# ANALYSIS OF THE PROBLEM SOLVING PERFORMANCE OF ENGINEERING STUDENTS IN STATICS IN RELATION TO ACADEMIC CONTEXTS

**Engr. Emir Lenard S.F. Sicangco**
Tarlac State University
Romulo Boulevard San Vicente, Tarlac City, Philippines
essicangco@tsu.edu.ph

**Abstract**

*This study analyzed the problem solving performance in Statics of 141 junior-standing engineering students from Tarlac State University, Philippines in relation to academic variables, namely, English language ability, core mathematical ability, and conceptual understanding in Statics. The study employed the correlational method of research. A series of standardized tests were administered, and it was found that the English language ability, core mathematical ability, and problem solving performance of the engineering students were average, while their conceptual understanding in Statics was below average. On the other hand, regression analysis revealed that the combination of the three independent variables explained about 27% of the total changes in the problem solving performance of the students in Statics. While English language and core mathematical abilities were found to be significant predictors of problem solving performance in Statics, the analysis has shown that conceptual understanding in Statics was not. In terms of conceptual understanding, the students were found weak in all the Statics topics that were covered. As regards problem solving, the students performed strongly in the topic of static equivalence and weakly in friction. The results of this study may be used as inputs to curriculum development and improvement of teaching strategies in the fields of Mathematics, English and Statics.*

**Keywords:** Problem-solving, Mathematics, Language, Conceptual Understanding, Engineering Education

## 1. Introduction

Problem solving is an integral and inevitable activity of man. In everyday contexts, including work and personal lives, people solve problems constantly (Jonassen, 2010). Popper (as cited in Jonassen, 2010) emphasizes the importance of problem solving and claims that "all life is problem solving." Everyday people encounter different situations that require the application of their problem solving skills in order to come up with possible solutions or courses of action. The National Council of Teachers of Mathematics (as cited in "Math Handbooks," n.d.) has identified problem solving as one of the five fundamental mathematical process standards along with reasoning and proof, communication, connections, and representations.

In the field of education, problem solving is considered as one of the most important skills that a student must learn and possess. Instruction centers mostly on problem solving because this is the most relevant learning activity students can engage in (Jonassen, 2010). Problems come in different forms as applicable in a given situation. A popular type of problem students encounter are story problems, more commonly referred to as word problems. These problems present situations in the form of narratives containing the given values needed to solve an unknown quantity. They can also contain accompanying figures to aid in understanding. The nature of the word problem implies that a combination of conceptual knowledge of the subject matter, mathematical or computational skills, proficiency in the language of instruction, and comprehension skills may be needed in the determination of the solution.

In the field of engineering education, analytical problem solving skills are considered to be the central skill in the education of an engineering student (Litzinger, Vanmeter, Firetoo, Passmore, Masters, Turns, et al, 2010). To be analytical is to address something whole into component or elemental parts, with the goal of arriving at a logical conclusion. One can only arrive at a sound end when all these elemental parts are dealt with accordingly and are in coherence with one another. Litzinger, et al (2010) further quotes the National Academy of Engineering as saying that the future engineer shall possess strong analytical skills. Maddocks, Dickens, and Crawford (2002) concur that prior to becoming competitive and well-rounded engineers, engineering students are expected to possess analytical skills in the solution of problems, alongside knowledge in their respective fields, design skills, ability to apply mathematical, scientific, and technological tools, and oral and written communication skills.

In educational institutions offering undergraduate engineering programs, the various engineering curricula focus mostly on problem solving. Incorporated in the subjects in the latter years are design problems, diagnosis-solution problems, decision-making problems, and troubleshooting problems to name a few. On the other hand, scattered around the entire curriculum are subjects that present other types of problems that require the application of engineering concepts and mathematical knowledge.

Engineering Mechanics is one subject being offered under all undergraduate engineering programs. Mechanics, as it is normally called, is the study of forces and their effects on bodies, and involves mathematical and computational work in their analysis. This subject can be divided into two branches, namely, Statics and Dynamics. Statics is a foundational course for many engineering disciplines, such as mechanical and civil engineering, and it is generally students' first experience with modeling. In addition, to the extent that design activities draw upon engineering science knowledge, Statics can play a key role in design (Harris and Jacobs, 1995; as cited in Steif, Lobue, Kara, and Fay, 2010). Some problems that are incorporated in a Statics course are visual in nature, in the sense that forces are represented in diagrams and the solution of the problem is based on the understanding of the figure. On the other hand, some problems are in word form, wherein a situation is being described in narrative form and the needed values are embedded within the block of text. Thus, Statics concepts, mathematical formulas, and even language come into play when solving problems in Statics.

Problem solving in Statics is more than just memorization of mathematical formulas and processes in order to come up with the desired result. The danger of mere memorization is when a problem is modified, the usual flow of solution is no longer applicable. Knowledge of mathematical principles is very important in solving problems, but it is just one component of problem solving in Statics and is not a lone indicator of proficiency in the subject.

Conceptual knowledge is another academic component that is viewed by experts as necessary for successful problem solving in Statics. Students need to draw upon relevant conceptual knowledge and apply it appropriately in a particular problem. Accordingly, students must recognize salient elements that relate to relevant concepts in the problem statement and diagram. Unfortunately, across many domains, research has shown that students often fail to select and apply appropriate conceptual knowledge when solving problems (Steif, et al, 2010). Instructors of engineering courses often feel that student understanding of Statics is a major impediment to their success in this course (Steif and Dantzler, 2005).

Performance in engineering subjects is also said to be related to the ability to use the language of instruction or comprehend the problems stated in a certain language. In the same way that language is an essential element of learning, of thinking, of understanding, and of communicating, it is also essential for mathematics learning (Riordain and O'Donoghue 2008) and engineering education (Wait and Gressel, 2009).

The lack of studies, particularly locally, related to the analysis of problem solving performance of students in Statics motivated the author to pursue this study. The researcher aimed to determine how academic factors, namely, conceptual understanding in Statics, mathematical knowledge, and English language ability affect problem solving performance in Statics. Moreover, topics in the subject where the students are strong and weak were enumerated.

## 2. Objectives

This study aimed to analyze the problem solving performance of junior-standing Tarlac State University Engineering students in Statics in relation to academic contexts. Specifically, it aimed to answer the following questions:

1. How are the students described in terms of their
    - 1.1. English language ability;
    - 1.2. Core mathematical ability;
    - 1.3. Conceptual understanding in Statics; and
    - 1.4. Problem solving performance in Statics?
2. How do English language ability, core mathematical ability, and conceptual understanding in Statics relate to students' problem solving performance in Statics?
3. In what areas in Statics are students strong and weak?

## 3. Methodology

The author employed the correlational method of research. The subjects of the study were 141 out of 183 (or $\underset{\sim}{}$ 77%) junior-standing engineering students of the Tarlac State University College of Engineering who had completed a one-semester course in Statics of Rigid Bodies in the 1st semester of school year (SY) 2012-2013. The students came from all the five undergraduate engineering programs in the college, namely: Civil, Electrical, Electronics, Industrial and Mechanical Engineering. The remaining 23% of the total population that did not become part of the study were either those who were not present during the conduct of at least one of the tests or those who intentionally opted not to take part at all.

Three tests were administered to the subjects at specific time intervals. The Metropolitan Achievement Tests (Prescott, Balow, Hogan, and Farr, 1978) which were used to determine the

English language and core mathematical abilities of the students, were administered before the end of the first semester of SY 2012-2013. The Conceptual Assessment Tool for Statics or CATS (Steif, 2010), used to determine the conceptual understanding of students in Statics, was administered in the middle of the second semester of the same school year. Lastly, the Problem Solving Test in Statics, which determined the problem solving performance of the students, was administered during the same period as the conduct of the CATS. The results of these tests were used to describe the students' abilities and were further subjected to regression analysis to identify whether the specified academic variables significantly predicted changes in the problem solving performance of the students.

## 4. Results and Discussion

### 4.1 Students' Abilities in Several Academic Contexts

Several intellective variables were measured through the administration of corresponding tests with the objective of analyzing their relationship with engineering students' problem solving performance in Statics.

#### 4.1.1 English Language Ability

English language ability refers to the ability of the students in the use of the English language and its components namely: grammar, spelling, and vocabulary, among others. The Language Arts component of the MAT was used to identify the student's English Language ability.

Table 1
English Language Ability of the Engineering Students, $N$ = 141

| Range of Scores | Frequency (%) | Verbal Description |
|---|---|---|
| 890 – 999 | 13 (9.22) | Above Average |
| 756 – 889 | 62 (43.97) | Average |
| 591 – 755 | 66 (46.81) | Below Average |

The mean scaled score of the students in the Language test was $M$ = 782.82 ($SD$ = 83.15). This corresponds to average English language ability among the students. This may imply that the students have an English language ability that may be adequate in some situations but still needs improvement especially when they would have to deal with more complicated tasks in the future. The highest scaled score obtained was 994 while the lowest was 628.

The figures are alarming considering that junior students have already taken up a series of English subjects in their first two years in the university. While the statement that says engineers are poor at English remains a joke, the results in this study actually support a recent study in India that looked into the English skills of 55,000 engineering graduates from 250 engineering institutions and found that around 40% of them cannot write grammatically correct sentences and around 50% cannot understand moderately sophisticated English words ("Engineers Flunk English Test", 2012).

### 4.1.2 Core Mathematical Ability

The core mathematical ability of the students refers to their ability in the Mathematics subjects that have an application in Statics. This was measured through the Mathematical Processes component of the MAT.

Table 2
Core Mathematical Ability of the Engineering Students, $N$ = 141

| Range of Scores | Frequency (%) | Verbal Description |
|---|---|---|
| 859 – 999 | 64 (45.39) | Above Average |
| 749 – 858 | 75 (53.19) | Average |
| 615 – 748 | 2 (1.42) | Below Average |

The mean scaled score of the students in the Mathematics test ($M$ = 856.37, $SD$ = 61.95) corresponded to an average ability. The result may be a good indication that the students have an ability to possibly go through highly mathematical subjects with little to no difficulty. The highest scaled score obtained was 998 while the lowest scaled score was 715.

While an average core mathematical ability sounds generally desirable as in the case of English language ability, more improvement is needed among engineering students since they are expected to excel in the field of mathematics.

### 4.1.3 Conceptual Understanding in Statics

Problem solving is often mistaken as merely procedural; memorizing the steps is deemed sufficient to arrive at the correct answer. But prior knowledge of the concepts involved is believed to be an important scaffold for problem solving (Higley, Litzinger, Van Meter, Masters, Kulikowich, 2007). Hence, it is essential to assess the conceptual knowledge of engineering students in Statics.

Table 3
Conceptual Understanding of Engineering Students in Statics, N = 141

| Range of Scores | Frequency (%) | Verbal Description |
|---|---|---|
| 23 – 27 | 0 (0) | Oustanding |
| 17 – 22 | 1 (0.71) | Above Average |
| 11 – 16 | 3 (2.13) | Average |
| 5 – 10 | 96 (68.08) | Below Average |
| 0 – 4 | 41 (29.08) | Poor |

Table 3 shows the level of conceptual understanding in Statics of the engineering students who took the CATS. It is highly surprising that majority (96 or 68.08%) of the students had an understanding of the fundamental concepts of Statics that was below average. Moreover, almost one-third of them (41 or 29.08%) had a poor level of conceptual understanding in Statics. The result may imply that the students passed their Statics course by relying mainly on procedural knowledge. This may be due to the fact that in the individual development of knowledge, procedural knowledge develops faster than conceptual knowledge (Haapasalo, 2008).

The mean score of the students in the CATS was $M$ = 5.85 ($SD$ = 2.49) which indicates that their level of conceptual understanding was below average. This number is even bordering near the poor level of understanding. One student obtained the highest score of 18 while one student got the lowest score which is 0.

### 4.1.4 Problem Solving Performance in Statics

The students' problem solving performance in Statics was determined using a test that was prepared, analyzed and validated by the researcher. The test was administered to them right after they had finished a one-semester course in Statics. They were asked to solve ten worded problems and were required to draw all necessary diagrams, assumptions, and computations instead of just giving the final answers. Each correct part of the solution was warranted corresponding points based on a scoring rubric (Leongson and Limjap, 2003; Schoenfeld, 1982), with each completely solved problem receiving a maximum of four points.

Table 4
Problem Solving Performance of Engineering Students in Statics, $N$ = 141

| Range of Scores | Frequency (%) | Verbal Description |
|---|---|---|
| 33 – 40 | 13 (9.22) | Oustanding |
| 25 – 32 | 30 (21.28) | Above Average |
| 16 – 24 | 58 (41.13) | Average |
| 8 – 15 | 37 (26.24) | Below Average |
| 0 – 7 | 3 (2.13) | Poor |

The mean score of the students in the problem solving test in Statics was $M$ = 20.68 ($SD$ = 7.46) which means that their overall performance in solving Statics problems was average. Two students got the highest score which is 38 while 3 students obtained the lowest score of 7.

The result in the problem solving test may seem to be in contradiction with the result in the test for conceptual understanding. But since problem solving is often viewed as an activity where students typically follow procedure-based rules or algorithmic steps through direct instruction from teachers (Paton, 2010), the result supports the previous statement that procedural knowledge develops faster than conceptual knowledge.

## 4.2 Relationship between Academic Variables and Problem Solving Performance in Statics

The scores of the students in the abovementioned tests were used to analyze and determine whether the academic variables included in the study could significantly predict a student's problem solving performance in Statics. These academic variables are English language ability, core mathematical ability and conceptual understanding in Statics.

Table 5
Summary of Regression Model

| Predictors | R | $R^2$ | F | *p* |
|---|---|---|---|---|
| English language ability<br>Core mathematical ability<br>Conceptual understanding in Statics | 0.523 | 0.274 | 17.203 | 0.000* |

*Significant at 0.05 level

Using full entry regression method, results from Table 5 show that the combination of the three variables provided significant prediction of a student's problem solving performance in Statics ($R^2 = 0.274$, $F(3, 137) = 17.203$, $p < 0.05$). The result implies that 27.4% of the total changes in the performance of a student in Statics problem solving were accounted for by the three predictors listed in the table.

Table 6
Coefficients for the Regression Model with $y$ = problem solving performance in Statics

| Predictors | $\beta$ | *T* | *P* |
|---|---|---|---|
| Constant | -28.590 | -3.569 | 0.000* |
| Conceptual Understanding, $x_1$ | -0.250 | -1.138 | 0.257 |
| English language ability, $x_2$ | 0.028 | 3.744 | 0.000* |
| Core mathematical ability, $x_3$ | 0.034 | 3.352 | 0.001* |

*Significant at 0.05 level

As shown in Table 6, further analysis of the regression model revealed that the significant predictors of problem solving performance in Statics were English language ability ($\beta = 0.028$, $t(137) = 3.744$ $p < 0.05$) and core mathematical ability ($\beta = 0.034$, $t(137) = 3.352$ $p < 0.05$) while conceptual understanding was not ($\beta = -0.250$, $t(137) = -1.138$ $p = 0.257$). Stepwise regression further revealed that conceptual understanding in Statics only explains about 0.7% of the total changes in the problem solving performance of a student in Statics.

The negative sign in the coefficient of the conceptual understanding variable indicates that it is a suppressor variable. This implies that if other variables were held constant, increasing the score in the test for determining conceptual understanding would lead to a decrease in the score in the problem solving test. This information may be a little bit surprising at first because it is normally assumed that the more a person understands a certain concept, the easier it will be for that person to perform an operation based on that concept (Maciejewski, Mgombelo, & Savard, 2011). But according to Haapasalo & Kadijevich (as cited in Haapasalo, 2008), there are four views that exist between conceptual knowledge and procedural knowledge, and one of these is called the inactivation view in which the two types of knowledge are not related at all. Another view is the dynamic interaction view which states that conceptual knowledge is a necessary but not sufficient condition for procedural knowledge. The regression model yielded the following equation for predicting problem solving performance of students in Statics:

$$y = -0.250x_1 + 0.028x_2 + 0.034x_3 - 28.590$$

### 4.3 Students' Strengths and Weaknesses in Statics

The questions in the Conceptual Assessment Tool for Statics (CATS) as well as the problem solving test in Statics involved these five main topics: free body diagrams (FBD), static equivalence of combinations of forces and couples, reactions at connections or supports, friction, and equilibrium conditions. Each item in the two tests was analyzed to determine the percentage of students who got the correct answer, as well as to determine the topics where they were strong and weak.

Table 7
Students' Strengths and Weaknesses in terms of Conceptual Understanding in Statics, *N* = 141

| Topic | Mean Correct Response Rate | Verbal Description |
|---|---|---|
| Free Body Diagram | 23.05% | Weak |
| Static Equivalence | 17.02 | Very Weak |
| Reactions at Connections and Supports | 17.61 | Very Weak |
| Friction | 33.69 | Weak |
| Equilibrium | 12.48% | Very Weak |

All in all, the students showed weakness in the conceptual aspect of all the topics involved. This implies that the students need to relearn the concepts because they are crucial especially when it is time for them to take up succeeding subjects that require the use of such concepts.

Table 8
Students' Correct Response Rate in Constructing Free Body Diagrams, *N* = 141

| Topic | Correct Response Rate, % | Verbal Description |
|---|---|---|
| Free Body Diagram | 58.58 | Moderately Strong |

For the topic FBD, a mean correct response rate was used. This is because the researcher counted the number of students who had correctly drawn the free body diagram for each problem and received one point for it. Table 8 shows that the students were moderately strong in constructing FBDs (*M* = 58.58%). This implies that in a way, majority of the students have a grip of the fundamentals of constructing FBDs.

Table 9
Students' Strengths and Weaknesses in terms of Problem Solving in Statics, *N* = 141

| Topic | Mean Score (Max score = 4) | Verbal Description |
|---|---|---|
| Static Equivalence | 2.73 | Strong |
| Reactions at Connections And Supports | 1.96 | Moderately Strong |
| Friction | 1.18 | Weak |
| Equilibrium | 2.08 | Moderately Strong |

Table 9 summarizes the areas in Statics where students showed strength and weakness in terms of problem solving. The students were generally strong in solving problems involving static equivalence ($M$ = 2.73). Moreover, they performed moderately strong in solving problems involving connections and supports ($M$ = 1.96) and in answering problems on equilibrium ($M$ = 2.08). Lastly, the students were found to be weak in dealing with problems on friction (1.18).

The result for the four aforementioned topics may imply that students had a hold of the procedures necessary to solve such problems, but did not have a deep understanding of the underlying concepts as revealed by their performance in the test for conceptual understanding. Procedurally speaking, they may be ready to solve problems, but conceptual-wise, much needs to be learned in order to successfully solve many types of problems in Statics.

## 5. Conclusions

The study has shown that the subjects had average ability in the English language, core mathematics subjects, and problem solving in Statics. Their level of ability may be adequate for some purposes but can still be developed for more complex tasks, particularly in mathematics and Statics. On the other hand, the students' level of conceptual understanding in Statics was below average and must be given due attention by the teacher.

Regression analysis revealed that the combination of the variables, namely, English language ability, core mathematical ability, and conceptual understanding in Statics significantly accounted for the total changes in the problem solving performance of students in Statics. However, the analysis revealed that conceptual understanding in Statics, by itself, did not significantly predict problem solving performance in Statics.

With regard to conceptual understanding, the students were weak in the concepts of free body diagram and friction. They were very weak in the concepts of equilibrium, static equivalence and reactions at connections and supports. This means that they need to re-learn or at least review all of these concepts for them to have a solid foundation in their future subjects in which Statics is a prerequisite. In terms of problem solving, the engineering students were strong in solving problems that involved static equivalence, moderately strong in constructing free body diagrams, solving problems that dealt with reactions at connections and supports and equilibrium, and weak in answering problems involving friction. This implies that they had a strong procedural background in most of the topics despite poor understanding of the underlying concepts.

In view of engineering education, the results may be used as inputs to the development of the engineering curricula of the university, improvement of the teaching strategies of teachers who handle Statics and other problem solving-based subjects, and enhancement of prerequisite subjects to strengthen students' foundation.

## 6. Recommendations

English for Specialized Programs (ESP) may be considered by curriculum developers to prepare engineering students for more complicated tasks that require the language, e.g. problem solving, formal reporting, oral communication, among others.

Although the core mathematical ability of the students seems generally desirable, investigating the existing teaching strategies being used by instructors by the college dean may be helpful in determining what is still lacking in terms of imparting what is really needed by the students in the different mathematics subjects.

Even though conceptual understanding was shown to be not related to problem solving performance in Statics, the university shall encourage faculty members who teach Statics, and any other similar subject, to give due focus on the development of the conceptual knowledge of the students because it is still undeniably important in a variety of situations. Creating a balance between imparting concepts and teaching procedures may possibly lead to better performance in solving problems in Statics.

Future researchers may possibly consider exploring more about the relationship between conceptual understanding and problem solving or procedural knowledge, not only in the field of Statics, but also in other problem solving – based subjects. They may also consider investigating other factors that might significantly predict and account more for the total changes in the problem solving performance of students in Statics, whether intellective or non-intellective factors. Lastly, further study on the reasons behind students' low conceptual understanding on Statics may be undertaken for it may contribute to comprehending the situation better and coming up with solutions to improve students' conceptual understanding.

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