Promoting Problem Solving Proficiency in First Year Engineering: PROCESS Assessment

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Abstract

The goal of this study is to enhance research-based practice in engineering education by evaluating the PROCESS assessment tool as a grading rubric in a coordinated first year engineering course. PROCESS is an acronym for a 7-stage model of problem solving: **P**roblem definition, **R**epresenting the problem, **O**rganizing information, **C**alculations, **E**valuating the solution, **S**olution communication, and **S**elf-assessment. Six assignments were graded with the PROCESS rubric throughout the semester. At the end of the semester, students (n=341), instructors (n=7), and graders (n=5) completed surveys about their perceptions of the course and PROCESS. Student perceptions were modestly positive and performance data indicated students were able to improve their assignment performance in the course, especially for students with average overall grades. Instructors and graders see potential in the PROCESS rubric, and provided insight into improving the tool. This investigation is instrumental to the improvement of students' problem solving skills by focusing on the process as well as the final solution. Conducting assessment using a validated problem solving assessment tool will make it possible to track learning gains through the strategic utilization of standardized data analytics.

Introduction

Problem solving is a critical skill for engineering students to master, and is therefore a primary issue in engineering education. Problem solving instruction has been approached in methodical ways for decades[1,2]; however, feedback on problem solving is typically provided through outcome-based grading, such as the final solution accuracy, rather than assessing the process used to arrive at the solution. Providing feedback on how well students are developing important skills requires a different form of assessment that examines cognitive processes and discrepancies in solution paths. Process-based analysis examines methods and systems to identify weak points in the process[3] and can also be used to assess efficiency of processes. Assessing the process by which a student arrives at an answer can uncover skills deficiencies and has the potential for significant improvement in student learning gains. However, providing such feedback can be time- and labor-intensive; a systematic approach may help reduce the effort required by instructors and graders to give meaningful feedback to students.

This research evaluates a multi-instructor implementation of the Problem Solving PROCESS assessment tool as a grading rubric in a first year engineering course. This course introduces first year engineering students to the knowledge and problem solving skills that form the foundation of all engineering disciplines. The course is taught by ten different instructors, seven of whom participated in the pilot implementation. These instructors gave the same six engineering problems to students to solve by hand. Graduate teaching assistants graded problem solutions using the PROCESS rubric for six problems. These problems were specifically chosen for use with the PROCESS rubric because they were complex enough to require decision-making to answer but had pre-defined elements to limit possible solutions to a finite set. Students also had assignments that were completed using a digital homework manager which were automatically scored based on solution accuracy. Students, instructors, and graders completed surveys about different learning tools that were utilized throughout the course and more detailed questions about the PROCESS rubric. This evaluation looks at variations in survey responses based on student performance in the class as well as variation in perceptions of students, instructors, and graders regarding performance improvements and use of the PROCESS rubric.

Literature Review

Teaching problem solving to first year engineering students presents several challenges. Students enter the engineering program through a variety of routes, so, capabilities and prior knowledge vary greatly from student to student. When prior conceptual knowledge is lacking or inappropriate, rote learning or memorization may occur, which involves retention with little or no comprehension or transferability[4]. This implies that even if the student learns engineering concepts, they may be unable to apply those concepts in their problem solving attempts. Novice problem solvers often employ weak, self-defeating strategies. For instance, they often jump into solving word problems or manipulating datasets immediately by plugging numbers into equations with little focus of planning[5]. Given enough time, students may successfully solve problems through inefficient methods, such as using a “plug and chug” approach or “pattern matching” based on previously completed work with little understanding as to whether the solution approach is appropriate[6]. Lack of awareness of performance errors has been shown to be a major impediment for novice problem solvers[5].

Innovative approaches to teaching problem solving skills have the potential of appealing to a broader range of students in engineering[7]. “Traditional pedagogical methods, such as requiring students to find information independently, assume a basic competency that not all students possess”[7]. Thus effective instruction that explicitly addresses problem solving skills that are relevant to engineering practice has the potential to engage students with diverse experiences and interests. However, as with any new innovation, with change comes the risk of alienating those who prefer traditional approaches.

Problem Solving PROCESS Assessment Tool

The Problem Solving PROCESS assessment tool was developed in an initiative to promote the development of problem solving skills[8–10]. This innovative assessment tool was developed from a study on tasks and errors associated with successful problem solving attempts[11–17]. The resulting taxonomy was utilize to create an assessment tool that serves too functions[18]. On the instructional side, PROCESS works as a visual primer, suggesting the use of tasks that have been shown by previous research to be correlated with higher rates of correct solutions. On the assessment side, PROCESS is used to evaluate the quality and accuracy of the solution and identify errors committed. The tool has been tested and refined in several engineering courses, though this was the first multi-class study implementation where instructors (except one who taught one section) had not been involved in the development of the assessment tool.

PROCESS is an acronym for seven stages of problem solving: **P**roblem definition, **R**epresenting the problem, **O**rganizing information, **C**alculations, **E**valuating the solution, **S**olution communication, and **S**elf-Assessment. PROCESS was offered to faculty as a learning aid they could use in the first year engineering courses to focus on developing engineering problem solving skills. Figure 1 depicts PROCESS as described to instructors before when deciding whether to utilize it in their classes.

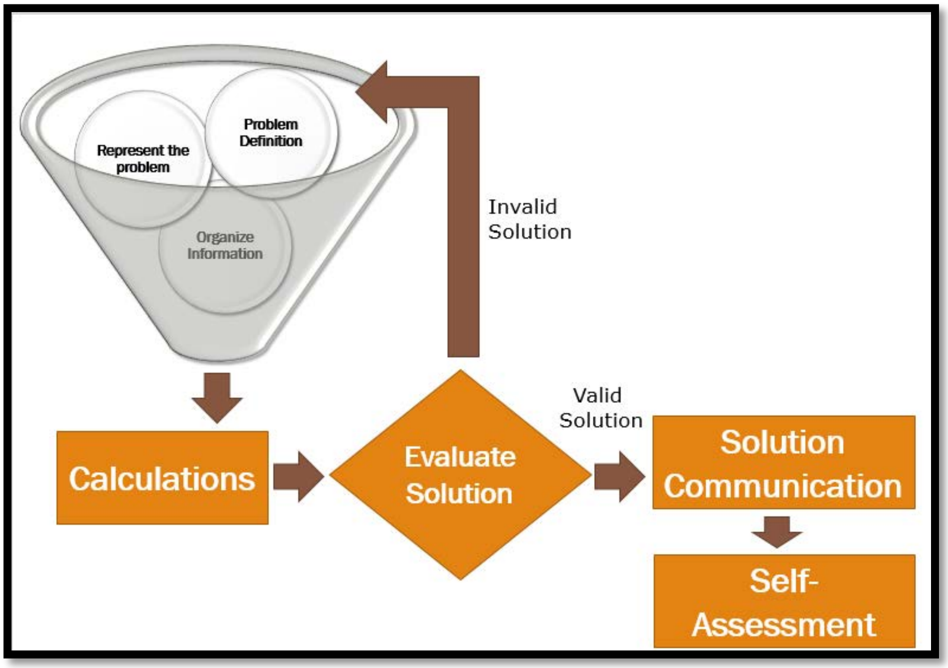

Figure 1: Problem Solving PROCESS. Start with conceptualizing the problem (PRO), then complete Calculations and Evaluate the solution for reasonableness and accuracy (CE) before communicating the solution (S). Finally, reflect on the process through self-assessment (S).

Data Collection Methods

Faculty were not required to use PROCESS in their classes and the level of integration of the PROCESS problem solving structure into classroom lectures varied across instructors. Before the semester started, faculty were provided with Figure 1, the PROCESS rubric, and a comprehensive user guide complete with code definitions and grading examples to help them determine whether they wanted to utilize PROCESS in their classroom instruction as a problem solving structure. In addition, all course sections were assigned a graduate teaching assistant that participated in a four-hour interactive training session on grading with the PROCESS rubric. While faculty were encouraged to attend this training session, none attended. Therefore faculty training was limited to self-study of the resources or through direct questions as they needed clarification. PROCESS was voluntarily implemented in 18 of 24 (75%) of the sections of the first year engineering course.

At the end of the term, students were surveyed about their experience in the course and the PROCESS rubric through course evaluations. Survey responses were collected from 12 of the 18 course sections in which PROCESS was implemented. Data from the other 6 sections was lost due to survey implementation errors on two of the instructor's course sites. In total, this analysis includes responses from 341 out of 616 students (55.5% response rate) enrolled in 12 course sections taught by 6 different instructors using PROCESS. This sample of students was used to evaluate the student learning outcomes and perceptions of the course and the PROCESS rubric. Instructors and graders completed a similar survey about the PROCESS rubric. Seven instructors and 5 graders completed the survey.

Sample Population

The distribution of final course grades of student survey respondents was representative of the distribution found overall. The sample population has a slightly higher response rate from students earning A or B grades and a slightly lower response rate from students earning D or F grades. As illustrated in Table 1, the sample appears to be a fair representation of the population based on course performance. No other factors were evaluated to determine differences between the sample and population groups.

Table 1: Distribution of student survey respondents to the overall number of students

Grade	*Student survey respondents (n=341)*	*Total number of students (n=1329)*	*percent difference*
A	112	379	+4%
B	144	488	+6%
C	76	298	0%
D	7	87	-4%
F	3	77	-5%

Results

Survey items were evaluated based on the sample, then by groups based on final course grade. Surveys for students earning D or F grades were not evaluated separately because their sample sizes were too small. The descriptive statistic included in Table 2 was created by multiplying the proportion of responses for each response by the response value on a scale from 1-5 with 5 being strongly agree, 4, being agree, 3 being neither agree nor disagree, 2 being disagree 1 being strongly disagree. Table 2 contains descriptive statistics for the survey responses from students.

In general students agreed that their problem solving performance and documentation improved over the semester. However, students were reluctant to credit the Problem Solving PROCESS with the improvement. In general students rated the PROCESS rubric as slightly above neutral on all items. The most interesting finding was that there was a good bit of variation between the A cohort and the C cohort on several items. The C cohort had much higher ratings than the A cohort for the item rating the effectiveness of PROCESS as a learning tool (3.7 to 3.3 respectively). A similar trend was evident for whether PROCESS was a useful structure for communicating solutions to engineering problems (3.8 to 3.3 respectively), whether it was easy to understand (3.5 to 3.1 respectively), whether it provided valuable feedback (3.6 to 3.2 respectively), and whether the self-assessment improved metacognition of problem solving skills (3.5 to 2.8 respectively). The C cohort also indicated a stronger likelihood of using the PROCESS structure in future classes (3.6 to 2.9 respectively).

Table 2: Summary of weighted scores of survey item responses grouped by performance level as determined by final grade in the course (A cohort = students earning an "A" in the course, etc.)

Survey Items	Overall	A cohort	B cohort	C cohort
My problem solving performance has improved	4.2	4.1	4.3	4.3
My problem solving documentation has improved	4.1	4.1	4.2	4.1
The problem solving PROCESS is a useful structure for communicating solutions to engineering problems	3.5	3.3	3.4	3.8
The problem solving PROCESS rubric was easy to understand	3.3	3.1	3.3	3.5
PROCESS rubric provided valuable feedback	3.3	3.2	3.3	3.6
I used the PROCESS to check my work before submitting it	3.4	3.3	3.5	3.4
I will use the PROCESS in future classes	3.2	2.9	3.3	3.6
The self-assessment made me more aware of my problem solving skills	3.1	2.8	3.2	3.5
PROCESS feedback on written assignments was effective as a learning aid	3.5	3.3	3.5	3.7

When student responses were compared to instructor and grader responses, several variations emerged. Instructors and graders recognized the structure of the PROCESS tool as being useful for communicating engineering problem solutions (4.6 for instructors, 4.5 for graders, 3.5 for students). Instructors also recognized the value in the PROCESS rubric feedback (4.3 for instructors, 3.0 for graders, 3.3 for students). Table 3 compares the weighted scores for survey responses from students, instructors, and graders.

Table 3: Summary of weighted scores by role in the course

Survey Items	Students	Instructors	Graders
My problem solving performance has improved	4.2	4.1	4.0
My problem solving documentation has improved	4.1	4.0	4.2
The problem solving PROCESS is a useful structure for communicating solutions to engineering problems	3.5	4.6	4.4
The PROCESS rubric was easy to understand	3.3	3.4	3.4
The PROCESS rubric provided valuable feedback	3.3	4.3	3.2
I will use the problem solving PROCESS in future classes	3.2	3.9	4.0

Several instructors and graders commented on the pros and cons of the PROCESS rubric. It was evident from the comments that instructors and graders saw potential in the PROCESS rubric and reported observations that mimic the findings shown in Table 2.

"At its core, I think the PROCESS rubric is a great idea. The challenge is getting graders to provide sufficient feedback." ~ Instructor

"I LOVE the PROCESS and it helped the 'middle ground' students improve greatly. In the higher ability students they complain about having to write out each step as it slows them down." ~ Instructor

"The PROCESS rubric is a great tool for young engineering students. I found that it made me think a little bit about my own homework and test problems" ~ Graduate Student Grader

Instructors and graders identified several potential ways of improving the implementation of the PROCESS structure into the course, improving the form design, and suggestions for turning the form electronic for enhanced course assessment and progress monitoring of student performance.

"The students would benefit even more if they were able to start on a better foot. I'm not sure it was stressed enough how important the structure and organization was. I could tell from grading that many students just didn't read the rubric. That being said, I could tell who the students were that were trying hard and saw clear improvement in those who put forth the effort!" ~ Graduate Student Grader

"The PROCESS rubric was a great tool in making the overall grading process more standardized, but it was a little hard to understand at first and a few categories seem repetitive. The confusion becomes less and less over time, and the initial confusion is outweighed by the advantages that standardization provides." ~ Graduate Student Grader

"I would like to see a little bit of reweighting of points. I feel like the PRO steps could be scored as a unit since they all serve the planning function. On the same note, ES may be good to group together since they are both metacognitive too. It just seems these steps should not each weigh as much as Calculations since those are all the cognitive tasks." ~ Instructor

An ad hoc analysis of assignment grades was conducted to see if there was any evidence to support the finding echoed by both faculty and graders that the PROCESS structure and rubric were most beneficial to C students than to A students. Linear regressions were used to model the progression of PROCESS rubric scores for the sample and A, B, and C cohorts. Linear trendlines were generated to illustrate the improvement on problem solving performance over time for the different groups. (Scores were converted from a 20 point scale to a 100 point scale.) Students from the C cohort exhibited a more rapid improvement rate (4.1% per assignment compared to 1.6% per assignment for the A cohort). While there is a trend that shows a larger rate of improvement in assignment scores for C cohort students, several factors influence this information. Scores for all groups of students trend toward 100 over time so incremental improvement will reduce over time. The larger rate of improvement seen in the C cohort of students may simply be attributed to having more opportunity for improvement as students earning lower final grades started with a lower average grade on the first assignment (69.7 to 81.7 respectively). This trend may also represent an improvement in documentation of problem solving and/or an improvement in problem solving ability. A longitudinal study or follow up interview could provide more insight into what conclusions can be drawn from this information.

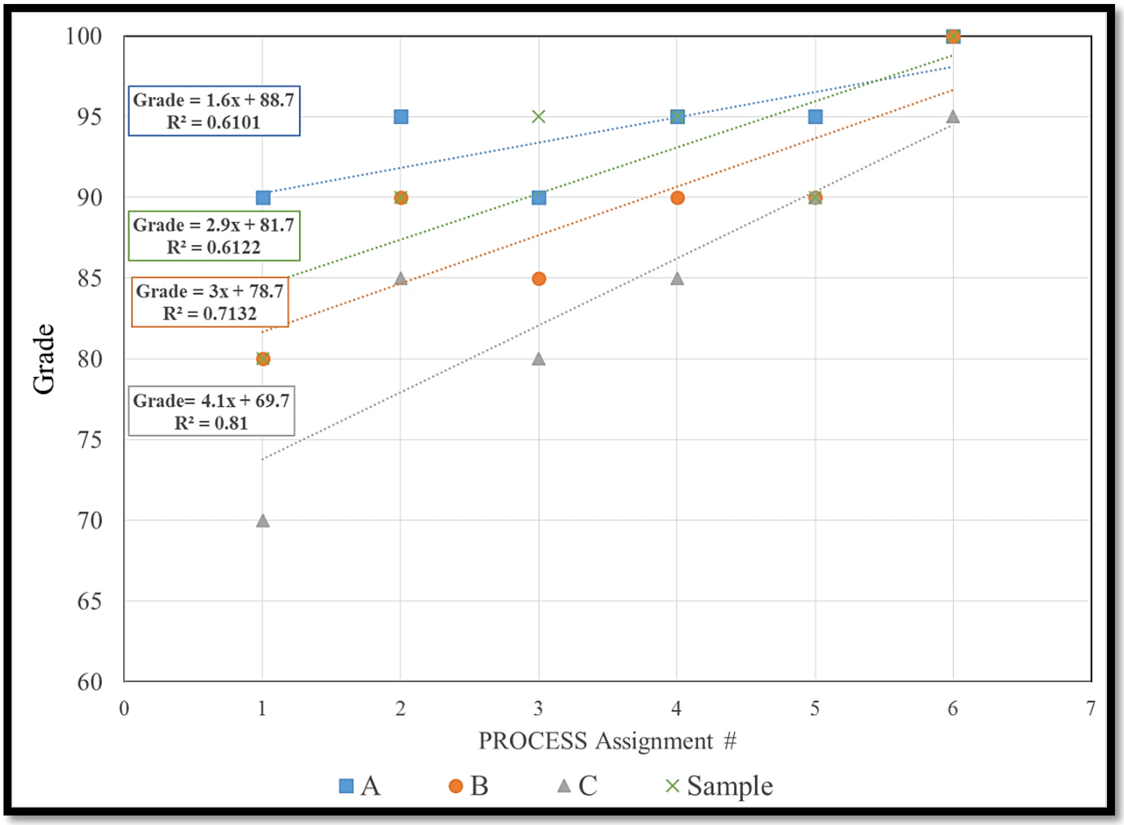

Figure 2: This graphic compares the incremental improvement on PROCESS assignments over time for the student sample as well as students of various performance levels (A, B, and C)

Discussion

While the perceptions of the PROCESS rubric by students, instructors, and graders were moderately favorable, some insights can be drawn from the variations seem in the data analysis. The PROCESS rubric needs further refinement to make the tool easier for students to understand and enable better methods of providing and interpreting feedback. The standardized grading method does have several positive aspects such as encouraging consistent assessment across students and assignments. However, it seems that the students were not able to grasp the full benefits of the PROCESS rubric as a learning tool because they associated it only as a grading rubric and disregarded it as something that graders would use, not the students. If instructors spent a little more time presenting PROCESS as a learning tool at the start of the semester, it may promote the adoption of the PROCESS as a structure to use during the solution attempt.

In addition, variations in survey responses and performance between high performing students and average performing students presents a challenge for marketing the use of the PROCESS tool. Low performing students seemed to embrace the PROCESS more than high performing students. Other factors may influence this phenomenon such as the students' motivation for completing assignments and the difficulty of the problems. If students feel like they can do the work in their head instead of writing it down, they may value the PROCESS structure less than if they were challenged beyond their comfort zone. These are important things to consider for future use.

Conclusions and Implications for Practice

The use of the PROCESS assessment tool as a grading rubric in a first year engineering program had mixed results. The most beneficial aspect of the PROCESS rubric was the standardized and consistent method for evaluating students' problem solving performance. Student perceptions of the PROCESS rubric were not overwhelmingly positive, though there was a modest positive correlation both based on self-report data and assignment score trends. It appears that the PROCESS rubric is a good tool for average students but may be less useful or even impeding for high performing students.

Future implementation of the Problem Solving PROCESS will include more instructor and student training on the PROCESS rubric, how to use the rubric throughout the problem solving attempt, and how to interpret graded feedback. Instructors will also be encouraged to utilize the PROCESS structure regularly in class during student problem solving challenges and instructor review of the solutions. The PROCESS rubric will also be refined to make it easier to understand without needing to rely on the user guide when grading or reviewing the assessment. Once structural refinements are made, initiatives will evaluate the feasibility of converting the PROCESS rubric from the current paper version to a means of capturing data electronically and provide for real time tracking of PROCESS score as a proxy for assessing learning gains in problem solving.

Ongoing research will evaluate the use of the tool in educational environments of varying complexity such as a K-12 math course and a third year bioengineering course to determine the reasonableness of using the PROCESS rubric in different student populations. A multi-institution implementation of the PROCESS rubric in various course levels is also planned.

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