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Assessing Civil Engineering Students Perceptions of Their Problem Solving Ability*

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The most widely utilized metric for judging academic achievement is grade point average (GPA). However, GPA is not always indicative of critical thinking and problem-solving ability, which are the universal traits required of engineers. This paper presents a new assessment tool for measuring an individual's self-appraisal of their technical problem-solving ability and the initial validation of the tool using a pilot study involving 73 undergraduate Civil Engineering students and faculty. The new assessment tool is called the engineering modified problem-solving inventory (EM-PSI) and is an adaptation of a more general problem solving inventory that has been utilized throughout psychology and counseling research. This paper investigates three pertinent questions: (1) What relationship, if any, exists between undergraduate students and faculty and EM-PSI score, (2) What relationship, if any, exists between gender and EM-PSI score, and (3) What relationship, if any, exists between undergraduate students with or without parents who are engineers and EM-PSI score? Internal reliability assessment of the EM-PSI was evaluated using Cronbach's alpha and determined that the modified survey was acceptably reliable. The results of a Wald ANOVA and post-hoc tests showed that there were significant differences in EM-PSI and subscale scores between undergraduate students and faculty members. Faculty self-appraisal of their problem-solving ability was higher than that of students. Additionally, two dimensions of problem-solving, approach-avoidance style and personal control, were identified to be most different between faculty and students. This paper demonstrates that the EM-PSI is a promising new assessment tool that may assist instructors in evaluating student problem-solving ability.

Keywords: problem solving inventory; critical thinking; engineering assessment

1. Introduction

Problem-solving and critical thinking are often lauded as the cornerstones of formal engineering education. This is witnessed in the 2018–2019 ABET Student Outcomes [1] for engineering, where many of the outcomes focus on the ability to identify, formulate, and solve complex engineering problems while taking into account the social, economic, and ethical repercussions of solutions. Many engineering courses are without a doubt taught by faculty who challenge students with complex problems and encourage them to think critically about different solution methods. However, those faculty do not have a metric or assessment tool for gauging how well students can problem-solve on their own. Nor do they have a tool to determine how confident students are at solving problems unassisted. Rather, most common academic assessments only test student proficiency at a specific skill or a specific subject; such as a Mechanics of Materials exam on stress-strain relationships using the theory of elasticity and Young's modulus.

Solving complex engineering problems requires the ability to determine the problem goals, formulate a plan based on engineering fundamentals, enact the plan to create a solution, and then evaluate if the solution seems reasonable and sufficiently meets the problem goals. Many instructors will be able to recall times when they could observe differences in student's ability to problem-solve, regardless of that student's GPA or class rank. Even among well performing students with high GPAs, there are those who are excellent at self-guiding through problems and those that don't seem to have underlying problem-solving skills, but may be able to follow a process through rote memorization. Assessment tools are needed to assist instructors in judging student problem-solving skill.

In psychology and counseling research, a problem-solving inventory was developed by Heppner and Peterson [2] that identified the underlying dimensions of real-word problem-solving and created a metric that scores individuals own appraisal of their problem-solving skill. The inventory has been widely validated and is utilized by researchers around the world to measure adults' individual perceptions of their problem-solving ability. The problem-solving inventory consists of three subscales, or dimensions of problem-solving: (1) problem-solving confidence (PSC), (2) approach-avoidance style (AAS), and (3) person control (PC). These subscales divide problem-solving ability into individual components that better articulate an individual's strengths and weakness. However, the Heppner and Peterson [2] problem solving

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inventory (PSI) was developed based on average adults' perceptions of day-to-day problem solving, not engineers focused on technical problem solving. Because of this, many of the original PSI questions are too vague to address perceptions about solving complex engineering-type problems.

2. Research questions

This paper presents a pilot study aimed at determining how well a modified Heppner and Peterson [2] PSI can be applied to measure engineering students and faculties appraisal of their technical problem-solving ability. The original PSI was modified from a 35 item inventory into a new 25 item inventory called the engineering modified problem solving inventory (EM-PSI), but retained the same structure as the Heppner and Peterson [2] PSI. The EM-PSI was administered through a survey to undergraduate Civil Engineering students and College of Engineering faculty at Washington State University during the 2017–2018 academic year. A pilot study using the responses of 73 students and faculty is presented here. The three specific research questions addressed in the study were:

Q1. What relationship, if any, exists between undergraduate students and faculty and EM-PSI score and its subscales?
Q2. What relationship, if any, exists between gender and EM-PSI score and its subscales?
Q3. What relationship, if any, exists between undergraduate students with engineer parents or without engineer parents and EM-PSI score and its subscales?

This paper is organized such that it first presents the background about the original PSI research. Next, detailed discussion is provided to describe how the original Heppner and Peterson [2] PSI was modified to form the EM-PSI and the internal reliability of the EM-PSI was validated using Cronbach's alpha. Then, a Wald ANOVA and post-hoc tests were conducted on the data set to determine if there were statistically significant differences in EM-PSI and subscale scores between undergraduate students, faculty, genders, and whether students had engineer parents. Lastly, comparisons between average faculty and undergraduate student scores in each of the subscales was presented and discussed.

3. Background

Critical thinking and problem-solving has been studied extensively in psychology [i.e., 3–5] and engineering education [i.e., 6–9]. Studies have identified that many engineering students have an inability to self-guide through complex problems [6, 7]. This supports the need to develop a quantitative measure of student problem-solving abilities.

The Heppner and Peterson [2] problem-solving inventory (PSI) was developed to measure adult perceptions about their problem solving ability and coping strategies and has been validated in over 130 different studies [10]. Individuals with poor perceived problem-solving using the PSI have been linked to display some of the following characteristics: (1) lack of confidence and follow through, (2) low motivation, (3) avoid dealing with their problems, (4) impulsivity, (5) difficulty making decisions, (6) tend to use emotion-focused coping, and (7) lack of awareness and utilization of helping resources [10]. Many of these characteristics anecdotally seem to also be present for engineering students who struggle with self-guided problem-solving.

Additional research on the PSI has linked it to career decidedness [11–13], career self-efficacy [14], study habits and academic performance [15], and vocational identity [16]. The PSI has been validated for internal consistency and reliability across several cultural groups for both students and instructors, such as Italian high-school students [13], Mexican-American high-school students [17], African American college students [18], Greek educators [19], and Turkish college students [20]. The majority of the prior PSI work has not focused specifically on technical problem solving skills nor engineering students.

Of the PSI research completed in engineering education, the majority has utilized it as a metric to judge the effectiveness of pedagogical interventions. Woods [21] utilized PSI to show that problem-based learning (PBL) for engineering students in workshops improved problem-solving skill better than a control group. Larson et al. [22] utilized PSI to measure engineering student problem-solving confidence between students who had or had not declared their major within engineering. Importantly, Larson et al. [22] showed that sophomore groups had significantly worse PSI scores than junior or senior students and that junior and senior student scores were close to the norm score for U.S. University students. They also demonstrated that GPA was poorly correlated to student problem-solving confidence as measured with the PSI [22].

Some critiques of the PSI have been made regarding difficulty in interpreting the scoring across different groups of individuals and lack of sufficient data for comparing group scores to the norm of general populations [23]. Additionally, locus of control, or the feeling than an individual can control elements of their life conditions, seems to be an important and interconnected concept with problem-solving ability [24]. However, since this study focused on providing initial validation to the modified PSI, utilizing an index to measure locus of control, such as Rotter [25], in tandem with the EM-PSI was not pursued.

Lastly, self-assessment of personal abilities is inherently affected by self-esteem. A poor appraisal of an individual's PSI could be associated with low self-esteem rather than actual shortcomings in problem solving abilities [26]. However, Heppner and Wang [27] demonstrated that PSI could be related to how an individual approached hardships they encounter and plays an important role in overall psychological health. Again, to keep the focus of this study on initial validation of the EM-PSI, no specific self-esteem measure was utilized. Furthermore, a recent study has demonstrated that student perceptions about their learning does not necessarily well predict their actual learning outcomes [28]. With that in mind, the EM-PSI is not foreseen as a replacement to traditional metrics, but rather as a supplement that can aid researchers and instructors in determining the impact of curricular modifications.

4. Methodology

This study was conducted to evaluate undergraduate civil engineering student's appraisal of their problem solving ability compared to engineering faculty. If there was no significant difference between student and faculty appraisals of problem-solving ability, given that faculty are objectively better at problem-solving than undergraduate students, then the EM-PSI cannot be judged as a useful metric for student problem-solving ability. However, if there was a significant difference, and if there were differences between the undergraduate classes, then the EM-PSI can possibly be utilized as a metric for student problem-solving ability. In addition to the student-faculty relationships, the study also sought to determine if gender or educational background of students' parents as engineers had any measurable effect on student's appraisal of their problem-solving ability.

This approach tacitly assumes there is a correlation between an individual's perception of their problem-solving ability and their actual problem-solving ability. The hypothesis is based on the idea that individuals are usually not confident and self-assured in skills that are not successful at. In other words, it would be unlikely for a student who routinely receives D grades to be highly confident that next semester they will receive straight A's. The assumption that student perception of their problem solving ability is correlated to actual critical thinking and problem-solving ability does introduce uncertainty into how EM-PSI data could be utilized in engineering education practice to inform curricular and pedagogical development. However, the initial phase of this research was to validate the modified instrument and to first ensure that EM-PSI scores are significantly different between educational groups. Future work utilizing the instrument will need to determine how to quantify any uncertainties and correlations between problem-solving perception and actual problem-solving ability.

To achieve the study objectives, the Heppner and Peterson [2] PSI was modified to be specific for technical problem-solving and was distributed online. The questionnaire consisted of two sections: the 25 questions that constitute the EM-PSI and 4 demographic questions that inquired about academic level, gender of all participants, years of experience (unused), and whether the undergraduate student's parents were engineers.

4.1 Engineering modified problem solving inventory (EM-PSI)

The original PSI is a 35 item instrument, with 3 filler items, (scored out of 32 items) and measures problem-solving abilities in everyday life. As stated previously, it measures an individual's appraisal of their own ability rather than serving as an external assessment of their ability. The PSI was modified because some of the original questions were too vague to illicit student perceptions about their *technical* problem solving, rather they would answer based on how they approach *everyday* problem solving. The intent of the EM-PSI instrument is to provide instructors with quantitative data on the problem-solving perceptions of engineering students to help shape curricular development and pedagogical interventions.

The original PSI consists of three interrelated factors or subscales, which were determined using principle-components factor analysis [2]. The three subscales are problem-solving confidence (PSC), approach-avoidance style (AAS), and personal control (PC). The EM-PSI retained the format of the three subscales, but modified and removed some of the items in each subscale to form an instrument with 25 total items. The instrument was reduced from 35 to 25 items to make it quicker to complete and with goal of increasing the number of participants who would complete the entire questionnaire.

The EM-PSI PSC subscale has 9 items (reduced from 11 in the original PSI) and assesses an individual's self-perceived confidence in the ability to effectively complete engineering problems. The EM-PSI PC subscale remained at 5 items like in the original PSI and assesses elements of self-control. The EM-PSI AAS subscale was reduced to 11 items (from the original 16) and assesses an individual's tendency to either approach or avoid challenging problems. All items for the EM-PSI were scored on a six-point Likert-type scale, ranging from 0 = Strongly Disagree to 5 = Strongly Agree. The Likert-type scale for the Heppner and Peterson PSI was the inverse of the EM-PSI (1 = Strongly Agree to 6 = Strongly Disagree) and therefore good-PSI scores using the Heppner and Peterson (1982) instrument are low, whereas good EM-PSI scores are high.

Tables 1–3 display the original PSI questions and the modified EM-PSI questions for each subscale. Some questions were modified from the original PSI more than others. For example, EM-PSI item 2 in Table 3 is almost exactly the same as it is in the original PSI, with the only modification being the addition of the word "method". On the other hand, many of the PC subscale questions were significantly re-worded to focus on aspects of technical problem solving. For example, EM-PSI item 25 in

Table 1. PSC questions for the Heppner and Peterson [2] PSI and the EM-PSI

PSI Item	Heppner and Peterson PSI – PSC	EM-PSI Item	EM-PSI – PSC
5	I am usually able to think up creative and effective alternatives to solve a problem.	5	I am usually able to think of creative and effective approaches to solve a problem.
10	I have the ability to solve most problems even though initially no solution is immediately apparent.	8	I have the ability to solve most problems, even if no solution is immediately apparent to me.
11	Many problems I face are too complex for me to solve.	9	Many problems I face regularly are too complex for me to solve without assistance.
12	I make decisions and am happy with them later	n/a	Deleted
19	When I make a plans to solve a problem, I am almost certain that I can make them work.	12	When I make a plan to solve a problem, I am almost certain that I can make it successful.
23	Given enough time and effort, I believe I can solve most problems that confront me.	15	If given sufficient time, I believe I can solve most problems without assistance.
24	When faced with a novel situation I have confidence that I can handle problems that may arise.	16	When faced with a new type of problem, I have confidence that I can handle potential difficulties.
27	I trust my ability to solve new and difficult problems.	24	I am confident that I can rely on my fundamental engineering knowledge to solve, or learn how to solve, most problems.
33	After making a decision, the outcome I expected usually matches the actual outcome.	21	After implementing a solution method for a problem, my expected outcome usually matches the actual outcome.
34	When confronted with a problem, I am unsure of whether I can handle the situation.	22	When confronted with complex problems, I am frequently unsure of whether I can solve them unassisted.
35	When I become aware of a problem, one of the first things I do is to try to find out exactly what the problem is.	n/a	Deleted.

Table 2. PC questions for the Heppner and Peterson [2] PSI and the EM-PSI

PSI Item	Heppner and Peterson PSI – PC	EM-PSI Item	EM-PSI – PC
3	When my first efforts to solve a problem fail, I become uneasy about my ability to handle the situation.	3	If my first effort to solve a problem was unsuccessful, I become unsure about my ability to solve the problem without assistance.
25	Even though I work on a problem, sometimes I feel like I am groping or wandering, and am not getting down to the real issue.	17	Frequently, when solving a problem, I feel like I am guessing or regurgitating past solutions of similar problems without understanding the underlying theory.
14	Sometimes I do not stop and take time to deal with my problems, but just kind of muddle ahead.	20	Sometimes I am overwhelmed by a problem and do not attempt to solve it unassisted.
26	I make snap judgements and later regret them.	23	If faced with a problem that I don't immediately know how to solve, I know what learning strategies work best for me.
32	Sometimes I get so charged up emotionally that I am unable to consider many ways of dealing with my problems.	25	If my first effort to solve a problem fails, I re-examine the problem and attempt it a second time using a different method.

Table 2 focuses on whether an individual re-attempts a complex problem if their original solution attempt failed. Whereas the original PSI question focuses on whether an individual can control their emotions enough to think. Most engineering problems are not emotionally taxing enough to make someone stop thinking, however they often require multiple attempts to find a good solution. The motivation behind each modification to the original PSI questions was to make the instrument more specific to engineering type problem-solving.

4.2 Groups and sampling

The survey population consisted of 73 undergraduate Civil Engineering students and engineering faculty. The survey was distributed through the Civil Engineering e-mail listserv to certified students, which are student whom have completed 60 credits of math, science, and general education coursework with a 2.5 GPA or greater. This sample population excludes all freshman and many sophomores who haven't completed the certification requirements. A sample population of

Table 3. AAS questions for the Heppner and Peterson [2] PSI and the EM-PSI

PSI Item	Heppner and Peterson PSI – AAS	EM-PSI Item	EM-PSI – AAS
2	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.	1	When I face a complex problem, I first define exactly what the problem goal(s) is.
1	When a solution to a problem was unsuccessful, I do not examine why it didn't work.	2	When a solution method to a problem was unsuccessful, I do not examine why it did not work.
4	After I have solved a problem, I do not analyze what went right or what went wrong.	4	After I have successfully solved a problem, I do not analyze what went right and what went wrong during the process.
6	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.	6	After I have attempted to solve a problem, I compare the actual outcome with my expected outcome.
7	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.	7	When faced with a new problem, I consider as many viable solution methods as possible.
8	When confronted with a problem, I consistently examine my feelings to find out what is going on in a problem situation.	n/a	Deleted
13	When confronted with a problem, I tend to do the first thing that I can think of to solve it.	10	When starting a problem, I tend to try the first solution method I think of to solve it.
15	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.	11	When deciding on a solution method, I do not consider the chances of success of each method versus the time investment required to implement each method.
16	When confronted with a problem, I stop and think about it before deciding on the next step.	n/a	Deleted
17	I generally go with the first good idea that comes to my mind.	n/a	Deleted
18	When making a decision, I weigh the consequences of each alternative and compare them against each other.	n/a	Deleted
20	I try to predict the overall result of carrying out a particular course of action.	13	I try to predict the overall outcome of carrying out a particular solution method before starting the problem.
21	When I try to think up possible solutions to a problem, I do not come up with very many alternatives.	14	If I try to think of viable solution methods, I usually do not come up with many options.
28	I have a systematic method for comparing alternatives and making decisions.	18	I have a systematic method for comparing viable solution methods to make problem-solving decisions.
30	When confronted with a problem, I do not usually examine what sort of external things my environment may be contributing to my problem.	n/a	Deleted
31	When I am confused by a problem, one of the first things I do is survey the situation and consider all the relevant pieces of information.	19	When I begin a new type of problem, I first conduct a literature survey to collect and research relevant information.

Table 4. Survey participants and demographic information

	Undergraduate				
Characteristic	**Sophomore**	**Junior**	**Senior**	**Faculty**	**Total**
Male	6	12	23	9	50 (68%)
Female	2	11	5	5	23 (32%)
Parent or Guardian is Engineer	2	4	4	n/a	10 (17%)
Parent or Guardian is not Engineer	6	19	24	n/a	49 (83%)

Table 5. Reliability for the respective study by academic level

Study Factor	Mean	SD	Min	Max	Cronbach Alpha
PSC	28.3	5.2	16	40	0.795
AAS	31.6	7.6	16	48	0.779
PC	15.2	4.4	5	25	0.742
Total EM-PSI	75.1	14.5	44	107	0.879

only Civil Engineering students, instead of all engineering students, was chosen for the pilot study to decrease the number of independent variables that could affect the EM-PSI. The survey was voluntary and could be completed only once. All Civil Engineering courses are taught in a traditional lecture or lecture plus laboratory manner, though there are of course instructional differences (i.e., no flipped or PBL courses).

Population characteristics are shown in Table 4. Of the full sample, 59 participants were undergraduate students (81%) and 14 were faculty members (19%). The class breakdown of undergraduate students was, 8 sophomores (11% of total), 23 juniors (32% of total), and 28 seniors (38% of total). 50 of the participants were male (68%) and 23 were female (32%). Of the undergraduate students, 17% had at least one parent or guardian that is an engineer. Of the faculty members, 13 had completed PhD degrees and one had completed a M.S. degree.

4.3 Internal reliability

The internal reliability of the survey was assessed using the widely utilized Cronbach's alpha, which measures inter-item correlation to scale items. A standard of 0.7 for Cronbach's alpha was used to indicate that the results were acceptably reliable [29] and all the EM-PSI subscales exceeded the minimum standard. Table 5 shows descriptive statistics and Cronbach's alpha coefficients for the EM-PSI subscales as well as the total EM-PSI for the entire survey population. Test-retest reliability was not determined for the EM-PSI, but many original PSI studies show it to be reliable [2].

5. Findings

The data was used to investigate the three research questions for this study using a Wald ANOVA analysis and post-hoc tests using the methods of Westfall [30]. The first two research questions utilized the entire sample set and the last research question only utilized the undergraduate student participants. The relationship between item scores and individual class level (faculty, senior, etc.), subscales, gender, and whether an undergraduate student had a parent that was an engineer was modeled using a generalized least squares linear model with unequal variances. The findings of the ANOVA analyses and post-hoc tests are presented in corresponding order to the research questions. The analyses were completed using R [31] and the rms package [32].

5.1 Investigating EM-PSI differences between undergraduates and faculty

The ANOVA analysis of the EM-PSI and the subscales showed that there were significant differences in subscale score by grade ($p < 0.0001$), subscale ($p < 0.0001$), and grade by subscale ($p < 0.0001$). The full ANOVA results are presented in Table 6.

The post-hoc tests examined if there were differences between grade levels within each subscale. For the PSC subscale, there was evidence that juniors were different from sophomores ($p = 0.030$), seniors were different from sophomores ($p = 0.012$), and that faculty were different from sophomores ($p = 0.009$), but that juniors, seniors, and faculty were not different from each other ($p > 0.05$ for all post-hoc tests). For the AAS subscale, there was evidence to suggest that faculty were different from all three groups of undergraduate students ($p < 0.001$), but that there was no discernable differences between the grade levels ($p > 0.05$). Lastly for the PC subscale, there was evidence that all groups are different from each other ($p < 0.01$) except for juniors and seniors ($p = 0.59$).

Table 6. Summary of Wald ANOVA statistics

Factor	Chi-Square	P
Grade level (Factor + Higher Order Factors)	116.75	< 0.0001
All interactions with Grade level	45.96	< 0.0001
Gender (Factor + Higher Order Factors)	9.13	0.1664
All interactions with Gender	8.92	0.1122
Subscale (Factor + Higher Order Factors)	2083.26	< 0.0001
All interactions with Subscale	44.87	< 0.0001
Parent engineer (Factor + Higher Order Factors)	3.02	0.3885
All interactions with Parent engineer	2.85	0.2403
Gender * Subscale	4.24	0.1200
Grade * Gender	4.39	0.2224
Grade * Subscale	41.46	< 0.0001
Subscale * Parent engineer	2.85	0.2403
TOTAL INTERACTION	49.63	< 0.0001
TOTAL	2241.67	< 0.0001

5.2 Investigating EM-PSI differences between genders

The ANOVA analysis determined that there was no significant difference in subscale score between gender or any higher order interaction with gender (p = 0.17). Higher-order interactions include any combination of subscale score, class status, and gender. In other words, there is no statistically significant difference between the difference in student AAS score and faculty AAS score versus female student AAS score and female faculty AAS score versus male student AAS score and male faculty AAS score.

5.3 Investigating undergraduate EM-PSI differences versus parent profession

The ANOVA analysis determined that there was no significant difference in subscale score between undergraduate students with or without parents that are engineers or any higher order interaction with parents being engineers (p = 0.39). Again, higher-order interactions include any combination of subscale score, class status, and parents either being or not being engineers.

6. Discussion

The motivation behind developing the EM-PSI was to provide faculty with a quantitative metric for student appraisal of their problem-solving ability. The EM-PSI is based on the Heppner and Peterson [2] problem solving inventory (PSI), which explores the underlying dimensions of problem-solving. The Heppner and Peterson [2] PSI was modified to investigate the underlying dimensions of technical problem solving for engineers and was called the engineering modified problem solving inventory (EM-PSI). It was assumed that the three subscales for the PSI, problem-solving confidence (PSC), approach-avoidance style (AAS), and personal control (PC), would remain consistent to the EM-PSI.

Table 7 displays the mean and standard deviation of the EM-PSI scores of the undergraduate students and faculty. The statistical analysis results concluded that there was a difference in EM-PSI score and subscale scores between faculty and the undergraduate students. Results were not uniform regarding if there were significant differences between class levels, but it did seem that sophomores were significantly different from juniors, seniors, and faculty. This result, that sophomores lag behind upperclassmen in problem-solving ability, is in agreement with the Larson et al. [22] study on university students utilizing Heppner and Petersons [2] PSI. One possibility for this, is that sophomores are still relatively new to critical problem solving. Many have just finished the freshman coursework, which is dominated by general education and math courses, and are currently in their first semester of Civil Engineering courses. By completion of their sophomore year, it appears that their appraisal of their problem-solving skill increases.

Another big difference in EM-PSI score is between juniors and seniors and faculty, which was expected and lend credibility to the EM-PSI as being a good judge of problem-solving ability. Interestingly, the variation (standard deviation) in faculty scores was also smaller than for undergraduate students, even though the age and experience of the faculty ranged more than 30 years (youngest assistant professors were in late-20's and oldest professors are in mid-60's). Faculty having greater

Table 7. EM-PSI results for undergraduate students and faculty, max score is 125 and higher is better self-appraisal of problem-solving ability

Grade Year	Number	Mean	Std. Dev.
Sophomores	8	57.5	11.1
Juniors	23	71.4	11.2
Seniors	28	74.9	12.0
Faculty	14	91.5	9.9

Table 8. EM-PSI subscale score results for undergraduate students and faculty

		PSC (max 45)		AAS (max 55)		PC (max 25)	
Grade Year	**Number**	**Mean**	**Std. Dev.**	**Mean**	**Std. Dev.**	**Mean**	**Std. Dev.**
Sophomores	8	22.6	5.2	25.4	5.4	9.5	2.9
Juniors	23	28.0	4.6	29.2	5.0	14.2	3.9
Seniors	28	29.4	5.4	30.4	6.7	15.1	3.3
Faculty	14	30.0	4.1	41.4	5.8	20.1	2.7

engineering experience than undergraduate students and greater EM-PSI score, could suggest that as engineering experience increases, so does an individual's appraisal of their problem solving ability.

Table 8 further breaks down the EM-PSI scores and presents the mean and standard deviation of each subscale for the undergraduate students and faculty. It can be seen that the largest difference in subscale scores between students and faculty were for the AAS and PC subscales. Juniors and seniors average PSC scores were not significantly different from faculty, leading to the conclusion that their appraisal of their technical abilities is high closer to graduation. It is important to remember that PSC measures *perception* of problem-solving confidence, not actual technical ability. In this light, the PSC subscale scores are encouraging and could be interpreted to mean that the upper level engineering curriculum is providing students with confidence in their technical abilities.

The benefit of utilizing the EM-PSI can be demonstrated by analyzing the differences in undergraduate student and faculty scores for the AAS and PC subscales. These two subscales are not measured using typical assessments (i.e., written tests), but are important underlying dimension of problem-solving ability. Based on average AAS score, faculty are approximately 33% more willing to approach complex problems than junior and senior students. Likewise, faculty exhibit greater self-control while solving problems. These results could be utilized to inform pedagogical interventions because it leads to a conclusion that confidence in solving-problems is not lacking, but the willingness to approach and preserve through solving complex problems needs greater attention. The long-term goal of the EM-PSI tool would be the ability for a Department to track subscale score for a given class year, i.e., AAS score of seniors, and determine how pedagogical and curricular interventions change the average score. A hypothetical example would be determining if introducing more problem-based learning courses at the junior level increases the AAS and PC subscale scores of subsequent senior level classes over the next five to eight years.

7. Conclusions

The EM-PSI was validated through an initial pilot study involving 73 undergraduate Civil Engineering students and engineering faculty. The internal reliability of the EM-PSI and its subscales were deemed acceptable using Cronbach's alpha coefficient. The Cronbach's alphas for PSC, AAS, and PC were 0.795, 0.779, and 0.742, respectively. The statistical analysis that addressed the first research question showed that there were significant differences in EM-PSI score and subscale scores between undergraduate students and faculty ($p < 0.0001$). Additionally, post-hoc tests showed that among undergraduate students, sophomores seemed to lag significantly behind juniors, seniors, and faculty in most dimensions of problem-solving. The statistical analysis also addressed the second and third research questions by determining that there were no significant differences in EM-PSI score and subscale scores between students of different gender or students who had engineer parents and those who did not.

Post-hoc analysis of the average EM-PSI score and subscale scores showed that the largest differences between undergraduates and faculty were in approach-avoidance style (AAS) and person control (PC). An example of how the EM-PSI could be used to influence classroom curriculum was presented as interpreting the data to mean that greater emphasis should be placed in junior and senior level courses on improving students willingness to attempt (approach) complex problems. Furthermore, the PSC subscale increases between sophomore, junior, and senior students, suggests that the current curriculum builds confidence in students ability to successfully solve technical problems. Both of these curricular modifications would need to be monitored with outcome-based metrics, such as GPA, test scores, or Fundamental of Engineering exam pass rates, as well as the EM-PSI to ensure that student perception of their ability aligns with their actual learning outcomes.

The implication for engineering instruction and practice is that the EM-PSI can be utilized by faculty to assess student perceptions of their problem-solving abilities. If used in conjunction with other data, such as test scores and GPA, it provides a way to longitudinally track how the curriculum is improving student problem-solving confidence and willingness to engage difficult problems. Development of the EM-PSI is still in its infancy and this study presents an initial validation using a pilot study on Civil Engineering students at one large U.S. University. Additional research is needed to further validate the EM-PSI with larger groups of students, at different Universities with different cultures, and for diverse engineering majors. Never the less, the EM-PSI has the potential to become a useful tool for engineering Departments seeking to collect data to improve their curriculum and learning experience.

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References

1. Accreditation Board for Engineering Technology (ABET), *Criteria for Accrediting Engineering Programs*, ABET, Baltimore, MD, 2018.
2. P. P. Heppner and C. H. Petersen, The development and implications of a personal problem solving inventory, *Journal of Counseling Psychology*, **29**, pp. 66–75, 1982.
3. R. Clarke, H. B. Gelatt and L. Levine, A decision-making paradigm for logical guidance research, *Personnel and Guidance Journal*, **44**, pp. 40–51, 1965.
4. J. Dewey, *How we think*, Heath, New York, NY, 1933.
5. R. M. Gagne, Problem solving, in A. W. Melton (ed), *Categories of human learning*, Academic Press, New York, NY, 1964.
6. N. J. McNeil, E. P. Douglas, M. K. Ljunberg, D. J. Therriault and I. Krause, Undergraduate students' beliefs about engineering problem solving, *Journal of Engineering Education*, **105**(4), pp. 560–584, 2017.
7. E. P. Douglas, M. K. Ljunberg, N. J. McNeil, Z. T. Malcolm and D. J. Therriault, Moving beyond formulas and fixations: solving open-ended engineering problems, *European Journal of Engineering Education*, **37**(6), pp. 627–651, 2012.
8. D. L. Butler, Individualizing instruction in self-regulated learning, *Theory Into Practice*, **41**(2), pp. 81–92, 2002.
9. S. E. Shadle, E. C. Brown, M. H. Towns and D. L. Warner, A rubric for assessing students' experimental problem-solving ability, *Journal of Chemical Education*, **89**, pp. 319–325, 2012.
10. P. P. Heppner, T. E. Witty and W. A. Dixon, Problem-solving appraisal and human adjustment: A review of 20 years of research using the problem solving inventory, *Counseling Psychologist*, **32**, pp. 344–428, 2004.
11. M. J. Heppner, D. G. Lee, P. P. Heppner, L. C. McKinnon, K. D. Multon and N. C. Gysbers, The role of problem-solving appraisal in the process and outcome of career counseling, *Journal of Vocational Behavior*, **65**, pp. 217–238, 2004.
12. L. M. Larson, P. P. Heppner, T. Ham and K. Dugan, Investigating multiple subtypes of career indecision through cluster analysis, *Journal of Counseling Psychology*, **35**, pp. 439–446, 1988.
13. L. Nota, P. P. Heppner, S. Soresi and M. J. Heppner, Examining cultural validity of the problem-solving inventory (PSI) in Italy, *Journal of Career Assessment*, **17**(4), pp. 478–494, 2009.
14. L. Y. Flores, L. Ojeda, Y. P. Huang, D. Gee and S. Lee, The relation of acculturation, problem-solving appraisal, and career decision-making self-efficacy to Mexican American high school students' educational goals, *Journal of Counseling Psychology*, **53**, pp. 260–266, 2006.
15. T. R. Elliott, F. Godshall, J. R. Shrout and T. E. Witty, Problem-solving appraisal, self-reported study habits, and performance of academically at-risk college students, *Journal of Counseling Psychology*, **37**, pp. 203–207, 1990.
16. P. P. Heppner and T. S. Krieshok, An applied investigation of problem-solving appraisal, vocational identity, and career service requests, utilization, and subsequent evaluations, *The Vocational Guidance Quarterly*, **31**, pp. 240–249, 1983.
17. Y. Huang and L. Y. Flores, Exploring the validity of the problem-solving inventory with Mexican American high school students, *Journal of Career Assessment*, **19**(4), pp. 431–441, 2011.
18. H. A. Neville, P. P. Heppner and L. Wang, Relations among racial identity attitudes, perceived stressors, and coping styles in African American college students, *Journal of Counseling and Development*, **75**, pp. 303–311, 1997.
19. N. Kourmousi, V. Xythali, M. Theologitou and V. Koutras, Validity and reliability of the problem solving inventory (PSI) in a nationwide sample of Greek educators, *Social Sciences*, **5**(25). 2016.
20. N. Sahin, N. H. Sahin, and P. P. Heppner, Psychometric properties of the problem solving inventory (PSI) in a group of Turkish university students, *Cognitive Therapy and Research*, **17**, pp. 379–396, 1993.
21. D. R. Woods, Problem solving skills, in *Problem-based Learning: How to Gain the Most From PBL*, W.L. Griffin, Waterdown, ON, 1994.
22. D. Larson, D. R. Scott, M. Neville, and B. Knodel, Measuring student's confidence with problem solving in the engineering design classroom, *Proc. of the ASEE Annual Conference*, Seattle, WA, June 28 –July 1, 1998.
23. S. G. LoBello, Test review of the problem solving inventory, in J. J. Kramer and J. C. Conoley (eds), *The Eleventh Mental Measurements Yearbook*, Buros Center for Testing, Lincoln, 1992.
24. P. P. Heppner, M. Kampa and L. Brunning, The relationship between problem-solving self-appraisal and indices of physical and psychological health, *Cognitive Therapy and Research*, **11**, pp. 155–168, 1987.
25. J. B. Rotter, Generalized expectancies for problem solving and psychotherapy, *Cognitive Therapy and Research*, **2**, pp. 1–10, 1978.
26. L. Butler and D. Meichenbaum, D. The assessment of interpersonal problem-solving skills, in P. C. Kendall and S. D. Hollon (eds), *Assessment Strategies for Cognitive-Behavioral Interventions*, Academic Press, New York, NY, pp. 197–225, 1981.
27. P. P. Heppner and Y. W. Wang, Problem-solving appraisal and psychological adjustment, in C. R. Snyder and S. J. Lopez (eds), *Oxford Handbook of Positive Psychology*, 2nd edn, Oxford University Press, New York, NY, pp. 127–138, 2009.
28. A. Yadav, V. Alexander and S. Mehta. Case-based Instruction in Undergraduate Engineering: Does Student Confidence Predict Learning?, *International Journal of Engineering Education*, **35**(1A), pp. 25–34, 2019.
29. J. A. Gliem and R. R. Gliem, Calculating, interpreting, and reporting Cronbach's alpha reliability coefficient for Likert-type scales, *Proc. of the Midwest Research to Practice Conference in Adult, Continuing, and Community Education*, Columbus, OH, October 8–10, pp. 82–88, 2003.
30. P. H. Westfall, Multiple testing of general contrasts using logical constraints and correlations, *Journal of American Statistical Association*, **92**, pp. 299—306, 1997.
31. R Core Team, R: A language and environment for statistical computing, R Foundation for Statistical Computing, https://www.R-project.org/, Vienna, Austria, 2018.
32. F. E. Harrell Jr., rms: regression modeling strategies, R package, version 5.1-2. https://CRAN.R-project.org/package=rms. 2018.

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