New Orleans JAZZED about Engineering Education

Paper ID #16970

Critical Thinking Skills in First-Year Engineering Students

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Critical Thinking Course for First Year Engineering Students

Introduction:

Critical Thinking has been defined as "an actively, purposeful, organized cognitive process used to carefully examine our thinking and the thinking of others, in order to clarify and improve our understanding" [1]. Critical Thinking skills have become necessary in today's society for students to acquire and practice in order to become successful both in college and in their future careers. In engineering, critical thinking skills are traditionally developed through problem-based learning and reflective practices [2-4].

As engineering education stands today, there is a significant gap that needs to be filled in the education of students who enter university with weak math skills. These students are at a serious disadvantage due to the fact that they are not exposed to engineering concepts early in their education, especially students that are non-calculus ready. These students tend to migrate out of engineering at a higher rate in comparison with calculus ready students or leave college without finishing a degree. Most institutional efforts and resources are allocated to engineering students that are calculus ready.

This paper introduces a course developed for non-calculus ready, first year engineering students. The main goal of this course is to introduce students to engineering problem solving, engineering design process, and critical thinking skills. Second, the course must be able to combine engineering and critical thinking skills with mathematics in order to prepare students for higher level courses. Third, since the development of an engineering identity has been linked with student retention, a goal of this project is to determine if an early exposure to engineering contributes to the development of an engineering identity in those non-calculus ready students enrolled in the course [5-7]. It is expected that with the development of these skills, higher retention rates of non-calculus ready students could be achieved.

Development of the Course:

A study has been conducted in an academic institution in the mid-Atlantic region. Participants were first year engineering students that were non-calculus ready at the time of enrollment in the study. This study was reviewed and approved by the WVU-Institutional Review Board.

Course Schedule: The course was developed using the CDIO (conceive, design, implement, operate) educational framework and includes activities that promote students' problem solving skills, and introduce students to research, experimentation, and engineering design [8-11]. Table 1 illustrates the list of topics covered in the course:

Table 1. Topics Covered in Class

What is Engineering?, Engineering Disciplines, History of Engineering
The Human Brain
Critical Thinking
Emotional Intelligence
Experimentation and Knowledge Discovery
Engineering Reasoning and Problem Solving
Engineering Design
Entrepreneurship and innovation
Sustainability
Oral and Written Communication

One of the main objectives of the course is to assist students in the development of their critical thinking skills. Table 2 summarizes some of the skills targeted by this course. These skills include: the ability to separate relevant versus irrelevant information in a problem, ability to use math skills to solve simple engineering and math problems, how to find a unique solution to a problem, understand the limitations of a solution, and identify additional information needed to solve a problem.

Table 2. Example of skills to be developed by students enrolled in the course

Skills Promoted in the Course
Skill 1: Summarize a pattern of information without making inappropriate inferences
Skill 2: Evaluate how strongly correlational-type data supports a hypothesis
Skill 3: Provide alternative explanations to observations
Skill 4: Identify additional information needed to evaluate a hypothesis or particular explanation of an observation
Skill 5: Determine whether an invited inference in an advertisement is supported by the information
Skill 6: Provide relevant alternative interpretations of information
Skill 7: Separate relevant from irrelevant information when solving a real-world problem
Skill 8: Analyze and integrate information from separate sources to solve a real world problem
Skill 9: Use basic mathematical skills to help solve a real-world problem
Skill 10: Identify suitable solutions to real-world problem using relevant information
Skill 11: Identify and explain the best solution for a real-world problem using relevant information
Skill 12: Explain how changes in a real-world problem situation might affect the solution

Projects Developed and Activities Completed: Four main projects were developed to teach critical thinking skills and to solidify problem solving skills in non-calculus ready, first year engineering students. The projects, shown in Table 3, include a research and a design component. Some of the skills mentioned in Table 2 were also reinforced through in class activities and homework.

Table 3. Projects Developed for the Course

Project	Topics
1	Design of a Tower
2	Research Methods to Desalinate Seawater
3	Design a Self-Propelled Vehicle
4	Design of a Tennis Ball Launcher

Student Enrollment: Seven students were enrolled in the first cohort and eleven students were enrolled in the second cohort of the study. All students were first year engineering students that were non-calculus ready at the time of enrollment. Table 4 summarizes the characteristics of all participants in the study. The participants were enrolled in either Algebra or Trigonometry at the time of the study.

Table 4. Characteristics of participants in the study

Characteristic	Parameter
No. of students	18
No. of Males	14
No. of Females	4
High School GPA	3.38±0.45*
SAT Math	500±60.66*
SAT Verbal	510±52.54*
ACT Math	23.1±1.53*
ACT Composite	23.4±2.38*

*****Represented as average ± standard deviation

Outcome Measured: Outcomes measured in the study include students' critical thinking skills, engineering identity, and persistence in engineering. These outcomes were measured using:

a) Critical thinking skills: Critical thinking skills are assessed using the Critical Thinking Assessment Test (CAT, developed by Tennessee Tech) and activities done in class [4, 12, 13].
b) Academic success is assessed using grades in Math and Sciences, GPA at the end of the semester, and number of credit hours approved versus total number of credit hours attempted.
c) Engineering Identity: measured, from the entrance and exit surveys, using questions from Jones et al. [14].
d) Interest in engineering: changes in interest in engineering were measured using entrance and exit surveys [15, 16].
e) Persistence in engineering: the number of students that continued pursuing a degree in engineering was obtained from institutional databases.

Statistical Analysis: Paired t-tests were performed to assess changes in engineering identity and interest in engineering in the study. Statistical significance was established with a p value less or equal to 0.05.

RESULTS

Critical Thinking Skills: For the first cohort (fall 2015), critical thinking skills were assessed mainly from student work, including in class activities and homework. For the second cohort (spring 2016), the CAT test was implemented in addition to the assessment done through in class activities and homework. At this point, the final analysis of critical thinking skills is being conducted and the results from the CAT will be available at the end of the spring 2016 semester. Some areas of concern were identified in the development of critical thinking skills in the first cohort. Students were having problems: a) reading and understanding verbal problems, b) identifying relevant versus irrelevant information in a problem, c) identifying the equations needed to solve a problem, and d) using their math skills to solve problems.

Engineering Identity: After analyzing the entrance and exit surveys, the first semester engineering students enrolled in the fall 2015 cohort did not experience a change in engineering identity. A paired t-test done in the data revealed that there were not statistical differences between the initial and final values obtained for engineering identity (data not shown). The data for the spring 2016 cohort will be available at the end of the spring semester.

Persistence in Engineering, and Interest in Engineering: All students enrolled in the study in fall 2015 were retained in the engineering program.

A survey conducted at the beginning and ending of the semester to observe changes in the level of interest in engineering during the semester indicated that most students experienced an increase in interest in engineering. As illustrated in Figure 1, five of the seven students enrolled in the course reported an increase in interest in Engineering; for one of the students the level of interest remained the same during the semester. Paired t –tests confirmed that this change in interest was statistically significant, with interest in engineering increasing.

When asked to describe events or experiences that led to this change in interest (increase or decrease in interest), students reported that their level of interest increased due to the engineering design projects done in class, and they enjoyed their interaction with the engineering faculty. For instance, they commented:

"Getting to build projects and interacting within the engineering department"

"I like designing things"

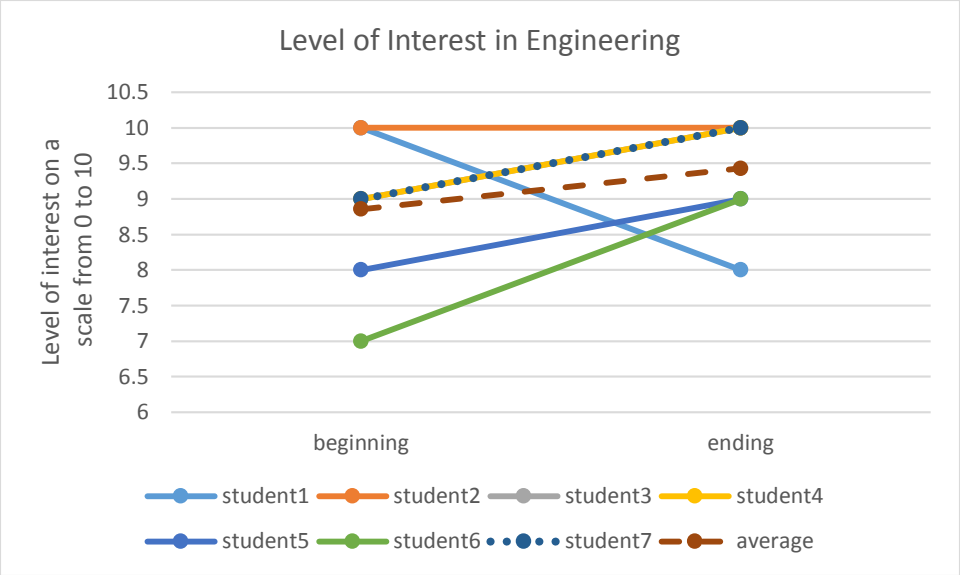

Figure 1: Changes in Interest in Engineering. Students were asked to indicate on a scale from 0 (no interest in engineering) to 10 (engineering is definitely for me) their current level of interest in engineering.

When students were asked about how they liked the course, their responses were generalized on how well they learned engineering aspects and enjoyed the project work. The friendly environment created within the class and with the professor was also sighted as a positive attribute of the course. For instance, students indicated that they liked:

"Doing the projects because it brought the class together and created a good social environment."

"Professor, projects, atmosphere"

"I liked how it was a small class, we got to learn about everyone in the class and become a close friend group."

Academic Success: Three of the seven students enrolled in the fall 2015 cohort experienced academic difficulty. Their main problem was a struggle with their level of proficiency in mathematics. For the spring 2016 cohort, math tutoring and supplemental math lectures are being provided to all students enrolled in the course. Also, math is being incorporated in the engineering problems solved in class.

Table 5: Outcome of the semester for the fall 2015 cohort

Characteristic	Value
Cumulative GPA	2.54±1.21 (Range 3.84-0.85)
Number credit hours approved/credit hours attempted	79±25 (Range 100%-43%)

One of the limitations of the study is the small sample size. It is expected that the sample size will increase as more students learn about the course. Plans are also being made to offer this course as a general elective for non-calculus ready students; this will attract more students into the course.

Conclusions:

This paper presents a course to teach critical thinking skills to first year engineering students that are non-calculus ready. The paper outlines components of the course, summarizes how the course was delivered, and explain some of the difficulties experienced in class. Although students' engineering identity did not change during the semester, students enrolled in the course experienced an increase in interest in engineering.

Acknowledgements:

The authors would like to thank Drs. Amy Kuhn and Alex Mejia for the helpful conversations and recommendations for the project. This project is supported by a grant from the National Sciences Foundation (Project # 10019502).

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