Language or Problem-formulation Difficulties? An FE Exam Experiment in a Hispanic Setting

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Abstract

This paper describes and discusses the results of an experiment that was conducted by the author in a course that trains mechanical engineering students to pass the Fundamentals of Engineering (FE) Exam. Passing the FE Exam is one of the requirements for professional licensure in engineering. The experiment took place in a required training course that is part of the mechanical engineering curriculum at a private university in Puerto Rico where the student population is essentially 100% Hispanic, i.e., Spanish is their first language. The primary objective of the experiment was to differentiate between language difficulties (the FE Exam is in English) versus weaknesses in formulating a problem. The motivation for the experiment stemmed from the fact that the passing rates in the FE Exam in Puerto Rico are approximately half than the national average reported by NCEES, which typically reports a national average passing rate for first-time exam takers of approximately 75%, including the exam takers from Puerto Rico. The language issue has been suspected as a probable cause for the lower passing rates in Puerto Rico. The author has also suspected difficulties in problem formulation. The experiment was designed to capture each of these two issues independently. The results showed that 100% of the students (n=27) were able to correctly and fully translate the problem from English to Spanish. Although it is only one experiment, the results suggest that the issue of the English language is not as critical as originally hypothesized. On the other hand, only 48% of the students were able to correctly formulate the given problem. This may turn out to be an important finding because, if this sample is representative of the entire population’s capacity to formulate, then a passing rate ceiling of 50% is predicted. The capacity to formulate is at the heart of passing the FE Exam. The process of formulating a problem requires critical thinking skills, i.e., to be able to discern the true from the false and know the reasons why. In particular, students must fully understand the concepts so that they know when to apply them (and when not to apply them) in a problem. This skill is encompassed in ABET Outcome E: The ability to identify, formulate, and solve an engineering problem. The paper fully describes the problem, the questions that were asked, and the structure for grading this problem, which was part of a class exam. The paper also discusses the misconceptions that students showed in their responses, issues with the lack of availability of FE Exam passing rate data, and ideas for future work. The author hopes that this paper will stimulate discussion among educators of Hispanic engineering students who, perhaps, have noticed similar patterns in their engineering courses.
Introduction

The Fundamentals of Engineering (FE) Exam lies in the path to obtain professional licensure in engineering. The National Council of Examiners for Engineering and Surveying (NCEES) develops and scores the exam. NCEES provides exactly the same exam in Puerto Rico as in the mainland USA. It is offered exclusively in the English language. The FE Exam is an attractive and robust instrument to use in engineering education research because it is an external, independent, and reputable form of assessment.

The FE Exam passing rates in Puerto Rico are approximately half than the FE Exam passing rates for the entire USA. The last numbers reported for Puerto Rico that are publicly available include data from years 2001-2005 [1]. The report unfortunately does not segregate the data into first-time exam takers and repeat exam takers. Instead, it aggregates the results of both groups. All five engineering institutions in Puerto Rico are represented in the data, all of which currently have the vast majority of their programs accredited by the Engineering Accreditation Commission (EAC) of ABET. This may be verified by using the internet search engine provided by ABET to find accredited programs.

From the data in Reference [1] the average passing rate for all the exam takers in Puerto Rico is calculated at 28.5% based on a volume of 10,222 exam takers and a pass volume of 2,918 (years 2001-2005). On the other hand, the most recent numbers reported directly by the NCEES for the entire USA, including Puerto Rico, are from the fiscal year 2016 [2]. The data provided by the NCEES [2] is richer than the data in Reference [1] because it segregates volume data for first-time exam takers and for repeat exam takers. To have a consistent comparison, the results from both groups in [2] were combined by the author. The overall passing rate for the USA was calculated at 64.5% based on a volume of 43,648 exam takers and a pass volume of 28,156. A direct comparison of the results shows that the overall passing rate in the USA is 2.3 times higher than in Puerto Rico (64.5% ÷ 28.5% = 2.3). Since the report from Puerto Rico [1] does not segregate the data into the two distinct groups of first-time exam takers and repeat exam takers, additional comparisons cannot be made.

The primary objective of this paper is to discuss and describe an experiment that was conducted by the author in a course that trains mechanical engineering students to pass the Fundamentals of Engineering (FE) Exam. The motivation for the experiment stemmed from the significant differences in passing rates between Puerto Rico and the entire USA.

The objective of the experiment was to differentiate between language difficulties (the FE Exam is in English) versus weaknesses in formulating a problem. The experiment was designed to capture each of these two issues independently.
The language issue has been suspected as a probable cause for the lower passing rates in Puerto Rico. Students in Puerto Rico are essentially 100% Hispanic so some of the research questions of interest are: are Hispanic students facing difficulties understanding the FE Exam which is offered in English? Are they able to translate a problem into Spanish, thus demonstrating that they clearly understand the problem statement?

The author, through personal experience in his 22-year teaching career, has also suspected that students may be facing difficulties in formulating a problem. The capacity to formulate a problem is at the heart of passing the FE Exam. The process of formulating a problem requires critical thinking skills, i.e., to be able to discern the true from the false and know the reasons why. In particular, students must fully understand the concepts so that they know when to apply them (and when not to apply them) in a problem. This skill is encompassed in ABET Outcome E: The ability to identify, formulate, and solve an engineering problem. The research question is: how capable are the Hispanic students in formulating a typical FE Exam problem?

A secondary objective of this paper is to hopefully initiate a discussion that could potentially lead to improvements in the FE Exam passing rates in Puerto Rico and perhaps other areas with large Hispanic populations. Puerto Rico’s population is essentially 100% Hispanic. At this time, it is unknown to the author if other areas with large Hispanic populations are also experiencing a similar pattern. The author has not yet been able to obtain any data outside of Puerto Rico.

The paper is organized as follows: Research Objective: Hypothesis; The Problem; Solution; Language Issue; Problem Formulation Issue; Discussion of Results; Additional Discussion on FE Exam Data Availability; Conclusions; and Future Work.

**Research Objective: Hypothesis**

The research objective of this experiment is to test the following two hypotheses:

1. To test the hypothesis that language is a barrier in the performance of Hispanics in the FE Exam (the exam is offered in the English language).

2. To test the hypothesis that the capacity to formulate a problem is a barrier in the performance of Hispanics in the FE Exam.
The Problem

The problem was selected from the course textbook, FE Review Manual [4]. The author of the textbook, Michael Lindeburg has decades of experience writing review books for licensure exams, including the FE Exam. The author of this paper is also a professional engineer who took and passed the FE Exam and, therefore, has personally faced typical FE Exam questions. The underlying assumption is that the problem may be considered typical of the FE Exam. No other form of validation of the problem was conducted.

The selected problem does not include a figure. This was chosen on purpose to test the students’ visualization skills required to comprehend the problem.

The problem was also chosen so that it was not a fully straightforward math problem that would only require the student to just solve it without any formulation; for example, solving an integral, or solving for the determinant of a given matrix. The problem was chosen as a word problem in which the student had to analyze and comprehend the text of the problem to identify what was asked for, and formulate the approach to solve it.

The problem was also chosen from the engineering mechanics area which is the area of expertise of the author. It is material that the students see in the Physics I course in addition to subsequent courses in engineering mechanics.

The problem statement is the following:

A spring has a constant of 50 N/m. The spring is hung vertically, and a mass is attached to its end. The spring end displaces 30 cm from its equilibrium position. The same mass is removed from the first spring and attached to the end of a second (different) spring, and the displacement is 25 cm. What is the spring constant of the second spring?

(A) 46 N/m
(B) 56 N/m
(C) 60 N/m
(D) 63 N/m

Instructions provided to the student (translated from Spanish)

a. Translate the problem statement to Spanish. Try to demonstrate to me that you clearly understand everything about the problem, including what you must find. You may use figures (recommended). The objective is to determine how well you
understand the English language to investigate if language is one of the causes for which the passing rates in the FE exam in Puerto Rico are approximately 2 times lower than in the USA.

b. Write a plan on how you would address the problem including a combination of words and mathematics. It is not necessary to solve the problem. My interest is in determining how well you can formulate a problem, and how well you approach the solution of a given a problem statement.

You may use the reverse side of the sheet if you run out of space.

Five questions have been eliminated from the exam to provide you approximately 15 minutes to write your answer. This problem will have a value of 5 points. All other problems in the exam have a value of 1 point, just as in the FE Exam.

Solution of the Problem

The way to quickly solve this problem is by using Newton’s 2\textsuperscript{nd} law. First draw a free body diagram of the spring-mass system, sum forces in the vertical direction, and arrive at the equation,

\[ F = kx \]

Since the force is equal to the weight of the mass, for spring 1

\[ W = k_1x_1 \]

Where \( W = mg \), \( k_1 \) is the constant of the first spring \((50N/m)\), and \( x_1 \) is the displacement of the first spring \((30 \text{ cm})\). The same process is conducted for the second spring to arrive at the equation,

\[ W = k_2x_2 \]

where \( k_2 \) is the unknown spring constant and \( x_2 = 25 \text{ cm} \). Since the mass is the same, the two equations may be set equal to each other, e.g.,

\[ k_1x_1 = k_2x_2 \]

from which we arrive at the solution,
\[ k_2 = k_1 \frac{x_1}{x_2} \]

A crucial step in formulating the problem is noting that the weights are equal and therefore, that \( k_1x_1 \) may be set equal to \( k_2x_2 \).

The solution is answer (C),

\[
k_2 = 50 \frac{N}{m} \cdot \frac{30 \text{ cm}}{25 \text{ cm}} = 60 \frac{N}{m}
\]

Similarly, the student could very well have chosen to numerically solve for the weight of the mass, based on the analysis of spring 1, and then used that weight to numerically calculate the answer of the constant for spring 2. In other words, the solution did not require the student to come up with the expression for \( k_2 \) as a function of \( k_1, x_1, \) and \( x_2 \), as shown above. The steps for the numerical calculation are shown below,

\[
W = k_1x_1 = 50 \frac{N}{m} (0.30 \text{ m}) = 15 \text{ N}
\]

\[
W = k_2x_2
\]

Solving for \( k_2 \),

\[
k_2 = \frac{W}{x_2} = \frac{15N}{0.25m} = 60 \frac{N}{m}
\]

The students may have also chosen to include a figure similar to Figure 1 below.

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**Figure 1. Undeformed and deformed states of the spring**
Results – Language Issue

100% of the students were able to clearly translate the problem to Spanish in its entirety. The author, who read all the responses, was able to conclude that the students were able to clearly understand the problem. This included identifying the problem to be solved, which in this case was to calculate the constant of the second spring.

85% of the students committed some orthographic errors in the translation. These orthographic errors, although an indication of sloppiness, did not alter the meaning of the translation. Students were able to clearly understand the problem even though they committed these errors. The distribution of errors is shown in Table 1 below.

Table 1. Percentage of students with orthographic errors in the translation
(n = 27, average = 2.67)

<table>
<thead>
<tr>
<th>Errors</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 errors</td>
<td>15%</td>
</tr>
<tr>
<td>1-2 errors</td>
<td>41%</td>
</tr>
<tr>
<td>3-4 errors</td>
<td>22%</td>
</tr>
<tr>
<td>5+ errors</td>
<td>22%</td>
</tr>
</tbody>
</table>

In 87% of the cases in which orthographic errors were committed, at least one of the errors consisted of not following the accentuation rules of the Spanish language. In Spanish, a tilde is used to accentuate some vowels to clearly identify which syllable should be stressed when spoken. The meaning of the word, however, is not compromised, especially if the original text is available, as in this case.

Table 2 shows the distribution of orthographic errors for students who formulated the problem correctly.

Table 2. Percentage of students with orthographic errors in the translation
Only includes students who formulated correctly (n = 13, average = 2.69)

<table>
<thead>
<tr>
<th>Errors</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 errors</td>
<td>15%</td>
</tr>
<tr>
<td>1-2 errors</td>
<td>31%</td>
</tr>
<tr>
<td>3-4 errors</td>
<td>38%</td>
</tr>
<tr>
<td>5+ errors</td>
<td>15%</td>
</tr>
</tbody>
</table>

Results – Formulation Issue

The three key components for demonstrating the skill of formulating the problem consisted of the following:
1. Selecting an appropriate concept to model the problem, in this case Newton’s 2nd law for static equilibrium (acceleration = 0, other than gravity).
2. Identifying and expressing the fact that the weight is the same in both springs which permits coupling the results of one spring to the other.
3. Formulating the relationship between the two springs, e.g., equating the weight terms. Similarly, the student may opt to calculate the weight and then substitute it into the model for spring 2 to numerically calculate the constant $k_2$.

A typical expected correct answer would be of the following type:

The force in the spring is given by $F = kx$, and since, by static equilibrium, the spring force is equal to the weight of the mass, for spring 1, $W = k_1x_1$. The same situation happens with the second spring so, $W = k_2x_2$. Since the weights on both springs are equal, we can equate both springs as $k_1x_1 = k_2x_2$, and therefore, $k_2 = k_1 \frac{x_1}{x_2}$.

The student may have also chosen to calculate it numerically as mentioned before; that is, mention that from the analysis of spring 1 the weight can be calculated ($W = k_1x_1 = 15N$), and then using the weigh to calculate $k_2 = \frac{W}{x_2} = \frac{15N}{0.25m} = 60 \text{ N/m}$.

The results of the experiment showed the following:

- 13 students (48%) were able to clearly formulate an approach to solve the problem. 8 of the students actually solved the problem and obtained the right answer (60 N/m), although it was not required. The remaining 5 students correctly explained the approach of how to solve it, in their own words. They included all the required steps.
- Regarding the students who were not able to formulate the problem:
  - 1 student (4%) correctly stated $F = kx$, but did not advance beyond this stage. That is, the student did not recognize that, by static equilibrium, the force was equal to the weight of the mass, which could have been calculated, and used for analysis of the second spring.
  - 2 students (7%) attempted to use the principle of conservation of energy to formulate the problem. This is a misconception. They merely stated that the elastic potential energy in the spring was expressed as $V_e = \frac{1}{2}kx^2$, which is a correct expression but does not lead to a solution to this particular problem. They did not mention the gravitational potential energy term $V_g = Wx$, and its required datum, nor the kinetic energy term $T = \frac{1}{2}mv^2$, all of which are represented in the principle of conservation of energy.
3 students (11%) attempted to use the 2nd order differential equation to model the vibration of a single-degree-of-freedom spring-mass-dashpot system, that is, $m\ddot{x} + c\dot{x} + kx = F(t)$. This is another misconception. They merely stated the equation but did not expand on it.

8 students (30%) did not attempt a solution and showed zero work.

Discussion of Results

The results showed that 100% of the students (n=27) were able to fully translate the problem from English to Spanish. Although it is only one experiment, the results strongly suggest that the issue of having the FE Exam in the English language is not as critical as originally hypothesized. However, additional research, needs to be performed before reaching any solid conclusions; for example, are these results repeatable? Also, will the results hold in other areas of the FE Exam, for example, problems in ethics or engineering economics, in which the vocabulary may be more difficult to comprehend and problem statements are usually longer in length?

Still, students committed orthographic errors in the translated text; however, these did not alter the meaning of the problem. The author was able to conclude that the students clearly understood the problem and had identified the problem to be solved (find $k_2$). Table 1 includes the distribution of errors committed by all the students (n=27). Table 2 includes the distribution only for those students who were able to formulate correctly (n=13). Both tables show a similar distribution. The average number of orthographic errors is almost identical: 2.67 errors (n=27) vs. 2.69 (n=13), so those students who were able to formulate correctly were equally apt to commit an orthographic error as those students who were not capable of formulating a solution.

Regarding formulation issues, only 48% of the students were able to correctly formulate the given problem. These students unequivocally showed the three required steps to solve the problem, that is: noting that the spring-mass system had a governing equation of the form $F = kx$; noting that the force, equal to the weight of the mass, was the same for both springs; and formulating the correct relationship based on the fact that the mass was the same for both springs.

Of the remaining 14 students (52%), only 1 (4%) was headed in the right direction by at least indicating the beginning of a potentially correct solution ($F = kx$). However, the student was not able to continue on and formulate the correct relationship with the weight of the mass to solve the problem.

Five students (19%) made a misconception error. Two students attempted to use the principle of conservation of energy (they mentioned $V_e = \frac{1}{2}kx^2$). Although the principle of
conservation of energy is a valid principle, it incorporates a kinetic energy term (as well as gravitational potential energy term). The spring-mass system, once deformed, would oscillate back and forth in harmonic motion with an unknown speed for the given data. Not knowing the speed, nor having the problem set up as a dynamic problem, renders this approach ineffective.

Three additional students started with the $2^{\text{nd}}$ order differential equation used for single degree of freedom vibration problems ($m\ddot{x} + c\dot{x} + kx = F(t)$). This initial step was a dead end and could not be used further. The misconception is similar to attempting to use the principle of conservation of energy in the sense that both misconceptions are due to the fact that they model dynamic systems, not a system in static equilibrium.

The remaining 8 students (30%) did not provide any work. It is not possible to know what they were thinking and, more specifically, if they were considering using the misconceptions mentioned before.

In summary, the results show that 48% of the students were able to formulate the problem correctly. The remaining 52% of the students were not able to formulate the problem, either because of misconceptions, or because they did not provide any work from which to make a judgment.

**Additional Discussion: FE Exam Data Availability**

The NCEES provides data to institutions on the performance of their graduates in the FE Exam. However, NCEES does not follow the same format that they used in [2], where they segregated results of first time exam takers and repeat exam takers. The segregated data would be ideal for research purposes because progress can be tracked for both groups. Prior to 2014, NCEES provided institutions data that combined both groups of first time exam takers and repeat exam takers. Since 2014, NCEES only provides institutions with the results of first time exam takers. The data on repeat exam takers is no longer available to institutions. The author contacted the NCEES to obtain the data on repeat exam takers and was referred to the Puerto Rico Licensing Board which do get a full report from the NCEES (similar to [2]), for all the engineering institutions in Puerto Rico, including the segregated data for first time exam takers and for repeat exam takers. In January 2017 the author petitioned the Licensing Board for the segregated data for graduates of his institution. The author also petitioned for segregated results for the entire population of FE Exam takers in Puerto Rico, without identifying the institutions, to use it as a benchmark in his research.

The lack of a full report on FE Exam results makes it difficult for researchers in engineering education to study the problem and seek solutions. The only publicly available data of FE Exam takers in Puerto Rico dates from 2001-2005. This contrasts sharply with results
from the licensure exam taken by lawyers in Puerto Rico (bar exam) in which the judicial branch publicly releases the results every year, after every exam [5]. In addition, the bar exam passing rates are also regularly published in local newspapers, for example, Reference [6]. Another case in which data is more readily available is the certification exam for K-12 teachers in Puerto Rico which is also regularly discussed in newspapers, for example, Reference [7]. Additional information on the performance in the K-12 teacher’s certification exam is also publicly available, for example, in Reference [8] which is a full report on the exam results provided by a university in Puerto Rico. The passing rate data is not always pleasant but, without data, it is impossible to test and validate alternative solutions that could lead to higher passing rates.

There are two positive developments regarding the availability of data. On February 2017, a bill was introduced in the legislature of Puerto Rico to order the Puerto Rico Licensing Board to release the licensure exam results within 10 days of becoming available [9]. It is not yet clear if the data will be segregated into first time exam takers and repeat exam takers but hopefully it will. It is also not yet clear if the total volumes for Puerto Rico will be reported. The total volumes would serve as a benchmark to compare the results of individual institutions.

Furthermore, the Middle States Commission on Higher Education (MSCHE), which is recognized by the U.S. Secretary of Education to conduct accreditation and pre-accreditation (Candidacy status) activities for institutions of higher education in Delaware, the District of Columbia, Maryland, New Jersey, New York, Pennsylvania, Puerto Rico, and the U.S. Virgin Islands [10], is also requiring universities to publish the results of licensure exams on their university websites, starting in 2017 [11]. The revision is part of MSCHE Standard II on Ethics and Integrity [12].

These two developments in 2017 will assist researchers in engineering education as data will become readily available to track the progress of first time exam takers and repeat exam takers.

Conclusions

This paper described and discussed the results of an experiment that was conducted by the author in a course that trains mechanical engineering students to pass the Fundamentals of Engineering (FE) Exam. The primary objective of the experiment was to differentiate between language difficulties (the FE Exam is in English) versus weaknesses in formulating a problem. The motivation for the experiment stemmed from the fact that the passing rates in the FE Exam in Puerto Rico are approximately half than the national average reported by NCEES. The language issue has been suspected as a probable cause for the lower passing rates in Puerto Rico. The author has also suspected difficulties in problem formulation. The experiment was designed to capture each of these two issues independently. The results showed that 100% of the students
(n=27) were able to correctly and fully translate the problem from English to Spanish. Although it is only one experiment, the results suggest that the issue of the English language is not as critical as originally hypothesized. Still, further research is required to determine if this result is repeatable. Also, if it will hold in problems in which reading comprehension is more complex, such as in the areas of ethics and engineering economics. On the other hand, only 48% of the students were able to correctly formulate the given problem. This may turn out to be an important finding because, if this sample is representative of the entire population’s capacity to formulate, then a passing rate ceiling of 50% is predicted. This ceiling is below the 64.5% national passing rate average in the USA for FY2016. Further research is also required in terms of formulation issues. The author hopes that this paper will stimulate discussion among educators of Hispanic engineering students who, perhaps, have noticed similar patterns in their engineering courses. The “future work” section provides some questions that will guide the next steps in this research program. A more complete set of data will become available beginning in 2017 to facilitate the future work. The Puerto Rico licensing board will hopefully provide segregated data of first time exam takers and repeat exam takers to each institution. The data would consist of the volume of exam takers in each group and the volume that passed the exam in each group. It would also accompany that data with the total volumes for Puerto Rico (also segregated into first time exam takers and repeat exam takers) so that it can be used as a benchmark.

**Future Work**

Some interesting research questions for future work are:

Q1: Are the language results reported in this paper repeatable?

Q2: Will the language results reported in this paper hold in other areas of the FE Exam, for example, problems in ethics or engineering economics, in which the vocabulary may be more difficult to comprehend and problem statements are usually longer in length?

Q3: How fast can a student translate a problem? Is it comparable to the time required for an exam taker whose first language is English? If there is a difference, is it relevant over the approximately six hours allowed for completing the FE exam?

Q4: Is the issue of low passing rates endemic to all Hispanic populations, including those in the mainland USA?

Q5: Is the difficulty in formulating the problem due to poor conceptual understanding or something else (i.e. lack of practice in formulating problems, time pressures, test anxiety, student beliefs in solving problems, etc.)?
Q6: Can we create “threshold” problems that will quickly predict the outcome of the FE Exam? This predictive capability would bring in significant improvements in providing early interventions.

Q7: To the extent that the problem is due to poor conceptual understanding, can certain interventions (concept questions, ranking tasks dealing with concepts, etc.) be used to improve student performance in this area?

If successful, this research program will identify the main causes for lower passing rates in the FE Exam in Puerto Rico, it will identify/create threshold problems that will predict the outcome of the exam, and it will use the threshold problems as a basis for providing additional interventions to raise the level of performance of the exam taker. This new predictive capability would bring in significant improvements in providing focalized interventions to students at risk of failing the FE Exam. It would also benefit the assessment efforts for ABET Outcome E: an ability to identify, formulate and solve engineering problems.

In addition, if this research program is successful, it will address the underrepresented group of Hispanic engineers, first within the boundaries of Puerto Rico, and potentially within all the Hispanic settings in the mainland USA. More licensed professional engineers would be added to the workforce. It could also lead to training programs to faculty that are based on novel predictive capabilities. It would also contribute to the educational mission of any university by providing excellence in education as measured by a standardized test (FE Exam) that has high prestige within the engineering community.

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