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A Measure of Problem-Solving Self-Efficacy for Undergraduate Engineering Students

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This Work-In-Progress examines higher education's struggles to increase the retention rate of engineering students despite scholarly attention and government funding [1], [2]. One recommendation made by researchers and policy-makers is to increase students' sense of engineering identity and engineering self-efficacy [2]. Conceptualizations of these constructs often include some form of problem-solving [2]-[4]. Therefore, it is reasonable to surmise problem-solving self-efficacy (i.e., belief in one's ability to solve problems) is a core component of engineering identity and engineering self-efficacy, and that increasing it will increase them. However, before investigating methods to increase problem-solving self-efficacy, researchers must operationally define it and adopt a reliable and valid measure of it, whether through scale development or adaptation of a pre-existing scale, the latter of which is the purpose of this study.

Conceptual Context

We first ground the study's conceptual context in literature describing the contructs of self-efficacy, identity, and self-concept. We then reference achievement goal orientation theory [5], together with implicit theories of intelligence [6] - [9], to provide a conceptual scaffolding for the study's research questions.

As noted above, the motivation to investigate problem-solving self-efficacy is its associations with engineering identity and self-efficacy [2] - [4]. A useful step in defining it is to place it within the nomological network of identity and self-efficacy. *Self-efficacy* is a psychological construct focused on one's belief or confidence that one can achieve a specific goal or task [10]. An important attribute of self-efficacy is that it is context-specific: one can have different levels of self-efficacy for different contexts [11]. For example, one may have a high degree of self-efficacy in following a scripted laboratory activity, but a low degree for problem-solving a real world engineering challenge. As a consequence, the instruments and scales needed to measure self-efficacy also vary greatly based on the specific context of the activity. Hence, there have been different scales developed for self-efficacy in different areas, such as mathematics and chemistry [12] - [15].

Identity is generally focused on the feelings, thoughts, and beliefs one has of oneself [16], which contribute to self-confidence and, therefore, self-efficacy. A closely related construct is *self-concept*, one's collection of beliefs about oneself [16]. Whereas both identity and self-concept focus on the perspective of oneself, self-concept primarily focuses on the cognitive aspect, whereas identity incorporates feelings and beliefs with the cognitive. Because self-concept is concentrated on one's skills, abilities, physical aspects, or behavior, it acts as a guide to identity [17]. As such, self-concept is particularly relevant to career choices [16], such as engineering. In addition, self-concept has been conceptualized as having different facets related to different areas of one's life, such as academic self-concept, professional self-concept, social self-concept, etc. [16]. These facets can have more or less specificity and be organized hierarchically from the most general to the most specific [16]. For example, a student may have both an academic self-concept and an engineering self-concept, as well as a problem-solving self-concept.

The role of identity in the retention of engineering students can be focused more specifically on the role of engineering self-concept, which with its focus on skills and abilities, has a direct bearing on engineering self-efficacy. Various pedagogical approaches seek to exploit this relationship, such as project-based learning, inquiry learning, and design-based learning [3], [4].

Social Learning Theory posits that people observe and imitate the actions and behaviors of those they perceive as having the same or higher status [18].These pedagogical approaches attempt to facilitate the development of students through social learning by encouraging collaboration with peers, teachers, and experts on solving problems [4]. However, what is often left unstated is the assumption that the students will grow in the belief or confidence they can solve problems on their own. In other words, they will grow in problem-solving self-efficacy. In fact, students appear to recognize this in their own self-descriptions of what they must accomplish in active learning [3].

However, two theories about learning and motivation may help explain how students will grow in self-efficacy, achievement goal orientation theory, and implicit theories of intelligence. Achievement goal orientation theory posits two thought processes and behaviors used to achieve self-efficacy in learning goals, whether directly assigned by the instructor or self-directed, as in various forms of active learning [5]. The first, *performance goal orientation*, is used by individuals who seek to gain competence by performing as well as possible relative to others. Such individuals seek competitive environments with clearly articulated achievement standards. The second, *mastery goal orientation*, is used by individuals who gain self-efficacy by engaging in deep learning about a particular topic. Such individuals seek environments with challenging tasks and the freedom to learn beyond baseline expectations. These thought processes and behaviors can be further divided into *approach* and *avoidance* goals. Performance goal approach orientation refers to an individual who strives to achieve self-efficacy through relative comparison of performance with others. Performancee avoidance orientation refers to individuals who avoid situations where performance relative to others is in doubt. Mastery approach orientation refers to individuals who achieve self-efficacy by learning as much as possible about a topic, whereas master avoidance orientation refers to individuals who avoid situations with barriers to achieving self-efficacy. One's level of self-efficacy depends on whether one adopts a performance goal orientation or a mastery goal orientation [19], [6]. On one hand, if an individual adopts a mastery orientation, self-efficacy remains high even in the face of a lack of belief by others in one's ability. On the other hand, if one adopts a performance orientation, one's self-efficacy is depleted by a lack of belief by others in one's ability.

Self-efficacy is also related to the two implicit theories of intelligence individuals have about themselves, *incremental theory* and *entity theory*. Incremental theory, or *growth mindset*, is generally defined as one's perception that one's personal qualities can be developed (i.e., grow) [6]-[9]. In contrast to incremental theory, entity theory, or a *fixed mindset,* views personal qualities as unchangeable. When one has a mastery goal orientation, one must also have an incremental theory of intelligence, because the goal is to grow in knowledge and ability. Thus, self-efficacy should be robust and resistant to enternal forces [6], [20]. When one has a performance goal orientation, one also tends to have an entity theory of intelligence, because the goal is a comparison of a fixed state with others. Thus, self-efficacy tends to be vulnerable to external factors and variable [6], [20]. Multiple studies have observed a positive association between an incremental theory of intelligence and academic achievement [9], [20], [21].

The Current Problem Area

Although theories reviewed above indicate increasing problem-solving self-efficacy would facilitate an increase in engineering self-efficacy and engineering self-concept, it remains an empricial question. However, before attempting to answer this question, problem-solving self-efficacy must be operationalized. Unfortunately, we found no direct measurement of problem-solving self-efficacy in a search of the STEM education literature. We did find limited studies of problem-solving as an outcome of self-efficacy in several areas—mathematics, chemistry, and in general [12] - [15]—but such studies did not examine self-efficacy in problem-solving per se.

The closest studies we found to investigating the construct of problem-solving self-efficacy were [22], [23]. Both studies examined everyday problem-solving as opposed to engineering problem-solving, but Heppner and Peterson [23] developed a more thorough and generalizable scale, the Personal Problem-Solving Inventory (PPSI). The PPSI is comprised of 32, six-point response items that form three factors: problem-solving confidence, approach-avoidance style, and personal control.

Purpose

In the present study, our purpose was to evaluate the validity of using the PPSI to measure problem-solving self-efficacy in undergraduate engineering students and modify it if necessary. More formally, we sought to address the following research questions:

1. What is the evidence for the validity of using the PPSI to measure problem-solving self-efficacy in undergraduate engineering students?

2. What modifications to the PPSI must be made to increase the validity of its use for that purpose?

Methodology

Participants and Procedure

We recruited 201 students enrolled in an introductory engineering course at a large Midwestern urban university during the fall semester. In the first week of class, participants completed an online questionnaire with the PPSI and scales measuring performance goal motivation, growth mindset, effort beliefs, and engineering identity. Some students did not fully complete the questionnaire (see Results for how we handled missing data), and we obtained demographic information for 187 students, 60 (32.1%) of whom were female. The majority of the students were freshmen (n = 167, 89.3%), and the rest were transfer students (n = 20, 10.7%).

Instrumentation

As noted above, the PPSI [23] is comprised of 32 items that employ a six-point "Likert-type" scale. Heppner and Peterson did not provide labels for the response options, so we inferred the following based on their description: 1 = *strongly disagree*, 2 = *disagree*, 3 = *slightly disagree*, 4 = *slightly agree*, 5 = *agree*, 6 = *strongly agree* (we also used this response scale for all other instruments except the Engineering Identity Scale). Heppner and Peterson found evidence for three dimensions in the scale scores using principal components analysis (N = 150): problem-solving confidence (e.g., "I am usually able to think up creative and effective alternatives to solve a problem"), approach-avoidance style (e.g., "When a solution to a problem was unsuccessful, I do not examine why it didn't work"), and personal control ("When making a decision, I weigh the consequences of each alternative and compare them against each other"). Subscales formed by the dimensions had the following respective estimates of Cronbach's alpha internal consistency reliability: .85, .84, and .72. For the total score, Cronbach's alpha was .90. Test-retest reliability ($n = 31$) had respective estimates of .85, .88, .83, and .89. Heppner and Peterson also provided evidence of criterion and construct validity.

We measured performance goal motivation using three items Blackwell et al. [21] borrowed from the Patterns of Adaptive Learning Survey's Task Goal Orientation Subscale [24]. Blackwell et al. reported Cronbach's alpha to be .84 and test-retest reliability to be .63. Cronbach's alpha was .71 in this study.

We measured growth mindset with the Theory of Intelligence Scale (TIS) [21], which is comprised of six items. Three items measure entity theory (i.e., fixed mindset) and three measure incremental theory (i.e. growth mindset). The entity theory items are reverse-scored and added to the incremental theory items for a total score, which has a Cronbach's alpha of .78 and a test-retest reliability of .77. Cronbach's alpha was .87 in this study.

We used a seven-item scale to measure effort beliefs adapted from Blackwell et al. [21]. Two items represented beliefs that effort leads to positive results, and five items represented beliefs that effort leads to negative results or is unrelated to any results. Cronbach's alpha was .79 in this study.

We measured engineering identity with the Engineering Identity Scale (EIS) [25], which is comprised of 15-items using the following five-point response scale: *definitely not* = 1, *probably not* = 2, *not sure* = 3, *probably yes* = 4, and *definitely yes* = 5. Patrick et al. presented evidence supporting four factors with acceptable to good internal consistency reliability: Performance/Competence, .86; Interest, .85, Engineering Identity, .73; and Recognition by Others, .86. Cronbach's alpha estimates in this study were, respectively: .93, ..93, .91, and .82.

Analytic Strategy

All analyses were conducted using SPSS v23. To address Research Question 1 (RQ1), we examined evidence of the structural validity of the PPSI using exploratory factor analysis. Although there is EFA evidence of the structural validity of the PPSI in its present form, the evidence is based on a different population (undergraduate psychology students) and a relatively small sample ($N = 150$) [23]. In addition, external replication of a factor structure with EFA is seen in some quarters as a more rigorous test than replication with confirmatory factor analysis (CFA), because in EFA, an item is free to covary with any other item, whereas in CFA, the researcher specifies which items may be covaried [26]. Principal axis factoring (PAF) was the method of extraction, and Velicer's MAP Test was the criterion for extraction. Factor solutions were rotated using an oblique method, Promax. To address RQ2, items were dropped if they did not have a factor coefficient of at least .40 on any single factor, or if they cross-loaded on two or three with loadings greater than .30. We dropped one item at a time, rerunning the analysis each time. After the final scale items were determined, we computed Cronbach's alpha for each of the subscales arising from the factors.

For RQ1, we also examined evidence of criterion validity using correlations between PPSI scores and the scores of performance goal orientation, the TIS, and the effort beliefs scale. These scores all represent key motivational variables [21], and therefore, should be positively correlated with problem-solving self-efficacy.

We also correlated PPSI scores with EIS scores to obtain evidence of construct validity. As explained in the literature review, engineering identity is closely related to engineering self-efficacy, which in turn is closely related to problem-solving self-efficacy. Therefore, engineering identity should be related to problem-solving self-efficacy.

Results

We examined the data set for missing data, and found that 30 (14.9%) participants were missing a response to at least one question, but just 8 were missing more than 10% of the data. No single item had more than 4.5% missing data. The pattern appeared to be missing completely at random (Little's MCAR test: chi-square (1506) = 1572.41, $p = .114$), so we used listwise deletion for PAF and Cronbach's alpha ($n = 187$), and pairwise deletion for correlations ($186 \leq n \leq 199$).

For PAF, Velicer's MAP Test indicated three factors for extraction. Following our analytic strategy, we dropped 14 items for a final revised PPSI of 18 items. Each item loaded on just one factor, and loadings ranged from .42 to .79 (see Table 1). Communalities ranged from .23 to .58. The factors explained 39.26% of the variance in the items. The first factor consisted of eight items from the original problem-solving identity subscale, so we kept that label, Problem-Solving Identity. The second and third factors consisted only of items from the original approach avoidance style subscale. The seven items of Factor 2 all expressed variations of the idea that the respondent engaged in little to no reflection either before or after solving a problem; they just did not want to think about it (e.g., "When I am confronted with a complex problem, I do not bother to develop a strategy to collect information so I can define exactly what the problem is"). The three items of Factor 3 expressed the opposite attitude of actively engaging in reflection before and after solving a problem (e.g., After I have tried to solve a problem with a certain course of action, I take time and compare the actual outcome to what I thought should have happened"). Therefore, we labeled Factor 2, Problem-Solving Avoidance, and Factor 3, Problem-Solving Approach. Factor correlations were weak, ranging from -.21 to .18. No items from the original personal control subscale were retained.

Cronbach's alpha estimates were good for each subscale: Problem Solving Identity, .81; Problem-Solving Avoidance, .80; and Problem-Solving Approach, .81.

Validity coefficients were computed for each PPSI subscale and reported in Table 2 (along with *M*s and *SD*s). Criterion validity was supported by significant moderate (i.e., $r > .30$) correlations between Problem-Solving Identity and performance goal motivation and the TIS, as well as a significant but weak (i.e., $r > .10$) correlation with effort beliefs. Problem-Solving Avoidance had negative moderate correlations with the TIS and effort beliefs. Problem-Solving Approach was not correlated with any motivational measure.

Construct validity was supported by positive moderate correlations between Problem-Solving Identity and each of the EIS subscale scores, except Recognition by Others, which was significant but weak. Problem-Solving Avoidance had weak negative correlations with Performance/Competence and Interest. However, Problem-Solving Approach was not correlated with any EIS subscale.

Discussion

The purpose of our study was to evaluate the validity of using the PPSI to measure problem-solving self-efficacy in undergraduate engineering students (RQ1) and modify it if necessary (RQ2). Initial exploratory factor analysis indicated a lack of structural validity for using the original PPSI with undergraduate engineering students, but we were able to use it modify the PPSI and provide evidence of structural validity for the revised version. The revised PPSI subscale scores had good internal consistency reliability, but there was mixed evidence of criterion and construct validity. Supportive evidence came in the form of moderate correlations between Problem-Solving Identity subscale scores and most aspects of engineering identity, as well as growth mindset, performance goal motivation, and effort beliefs. In addition, Problem-Solving Avoidance subscale scores were negatively correlated with growth mindset, effort beliefs, and the Performance/Competence and Interest subscale scores of the EIS. These relationships reflect the theory that positive dispositions toward challenging activities result in increased approach behaviors and decreased avoidance behaviors. However, Problem-Solving Approach scores did not correlate with any other variable when they would have been expected to have positive correlations where Problem-Solving Avoidance scores had negative correlations.

One reason Problem-Solving Approach failed to have significant correlations may be that it had the fewest items, three, thus limiting its variance as compared to the other subscales. Correlations represent the covariability of two variables, and therefore are limited by the variability of each. In fact, Problem Solving Approach had a *SD* of 2.52, whereas the *SD*s of Problem-Solving Identity and Problem-Solving Avoidance were 4.36 and 5.75, respectively, meaning the variances were approximately three and five times larger, respectively. Future research may address this with additional items suggested by subject matter experts.

Other limitations of the study include a lack of information about the race/ethnic characteristics of the participants, so the representativeness of the sample in that regard cannot be ascertained. In addition, the use of just one type of measurement, self-report scales, may lead to monomethod bias resulting in an overestimation of the strength of the correlations. We recommend a differential approach to measurement in future studies, which would have the added benefit of gathering additional evidence of validity. We also recommend multiple measurements over time so test-retest reliability and predictive validity can be estimated.

Despite these limitations, our results provide good evidence of the validity of using the revised PPSI to measure problem-solving self-efficacy in undergraduate engineering student. We posit that fostering problem-solving self-efficacy can be an effective lever for increasing a sense of engineering identity and self-efficacy, especially when active learning pedagogies, such as project- and designed-based learning, are encouraged for engineering programs [2]. The associations we observed in the present study provide insight into why active learning approaches are associated with engineering self-efficacy and identity [3], [4], and using the PPSI as a pre- and posttest measure in engineering courses can assist instructors in monitoring the extent to which their active learning lessons are fostering this fundamental aspect of engineering self-concept. But the first step in fostering problem-solving self-efficacy is measuring it reliably and validly; the revised PPSI promises to be an instrument that will enable such measurement in a usable, efficient manner.

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Table 1.

Revised PPSI Item Stems, Factors, Coefficients, and Communalities (N = 187)

	Factor[a,b]			
Item stem	*1*	*2*	*3*	h^2
1. I am usually able to think up creative and effective alternatives to solve a problem.	**.79(.75)**	.09(-.07)	-.10(.03)	.49
2. I have the ability to solve most problems even though initially no solution is immediately apparent.	**.69(.70)**	.02(-.13)	.08(.20)	.39
3. Many problems I face are too complex for me to solve.	**.66(.69)**	-.14(-.28)	.01(.14)	.30
4. I make decisions and am happy with them later.	**.63(.60)**	-.01(-.12)	-.17(-.06)	.23
5. When I make plans to solve a problem, I am almost certain that I can make them work.	**.58(.58)**	.07(-.06)	.10(.2)	.35
6. Given enough time and effort, I believe I can solve most problems that confront me.	**.53(.56)**	-.08(-.20)	.07(.17)	.33
7. When faced with a novel situation I have confidence that I can handle problems that may arise.	**-.48(-.48)**	.18(.26)	.23(.13)	.49
8. I trust my ability to solve new and difficult problems.	**.45(.45)**	.11(.01)	.15(.22)	.58
9. When I am confronted with a complex problem, I do not bother to develop a strategy to collect information so I can define exactly what the problem is.	.16(.06)	**.74(.70)**	.19(-.06)	.25
10. After I have solved a problem, I do not analyze what went right or what went wrong.	.22(.04)	**.74(.69)**	-.04(.16)	.26
11. When confronted with a problem, I tend to do the first thing that I can think of to solve it.	-.12(-.25)	**.65(.67)**	.06(-.02)	.43
12. When deciding on an idea or possible solution to a problem, I do not take time to consider the chances of each alternative being successful.	-.06(-.23)	**.57(.60)**	-.26(-.33)	.23
13. I generally go with the first good idea that comes to my mind.	-.09(-.21)	**.56(.58)**	.01(-.05)	.42
14. When I try to think up possible solutions to a problem, I do not come up with very many alternatives.	-.09(-.20)	**.47(.49)**	-.05(-.11)	.55
15. When confronted with a problem, I do not usually examine what sort of external things my environment may be contributing to my problem.	-.10(-.22)	**.42(.45)**	-.20(-.25)	.46
16. After I have tried to solve a problem with a certain course of action, I take time and compare the actual outcome to what I thought should have happened.	-.08(.25)	.11(-.18)	**.65(.63)**	.53
17. When I have a problem, I think up as many possible ways to handle it as I can until I can't come up with any more ideas.	.12(.02)	-.10(.07)	**.60(.63)**	.44
18. When confronted with a problem, I consistently examine my feelings to find out what is going on in a problem situation.	-.06(.04)	-.11(-.14)	**.46(.46)**	.34

Note. h^2 = communality. a. Factor correlations were as follows: r_{12} = .-.21, r_{13} = .18, r_{23} = -.09. b. Pattern coefficients are followed by structure coefficients in parentheses. Primary factor coefficients are in boldface.

Table 2

Scale Means, Standard Deviations, Reliabilities, and Pairwise Correlations

Scale	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*
Problem-Solving									
1. Identity	(.81)								
2. Avoidance	**-.15**	(.80)							
	186								
3. Approach	.11	-.09	(.81)						
	187	*191*							
EIS									
4. Performance/ Competence	**.48**	**-.24**	.01	(.93)					
	191	*193*	*194*						
5. Interest	**.43**	**-.18**	.02	**.71**	(.93)				
	191	*193*	*194*	*198*					
6. Identity	**.34**	.01	.09	**.50**	**.64**	(.91)			
	192	*193*	*194*	*198*	*198*				
7. Recognition	**.18**	.04	.11	**.32**	**.39**	**.57**	(.82)		
	192	*193*	*194*	*198*	*198*	*199*			
Motivation									
8. TIS	**.34**	**-.31**	.02	**.24**	**.27**	.11	-.02	(.71)	
	189	*191*	*193*	*196*	*196*	*196*	*196*		
9. Effort beliefs	**.29**	**-.47**	.04	**.18**	**.15**	.02	.02	**.40**	(.87)
	186	*187*	*190*	*192*	*192*	*192*	*192*	*191*	
10. Performance goal motivation	**.32**	**-.09**	.14	**.21**	.12	.08	.08	**.35**	**.32**
	189	*191*	*193*	*196*	*196*	*196*	*196*	*195*	*191*
M	36.49	21.55	12.54	3.87	4.23	3.31	3.37	27.27	32.46
SD	4.36	5.75	2.52	0.83	0.81	1.31	1.12	5.94	5.64
n	192	193	194	198	198	199	199	196	192

Note. Boldfaced correlations are significant at the .05 level. Pairwise sample sizes are in italics. Cronbach's alpha reliabilities are in parentheses. Performance goal motivation: M = 14.33. SD = 2.37, n = 196, Cronbach's alpha = .79. EIS = Engineering Identity Scale. TIS = Theories of Intelligence Scale.