Introducing First Year Engineering Students to Engineering Reasoning

Dr. Lizzie Santiago, West Virginia University

Lizzie Y. Santiago, Ph.D., is a teaching associate professor for the freshman engineering program in the Benjamin M. Statler College of Engineering and Mineral Resources. She holds a Ph.D. in chemical engineering and has postdoctoral training in neural tissue engineering and molecular neurosciences. She teaches freshman engineering courses and supports the outreach and recruiting activities of the college. Her research interests include neural tissue engineering, stem cell research, absorption of air pollutants in human upper airways, attrition and university retention, increasing student awareness and interest in research and engineering, STEM education, and recruitment and retention of women and minorities.

Ms. Anika Rachelle Coolbaugh
Miss Sai Sadhika Veeramachaneni, West Virginia University
Dr. Melissa Lynn Morris, West Virginia University

Melissa Morris is currently a Teaching Assistant Professor for the Freshman Engineering Program, in the Benjamin M. Statler College of Engineering and Mineral Resources at West Virginia University (WVU). She graduated Summa cum Laude with a BSME in 2006, earned a MSME in 2008, and completed her doctorate in mechanical engineering in 2011, all from WVU. At WVU, she has previously served as the Undergraduate and Outreach Advisor for the Mechanical and Aerospace Engineering department and the Assistant Director of the Center for Building Energy Efficiency. She has previously taught courses such as Thermodynamics, Thermal Fluids Laboratory, and Guided Missiles Systems, as well as serving as a Senior Design Project Advisor for Mechanical Engineering Students. Her research interests include energy and thermodynamic related topics. Since 2007 she has been actively involved in recruiting and outreach for the Statler College, as part of this involvement Dr. Morris frequently makes presentations to groups of K-12 students, as well as perspective WVU students and their families.

Dr. Morris was selected as a Statler College Outstanding Teacher for 2012, the WVU Honors College John R. Williams Outstanding Teacher for 2012, and the 2012 Statler College Teacher of the Year.

Introducing First Year Engineering Students to Engineering Reasoning

Introduction

Critical thinking, defined as self-directed and self-corrected thinking, is considered an essential skill for student success in college (Ennis, 1993; R. Paul, 1992, 2005; R. Paul & Elder, 2006, 2008). In order to enhance critical thinking skills, students' abilities and dispositions towards thinking are both equally important (Facione, Sánchez, Facione, & Gainen, 1995). In college, curricular and outside class experiences seem to contribute to the development of students' critical thinking skills (Terenzini, Springer, Pascarella, & Nora, 1995). In engineering, critical thinking has been taught in the context of problem-based and project-based learning. Educators recognize that teaching critical thinking to students is important, but feel they are unequipped to introduce critical thinking skills in the classroom.

This paper discusses changes implemented in a course that was developed to introduce critical thinking skills to first year non-calculus ready engineering students (Coolbaugh, Veeramachaneeni, Morris, & Santiago, 2017). The description of the course, based on Paul and Elder's theory on critical thinking, was presented at the 2016 ASEE Conference (R. Paul, 1992, 2005; R. Paul & Elder, 2005, 2006, 2007, 2008; R. W. Paul, 1993; Veeramachaneeni, Coolbaugh, & Santiago, 2016). This paper summarizes findings after the implementation of a recitation into the course. The recitation was added to enhance students' math and engineering reasoning skills. Specific aims of this part of the study were: a) identify the topics in algebra where intervention is needed, b) assess the effect of the course on students' math grades, math placement in college, cumulative GPA, and retention in engineering, and c) assess the effect of the course on students' critical thinking skills. This research will benefit institutions and administrators looking for ways to improve the retention in engineering of students that are not calculus ready.

Methodology

Participants: Sixty first year engineering students that were non-calculus ready participated in this part of the study. All participants were enrolled in College Algebra.

Table 1. Characteristics of Participants

Parameter		Control	Experimental
Gender	M	n = 78 85%	n = 49 83%
	F	n = 14 15%	n = 11 18%
High School GPA*		3.52 ± .39	3.49 ± .37
Math SAT*		542 ± 28	535 ± 31
Comp SAT*		1059 ± 68	1058 ± 68
Math ACT*		24 ± 1	24 ± 1

*mean±standard_deviation

Table 1 summarizes students' characteristics for the control and experimental groups. As indicated in Table 1, most participants were males enrolled in a first year engineering program at an academic institution in the mid-Atlantic region. Institutional data from students enrolled in College Algebra but not enrolled in this course was used to establish the control group for the study. No significant differences were observed in the pre-college characteristics of both control and experimental groups.

Initially, all students signed a consent form and completed an entrance questionnaire. Critical thinking skills were assessed using the Tennessee Tech Critical Assessment Test (CAT), which was administered in week 3 and re-administered during the last week of the course. A math assessment test developed by the research group was administered during week one and re-administered during week 14 of the course.

Engineering Program: Upon entrance, all students are initially enrolled in a first year engineering program where they complete six basic courses (English, General Chemistry, Engineering Seminar, Engineering Problem Solving I, Engineering Problem Solving II, and Calculus I). Upon completion of those six courses with C or better and with a grade point average (GPA) above 2.25, students are allowed to move to an engineering department. To graduate with a degree in engineering, all engineering students are required to complete four semesters of college calculus. Students that enter engineering at the College Algebra level must complete Trigonometry before moving into the first calculus course. Some students that earn A's or B's in their Algebra course are allowed to progress to pre-calculus. Students in this study can also place into Calculus 1 by taking a math placement test at the end of their first semester.

Brief Description of the Course: The description of the course was presented at the 2016 ASEE Conference (Veeramachaneeni et al., 2016). The course, which was developed to increase students' critical thinking skills, introduces students to elements of thought, intellectual standards, intellectual traits, and arguments, among other topics. A recitation was incorporated into the course to strengthen students' algebraic knowledge and to assist students in the development of their math and engineering thinking skills.

Math Component of the Course: Table 2 summarizes some of the topics discussed in the recitation portion of the course. Application problems were developed to reinforce math and engineering concepts, and to promote reasoning skills.

Table 2. Mathematics Concepts Emphasized in the Recitation Part of the Class

Math Concepts Reinforced in the Recitation
Topic 1: Factoring quadratic equations
Topic 2: Algebraic manipulation
Topic 3: Developing and solving a linear equation from a word problem
Topic 4: Developing and solving a polynomial equation from a word problem
Topic 5: Graphing quadratic equations
Topic 6: Solving logarithmic equations

Once per week, students attended a 2 hour long recitation in which students were exposed to the topics shown in Table 2 through short lectures, skills practice, and application problems. For each recitation, students were required to complete a quiz, a homework, and to solve word problems involving applications of algebra to engineering. As indicated in a publication presented at the 2016 ASEE Conference, students were taught critical thinking in the context of problem-based and project-based learning (Veeramachaneeni et al., 2016). Paul and Elder's critical thinking theory was used to introduce students to reasoning (R. Paul, 1992, 2005; R. Paul & Elder, 2005).

Statistical Analysis: This study was approved by the West Virginia University Institutional Review Board (WVU-IRB). Paired t-tests were used to assess differences in students' pre- and post- critical thinking scores. A p-value ≤ 0.05 was considered significant.

Results and Discussion

A math pre-assessment test was used to identify students' conceptual difficulties associated with algebra knowledge. As indicated in Table 3, students performed weak in most of the concepts tested in the pre-assessment test. The test was also used to assess students' knowledge of some trigonometry concepts.

Table 3. Areas in Algebra Problematic to Students

Algebra and Trigonometry Concepts Tested in Math Assessment
Concept 1: Factoring quadratic equations
Concept 2: Algebraic manipulation
Concept 3: Developing and solving a linear equation from a word problem
Concept 4: Developing and solving a polynomial equation from a word problem
Concept 5: Basic trigonometry skills
Concept 6: Solving quadratic equations
Concept 7: Solving non-right triangles
Concept 8: Graphing quadratic equations
Concept 9: Solving logarithmic equations

The math post-assessment test showed that at the end of the semester, students experienced significant gains in knowledge in all algebra concepts reinforced in class. The highest gains of knowledge were on concepts 2 and 6 (algebraic manipulations and solving quadratic equations) from Table 3.

At the end of the semester, as illustrated in Figure 1, 46% of the students enrolled in the course obtained A in their Algebra course. In contrast, only 30% of the students in the control group obtained an A in Algebra.

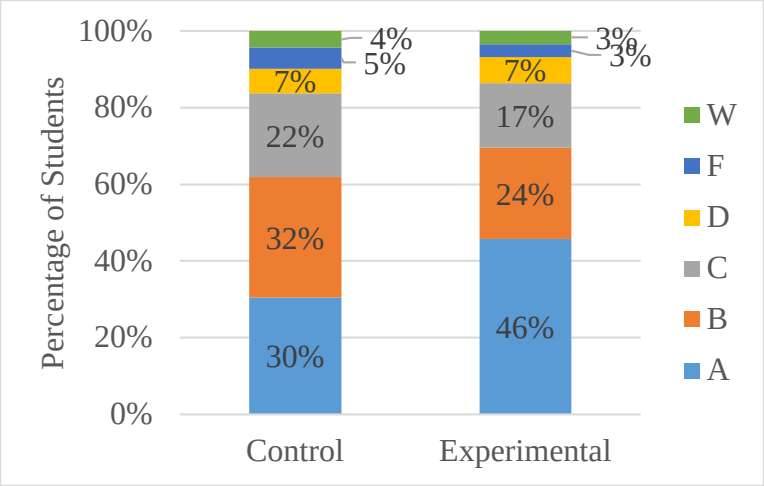

Figure 1. Grades in Algebra at the End of the First Semester (expressed as a percent of all students enrolled in that group)

Table 4 summarizes the first semester GPA, credit completion rate, retention in engineering, and retention in college for both the control and experimental groups. The experimental group (students enrolled in the engineering reasoning course) showed a slightly higher first semester GPA, retention in engineering, and credit completion rate in comparison with the control group.

Table 4. GPA and Success Rate at the End of the First Semester for the Control and Experimental Groups

Parameter	Control	Experimental
1st Semester GPA *	2.77 ± .98	2.97 ± .83
Received an A in Algebra	30%	46%
Retention in University	98%	100%
Retention in Engineering	89%	97%
Course Credit Completion Rate**	88% ± 23%	93% ± 18%

*(credits hours completed/credits hours attempted) expressed as mean±standard_deviation;
*mean±standard_deviation; %: percent of all students enrolled in that group

In comparison to the control group, almost 50% of the students enrolled in the course moved to pre-calculus, whereas in the control group, only 32% of the student were able to advance to pre-calculus (see Figure 2). For the control group, a large number of the students progressed from Algebra to Trigonometry. For Business Calculus, since students are able to move to Business Calculus after completing Algebra with a grade of C or better, the investigators decided not to consider this progression in the analysis of the data.

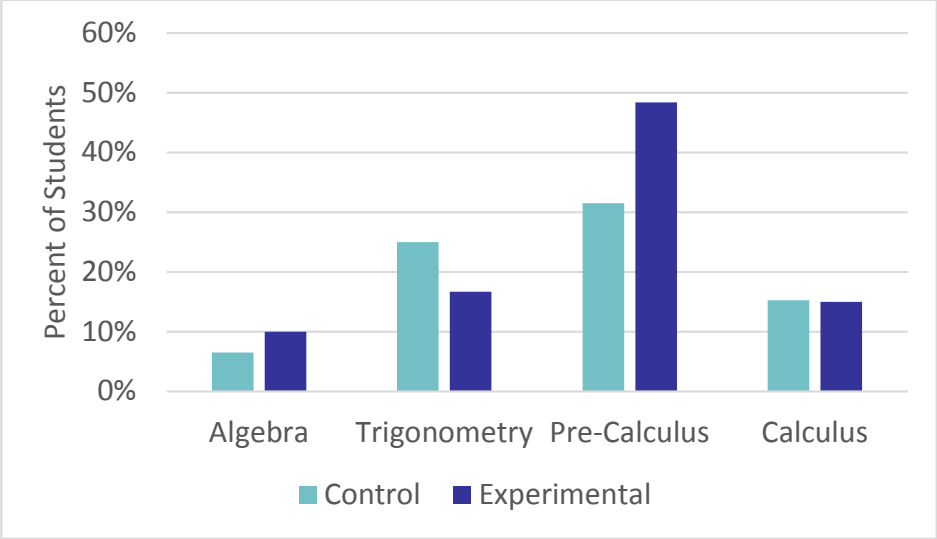

Figure 2. Math Placement in the Second Semester

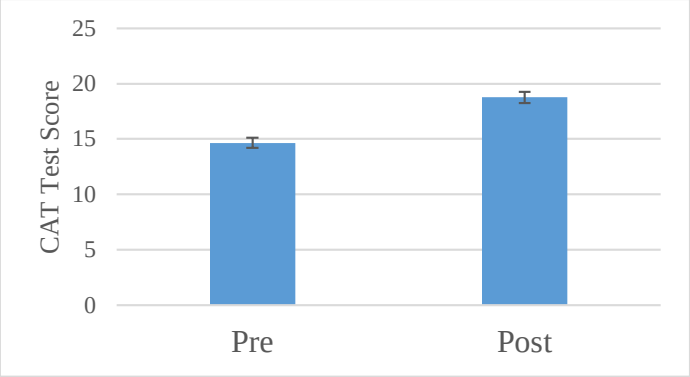

Figure 3. Overall CAT Test Scores from the Experimental Group

(expressed as mean±standard error)

The average values for the pre- and post- CAT test were 14.6 and 18.8, respectively. The pre- and post- CAT test scores indicate that students' critical thinking skills were significantly increased by the course (p-value≤0.001). The CAT test scores illustrate improvement in all four subscales of the test: effective communication, creative thinking, problem solving, and in students' ability to evaluate and interpret information.

Several engineering programs accept students that are non-calculus ready in their programs. Non-calculus ready students are required to take algebra, trigonometry and pre-calculus before they are allowed to enroll in their first engineering courses. The retention and engineering graduation rate of students that are not calculus ready is known to be low. Not only do these students experience a lack of exposure to engineering in their first few years in college, but they also spend more time enrolled in remedial courses before beginning courses for their major. The long term goal of this study is to create a path to accelerate the course progression of non-

calculus ready students and to understand the effect of improving their critical thinking skills in these students' retention and graduation in engineering.

Conclusions

This paper summarizes the results obtained from a project aimed at increasing students' critical thinking skills in the context of engineering problem solving. In this study, non-calculus ready first year engineering students enrolled in the course showed increases in critical thinking scores and math proficiency as indicated by their CAT scores, pre-and post- math assessments, and final grade in their math course. In comparison to students not enrolled in the course, a higher percentage of the students enrolled in the course obtained A in their algebra course and were retained in engineering. In addition, a higher percentage of the students were able to progress to a higher level math course (for many, a move from algebra to pre-calculus). This progress will allow students move faster to their engineering departments, and could potentially increase student retention. The results of advancing students in math and improving their critical thinking skills in student retention and graduation rate in engineering is currently being investigated.

Acknowledgements

This research is supported by a grant received from the National Science Foundation (Grant # DUE-1504730). The opinions expressed are those of the authors and do not necessarily represent those of the NSF. The authors would like to thank Drs. Amy Kuhn and Robin Hensel for their assistance and recommendations in the project.

References

Coolbaugh, A., Veeramachaneeni, S., Morris, M., & Santiago, L. (2017). *Promoting Critical Thinking Skills in Non-Calculus Ready First Year Engineering Students*. San Juan, PR.

Ennis, R. H. (1993). Critical thinking assessment. *Theory into practice, 32*(3), 179-186.

Facione, P. A., Sánchez, C. A., Facione, N. C., & Gainen, J. (1995). The disposition toward critical thinking. *The Journal of General Education*, 1-25.

Paul, R. (1992). Critical thinking: What, why, and how. *New directions for community colleges, 1992*(77), 3-24.

Paul, R. (2005). The state of critical thinking today. *New directions for community colleges, 2005*(130), 27-38.

Paul, R., & Elder, L. (2005). *A guide for educators to critical thinking competency standards: Standards, principles, performance indicators, and outcomes with a critical thinking master rubric*: Foundation Critical Thinking.

Paul, R., & Elder, L. (2006). Critical thinking: The nature of critical and creative thought. *Journal of Developmental Education, 30*(2), 34.

Paul, R., & Elder, L. (2007). Critical thinking: The art of Socratic questioning. *Journal of Developmental Education, 31*(1), 36.

Paul, R., & Elder, L. (2008). Critical thinking. *The Foundation for Critical Thinking*.

Paul, R. W. (1993). The logic of creative and critical thinking. *American Behavioral Scientist, 37*(1), 21-39.

Terenzini, P. T., Springer, L., Pascarella, E. T., & Nora, A. (1995). Influences affecting the development of students' critical thinking skills. *Research in higher education, 36*(1), 23-39.

Veeramachaneeni, S., Coolbaugh, A., & Santiago, L. (2016). *Critical Thinking Skills in First Year Engineering Students.* Paper presented at the American Society for Engineering Education (ASEE), New Orleans, LA.