was not statistically significant.

TABLE III
LINEAR REGRESSION MODEL FOR PERCEIVED CHANGE IN ENGINEERING DESIGN SELF-EFFICACY.

Model Term	Estimate	S.E.	t	Sig.
Intercept	871.21	302.57	2.88	0.006
Age	-40.21	16.06	-2.50	0.016
Gender (woman)	46.81	21.59	2.17	0.036
Preparation (true)	-58.96	21.56	-2.74	0.009
Race/Ethnicity (minority)	32.67	23.66	1.3809	0.175

DISCUSSION

The use of a design challenge assessment with a reflection component effectively increases engineering design self-efficacy. As mentioned in the results, a significant increase between pre and post engineering design self-efficacy was observed. This would suggest that students' confidence in engineering design tasks increased as a result of completing the design challenge assessment.

Additionally, students perceived significantly greater increases in self-efficacy due to the design challenge, as compared to the computed change in engineering design self-efficacy. Although 92% of students reported an increase in perceived engineering design self-efficacy, only 72% of students had a computed change in engineering design self-efficacy. Taken together, these results imply that students were overconfident in their own skill sets prior to the start of the design challenge. As shown in Figure 4 overconfidence accounts for to 12.1% of pre-survey engineering design self-efficacy. This is a critical finding for engineering educators as it highlights the ability of alternative design assessments to hone engineering students' perceptions about their own beliefs.

Reviewing the regression model for post-assessment engineering design self-efficacy provides another perspective. We found that women were more likely to report higher levels of engineering design self-efficacy after the assessment. This result is extremely important for engineering educators as increasing underrepresented groups is a critical push in engineering education [30]–[32]. Self-efficacy has been shown in previous work to increase retention rates [33] and the increased engineering design self-efficacy resulting from an alternative design assessment holds promise for those educators working to increase the number of women in engineering majors. Interestingly, students who had not prepared for their assessment, had higher scores in engineering design self-efficacy in the post-assessment survey. We hypothesize this was due to the timing of the pre-survey. Because students took the pre-survey immediately before the assessment we believe that those students who had not prepared may have felt some sense of panic or stress, and thus rated their engineering design self-efficacy much lower. Once the survey was complete students may have felt better about their performance or may have navigated the design challenge better than expected, resulting in higher scores on the post-survey.

Perceived change in engineering design self-efficacy was significantly predicted by gender, age, and preparation. Specifically, the regression model suggests that as age increased amongst participants, perceived changes in engineering design self-efficacy decreased. We hypothesize that older students were more in tune with their true engineering skills at both the start and conclusion of the engineering design challenge, as compared to younger students. So, while older students reported positive changes in their engineering design self-efficacy, their perceived gains in engineering design self-efficacy were more likely

lower than their younger counterparts. We postulate this is due to the Dunning-Kruger [34] effect and older students are aware of their own gaps in skills and knowledge, while younger students may not be aware of these gaps. Also, the model indicates that women were more likely to perceive a greater change in engineering design self-efficacy. Once again, this is an important finding as it highlights the power of alternative design assessments that are more authentic to increase the confidence of underrepresented groups in engineering majors. Additionally, the regression model suggests that students that did not prepare for the assessment were more likely to perceive greater gains in engineering design self-efficacy. Once again, we hypothesize that these students outperformed their own expectations at the start of the design challenge, and thus reported a larger perceived increase in engineering design self-efficacy. It is also worthwhile to note, that while we did not see any significant effects due to race/ethnicity we believe this was trending towards a significant effect. While the individual variable was not significant independently it was a part of the larger model, that was significant. We believe with a larger sample size, or a more diverse group, we might observe statistically significant effects due to race or ethnicity. The current data points to minority students perceiving larger gains in self-efficacy. This result should be explored in greater detail in future work as it could be a critical finding for design educators looking to increase retention in minority groups.

LIMITATIONS

The primary limitation of this study is the relatively small sample size of 50 students. Increasing the number of students would enable more rigorous statistical analyses and conclusions to be drawn. A related limitation is the fact that students were assessed in two sections of the course with different instructors. For this reason, student self-efficacy may be conflated with instructional style.

In addition, this work only considers a single assessment type, fundamentally limiting the conclusions that can be drawn. Variations upon the assessment or comparison against traditional written assessments (e.g. exams) would enable more definite conclusions. Further, the assumption that pre-assessment self-efficacy can be retrospectively sectioned into overconfidence and retrospective skill level has not been validated or verified.

CONCLUSIONS

This work focused on the evaluation of an assessment that integrated a team-based design challenge with an individual reflection completed within 48 hours. This assessment was designed to emulate a common industry working environment and also to prepare students to better navigate case study interview that are increasingly common. Data was collected from students using a pre-assessment survey (completed immediately before the assessment began) in

conjunction with a post-assessment survey (completed out of class after submitting a reflection).

First, the relative values of pre-assessment engineering design self-efficacy, post-assessment engineering design self-efficacy, and perceived change in self-efficacy were compared. It was found that engineering design self-efficacy increased over the course of the assessment. In addition, the retrospective perceived increase in self-efficacy was significantly larger than the computed increase in self-efficacy.

Next, regression analyses were undertaken using an all possible subsets approach. Interestingly, these analyses indicated that students who did not prepare for the assessment were likely to have higher post-assessment self-efficacy and a larger perceived increase in self-efficacy over the assessment; this effect was likely due to a deflated sense of confidence going into the assessment. In addition, the regression models indicated that women were likely to experience higher post-assessment self-efficacy and a larger perceived increase in self-efficacy. Since engineering suffers from a general lack of diversity, increasing the self-efficacy of women in engineering is potentially beneficial.

The current work indicates three directions for future inquiry. First, the assessment here is composed of two distinct components with drastically different characteristics. Which component contributes the most to the observed self-efficacy phenomena? Future work should assess the contributions from each separately. Second, as noted under limitations, student self-efficacy may be confounded by instructional style. A larger number of course sections would enable the introduction of dimensions of instructional style to the regression analyses. Third, the assessment used here may increase self-efficacy more for women. This effect must be studied in greater detail, as adoption of this assessment style may help to empower populations that are typically underrepresented in engineering.

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AUTHOR INFORMATION

Christopher McComb Assistant Professor, The Pennsylvania State University, mccomb@psu.edu

Catherine Berdanier Assistant Professor, The Pennsylvania State University, cberdanier@psu.edu

Jessica Menold Assistant Professor, The Pennsylvania State University, jessmenold@psu.edu