2026 ASEE ANNUAL CONFERENCE June 21–24, 2026 | Charlotte Convention Center, NC

Host Sponsor UNC Charlotte

Paper ID #53980

NSF IUSE: Metacognitive Intervention to Improve Problem Solving Skills in First-Year Engineering Students

Dr. Lizzie Santiago, West Virginia University

Dr. Lizzie Santiago is a Professor and Director of the Fundamentals of Engineering Program in the Benjamin M. Statler College of Engineering and Mineral Resources at West Virginia University. She holds a Ph.D. in Chemical Engineering and has postdoctoral training in neural tissue engineering and molecular neurosciences.

Adam Adam Ogunjembola, West Virginia University
Mr. Michael Keith Brewster, West Virginia University
Jake Follmer, West Virginia University

Dr. Jake Follmer is an Assistant Professor (Educational Psychology) in the College of Applied Human Sciences at West Virginia University. He teaches courses related to quantitative methods, applied statistical analysis, and self-regulated learning. His research examines methods of promoting learning strategy use and success among students traditionally underrepresented in postsecondary education.

NSF IUSE: Metacognitive Intervention to Improve Problem Solving Skills in First-Year Engineering Students

Introduction

Metacognition involves the ability to apply appropriate learning strategies in conjunction with knowledge of the task and context to plan, monitor, and evaluate one's thinking and strategies. Zimmerman's theory links metacognition with self-regulated learning (SRL) through a three-phase model describing how learners regulate their learning processes across forethought, performance, and reflection [1]. During the forethought phase, students set goals and plan their approach. In the performance phase, learners implement strategies and monitor their progress. In the reflection phase, learners evaluate outcomes, identify what was effective or ineffective in their learning efforts and strategies, and adjust strategies accordingly. Together, these phases promote active engagement in learning with the goal of promoting and sustaining strategic learning and academic success. It has been documented that students with strong metacognitive skills tend to demonstrate significantly better academic performance and learning outcomes, across a range of academic domains including engineering [1, 2].

This paper presents the results of a study that implemented a metacognitive intervention aimed at enhancing problem-solving skills among first-year engineering students. The study examined (a) the role of the intervention in developing students' metacognitive skills and (b) whether improvements in metacognitive accuracy were associated with gains in problem-solving performance. The findings may benefit academic institutions seeking effective approaches to improving student academic performance and learning strategies, particularly for first-year students or in programs that aim to promote interest and retention in foundational engineering curricula.

Methodology

This project was conducted at a public research institution in the Mid-Atlantic region of the United States. In this study, ninety-six first-year engineering students enrolled in College Algebra at the time of the study were co-enrolled in an engineering problem-solving course. Since these students are enrolled in a first-year engineering program, they have not yet declared a major. Multiple sections of the course were taught; one of the sections served as the experimental group (G1) and the other section served as the active control group (G2). A metacognitive intervention was embedded in the experimental group (G1) that consisted of three lectures on self-regulation, metacognition, and study skills, and weekly practice of word problems in which self-reflective prompts were embedded in each problem. For the active control group (G2), the students were enrolled in the course in which weekly word practice problems were completed without self-reflective prompts. Custom-designed word problems integrating algebra and engineering concepts were used throughout the course. In the control group (G2), students did not receive lectures on metacognition and self-regulation. The students in the control group solved the same word problems as the experimental group, without the inclusion of reflective prompts in the problems completed in class or in the homework.

Two exams were completed by both control and experimental groups, each consisting of multiple word problems that integrated mathematical and engineering problem-solving with reflective prompts embedded in the exams. The prompts asked students to reflect on the accuracy of their solutions and to indicate why they rated their accuracy at a given level.

For each problem, metacognitive accuracy was calculated by comparing the student's confidence judgment to their actual performance. All word problems (from homework and from the exams) were graded, and the accuracy of the learner's judgement (AJ) was calculated using the equation, AJ= |score as a fraction - confidence as fraction|. If the AJ score was below or equal to 0.25, the judgement was accurate. If the AJ score was between 0.26 and 0.5, the judgement was somewhat inaccurate. If the AJ score was greater than 0.5, the judgement was considered as inaccurate. Thematic analysis was used to examine qualitative responses to the reflective prompts, identifying specific aspects of problem-solving that students found challenging. The study was approved by the Institutional Review Board.

Results

For each problem, the investigators evaluated the accuracy of students' judgments. Figure 1 shows the distribution of judgment accuracy for students in the experimental group (G1) and the control group (G2) for one of the problems completed. This problem illustrates the differences observed in the judgement accuracy between the experimental and control groups.

> *Technetium-99m has a half-life of almost exactly 6 hours. A technician prepares a sample of this radioactive material to image the heart of a patient suspected of having a mild heart*

attack. At noon, the patient is given 10mCi (millicuries) of Technetium-99m. Write a function to model the radioactivity level (Q) as a function of time. How much radioactive material will remain from the heart scan in ten hours?

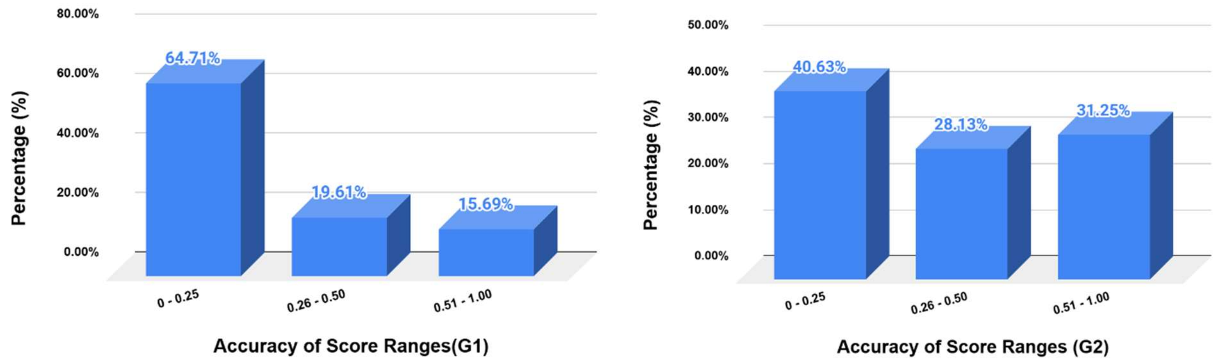

Figure 1. Accuracy scores for one of the problems. G1 represents the experimental group and G2 represents the control group.

Thematic analysis was also used to identify areas of concern during problem solving.

Table 1. Thematic analysis was used to identify areas of concern during problem solving.

Main Category	**Item**	**Code**
Student statement is not clear; information not clear	Vague	Vague
Problem Solving	Problems understanding the statement of the problem	Statement
	Problems remembering the equations or formulas or theory to use (Declarative Knowledge - factual information)	Formulas
	Problem translating the problem statement into an equation	Equation
	Procedure / math procedure could be wrong (Procedural Knowledge - how to)	Procedure
	Answer: Student checked the answer (and seems correct or not)	Answer correctness
	Answer: Solution does not make sense (solution not checked)	Answer make sense
	Conditional Knowledge: Student knows the theory (declarative) and the procedure (procedural), but have issues determining when to apply those (conditional)	Conditional
Personal reasons	Student was tired	Tired
	Test Anxiety	Anxious
	Nervous	Nervous
	Did not study enough	Study

For all problems analyzed, thematic analysis confirmed that most students (60-75%) experienced difficulties in: a) statement: understanding the wording or meaning of the word problem; b) procedure: errors in applying the correct engineering and mathematics procedures, indicating challenges with procedural knowledge.

Table 2 summarizes descriptive statistics for the measures of problem-solving performance and calibration accuracy. Scores on the measures demonstrated approximate normality and variability based on condition. Students completing the metacognitive reflection intervention obtained a post-course score on the assessment of applied problem-solving (*M*=0.70) that was 0.14 points higher than those in the control condition (*M*=0.56; Cohen's *d*=-0.64), and obtained a score on the measure of calibration accuracy (*M*=0.22) that was 0.06 points lower - indicating greater accuracy in their monitoring during problem-solving - than those in the control condition (*M*=0.28; Cohen's *d*=0.44). Further, students completing the metacognitive reflection intervention obtained higher course grades, representing end-of-year mathematics achievement, in the plane trigonometry course at the conclusion of the subsequent spring semester (*M*=2.88; *M*=2.34; Cohen's *d*=-0.51).

Table 2 *Descriptive Statistics for Primary Measures*

Measure	Intervention condition		Control condition		Skewness	*d*	Possible range, Observed range
	M	*SD*	*M*	*SD*			
End-of-course outcomes							
Problem-solving performance	0.70	0.22	0.56	0.23	-0.22	-0.64	0.00-1.00, 0.17-1.00
Metacognitive monitoring	0.22	0.11	0.28	0.12[a]	0.85	0.44	0.00-1.00, 0.07-0.59
End-of-year outcomes							
Mathematics course grades	2.88	0.98	2.34	1.12	-1.12	-0.51	0-4, 0-4

Note. *M*=mean. *SD*=standard deviation. *d*=Cohen's *d* as an estimate of effect.
[a]Levene's test of homogeneity of error variances indicated no detectable differences in variances for the post-course measures.

Scores on the assessment of problem-solving were moderately correlated with students' calibration accuracy scores at the end of the course, r=-0.47, 95% CI: -0.25, -0.63; indicating students with more accurate monitoring during problem-solving obtained higher scores on the problem-solving assessment. Scores on the assessment of problem-solving were weakly to moderately correlated with students' end-of-year mathematics achievement, r=0.29, 95% CI: 0.05, 0.49, BF_{10}=2.36.

Discussion and Conclusion

Previous studies conducted by our group have identified deficiencies in problem-solving skills among first-year engineering students who begin their studies at the College Algebra level [3, 4]. In addition, we have pinpointed specific algebraic concepts with which students consistently struggle. Targeted interventions in these areas led to improvements in student retention and performance in early mathematics courses [3, 4]. However, these findings also indicated the need to address students' metacognitive skills to support more sustained and transferable gains.

The metacognitive intervention implemented in the course led to improvements in students' metacognitive accuracy. Furthermore, students who participated in the intervention demonstrated better performance in their College Algebra course compared to first-year engineering students who were not enrolled in the problem-solving course. The data revealed that students frequently overestimated the accuracy of their solutions, with overconfidence being especially prominent at the beginning of the semester. Students with more accurate monitoring during problem-solving obtained higher scores on the problem-solving assessment. We are currently analyzing the data for a new cohort of students that received the intervention in Fall2025. This ongoing analysis will inform the refinement of the intervention to better support students in using metacognitive strategies to improve their engineering problem-solving skills. This work is critical as we aim to better prepare students to meet the complex demands of solving real-world engineering problems.

Acknowledgements

This material is based upon work supported by the National Science Foundation under Grant Number 2236126. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.

References

[1] B. J. Zimmerman and M. Campillo, "Motivating Self-Regulated Problem Solvers," in *The Psychology of Problem Solving*, J.E. Davidson and R.J. Sternberg, Eds. Cambridge: Cambridge University Press, 2003, pp. 233-262.

[2] B. J. Zimmerman, "Attaining Self-Regulation," in *Handbook of Self-Regulation*: Elsevier, 2000, pp. 13-39.

[3] L. Santiago, A. C. Pirkey, H. A. Markle, R. A. Hensel, and M. L. Morris, "Board 129: Algebra-Related Misconceptions Identified in a First-Year Engineering Reasoning Course," in *2018 ASEE Annual Conference & Exposition*, 2018.

[4] L. Santiago and A. C. Pirkey, "Identifying Deficiencies in Engineering Problem-Solving Skills," in *2020 ASEE Virtual Annual Conference Content Access*, 2020.