AC 2012-3446: VISUAL REPRESENTATIONS IN MECHANICAL ENGINEERING EDUCATION

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Visual Representations in Mechanical Engineering Education

Abstract – In all forms of education, the style by which the visual representation of concepts is presented has a strong effect on both the learning of the students as well as the overall language and processes that the students will use when dealing with those concepts. With a focus specifically on mechanical engineering education, this paper provides an investigation of the role of visual representations in learning concepts in mechanical engineering. One of the main examples of such a visual representation is the free-body diagram which is used to display and analyze forces acting on a body. While, in general, these diagrams are universal in mechanical engineering, each subject within a field (e.g., statics, dynamics, vibrations, etc.) has its own "dialect." That is, while similar, each has distinct characteristics that focus on the specific information needed in that subject. These representations used in engineering education not only influence the learning of the students, but also affect the analytical methods used by students when they encounter similar concepts in their work. This investigation of the role of visual representations in engineering and the students' understanding thereof consists of several parts. First, an overview of such representations in mechanical engineering education is provided. Then a comparison of the different types of visual representations is presented. This paper culminates in a discussion and comparison of the results of this investigation of student learning at various stages in their educational careers. Data is collected from a first-year introductory engineering class and from a senior capstone design course.

Introduction

Whether a textual description, a figure, or an equation; representations are an integral part of any form of communication. In education, representations are even more critical, because the types of representations used and the method in which they are generated can have a great effect on the level of understanding fostered in the student. If the representations used are confusing or difficult to understand it can hinder the students learning since, before the student can realize the concept conveyed, they first need to figure out the manner in which it was represented.

Since each new type of representation encountered by students is akin to a new language, it would seem unwise to try to introduce students to multiple forms of representations at once. This is exactly what is often done in engineering, science, and math education. [1]

In this introductory review of representations in mechanical engineering education, first a general overview of representations in mechanical engineering is presented. Following that, some of the differences in the common types of these representations are discussed. Lastly, the effect that the representations have on the language used by the students is discussed.

Representations in Mechanical Engineering Education

In mechanical engineering education, the approach taken to solving a problem is often presented as a three part process: (1) The educator explains the problem that is to be solved, (2) a sketch of the problem is made to help explain the problem, and (3) finally the applicable equations are introduced. This process is reinforced throughout the discipline and each of the three steps corresponds to one of the following three types of representations; (1) textual, (2) diagrammatic, and (3) symbolic. As is demonstrated in FIGURE 1; each is a separate description of the same system. The first part of this process is a textual description of the problem. The second part is a diagram demonstrating the system described. The last part of this is the set of equations that describe the system.

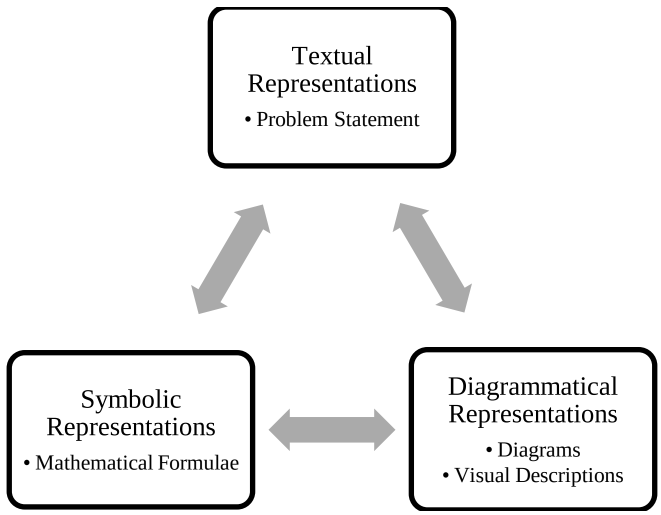

FIGURE 1:
REPRESENTATIONAL INTERRELATIONS

This process mirrors the three main phases of problem solving; problem recognition, problem framing, and problem synthesis. The problem recognition phase is related to the textual representation in that all the information regarding the details of the problem is found in the text. Next, the problem framing phase is associated with the diagrammatic phase in that, when framing the problem, an engineer sketches out the problem and generates assumptions based on the findings of the first phase. Lastly, the problem synthesis phase corresponds to the symbolic phase in that the engineer will use formulae in order to solve the problem as framed.

Another process that mirrors this is “back of the envelope” calculations. Although similar to the general problem solving, in back of the envelope calculations a simplified model of the system is used to find a rough estimate of the solution. These calculations generally involve the same types of translations from text to diagrams to equations as described above, but are performed to find a solution when speed is preferred over accuracy. In the end, the different representations are very simplified and involve many assumptions. [1]

Visual Representations in Mechanical Engineering

In the textual, diagrammatic, and symbolic representational system used in mechanical engineering education, the diagrammatic representation can also be described as a visual representation of the system. There are many types of visual representations in mechanical engineering education including diagrams, flowcharts, and graphs, since they are a method of communication beyond that which textual descriptions alone can provide. [2] Some of these visual representations are free-body diagrams and system schemas. In this section, each of these types of diagrams and their uses will be described.

Free-Body Diagrams

The most common diagrammatic representation used in mechanical engineering is the free-body diagram. That is, a diagram showing the forces acting on the body of interest. The primary use of a free-body diagram is to allow the student to describe the body as a stand-alone element, where all interactions with other parts of the system are indicated only as forces. This allows the student to more easily understand the interactions.

These diagrams are generated through showing only the body of interest and replacing any interaction it has with other bodies as the resulting forces. In a free-body diagram, the body of interest is shown in a simplified shape drawn around the center of gravity. Once the body is drawn, the next step is to indicate the forces acting on the body. An example of this is shown in FIGURE 2. The forces included are the upward force of the wire, T, and the downward force of the weight of the mass, w.

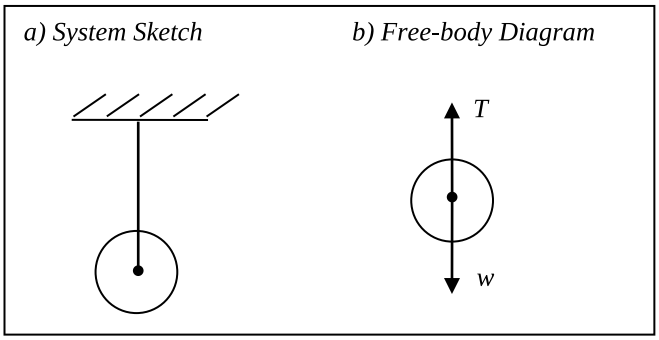

FIGURE 2:
FREE-BODY DIAGRAM OF MASS ON A WIRE

Free-Body Diagrams with Directions

As is shown in FIGURE 3 this visual representation is very similar to the above mentioned simple free-body diagrams. The slight modification that this contains is the inclusion of the angles between all forces and the coordinate axes, even when these angles seem obvious. The purpose of this is to aid the students in their understanding that all forces are vectors that contain both magnitude and direction. Another purpose of this is to help the students avoid errors due to incorrect signs when using sines and cosines. Including the angles allows students to calculate the sum of the forces in either the x or the y direction without needing to worry about which forces are applied where and instead uses the values of the sines and cosines to cancel out those values that do not apply. [3]

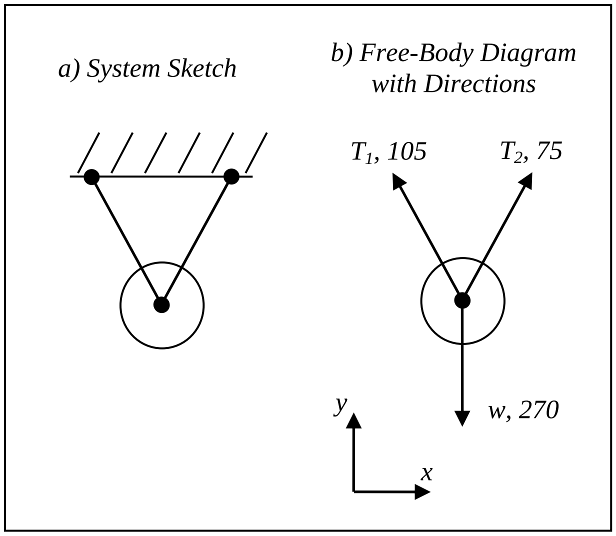

FIGURE 3:
FREE-BODY DIAGRAM WITH DIRECTIONS

System Schemas

An alternative visual representation in mechanical engineering is a system schema, which is created in support of the free-body diagram. This is a representation of the system as a whole that indicates all interactions between the separate parts. The primary purpose of this is that it enables the student to keep track of how all the parts in the system interact with each other, which in turn serves as a reminder for what forces to include in the free-body diagram.

In this representation each part of the system is indicated with a circle. Once all parts have been identified, lines are drawn between the circles to indicate interaction. Whenever a line ends on a circle, it indicates that a force acts between the two bodies. An example of this is shown in FIGURE 4. [4]

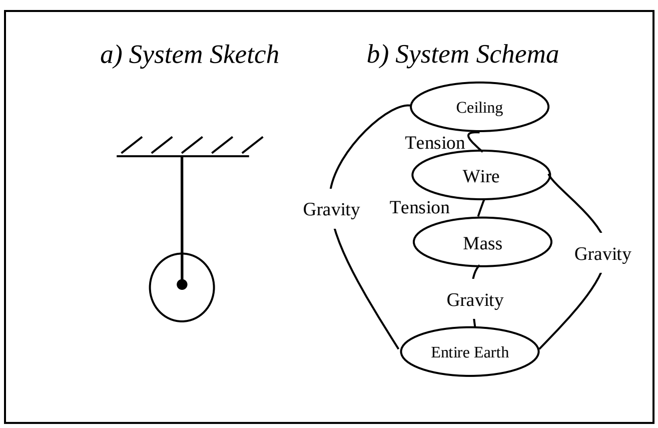

FIGURE 4:
SYSTEM SCHEMA OF A MASS ON A WIRE

Description of the Assessment Survey

The purpose of the study was to analyze the difference between students in a freshman engineering course and seniors in a capstone design course. The survey was designed for this purpose. A focus was made on physics principles in the form of various representations. A question was given in each of the forms: text, visual, and symbolic, An answer was requested to be in a different form than the question. An example is shown below in FIGURE 5. This was done to test the students' abilities to convert between the forms. The students were also requested to provide information regarding their school year, major, and level of physics they had taken. This was done so that students could be classified into groups for statistical data.

Academic year – based on courses taken, not total credit hours. Mark only ONE.

Freshman ☐ Sophomore ☐ Junior ☐ Senior ☐

Highest level Physics I course. Mark only ONE.

College (Calc.) ☐ College (Alg.) ☐ Highschool (AP) ☐ Highschool (not AP) ☐

Major: ____________________

1. Given the following equations of motion, draw a visual representation of the motion:
   $\theta = 30 \quad v_i = 5$
   $0 = v_i \sin(\theta) - \frac{gt}{2}$
   $d = v_i \cos(\theta)\, t$
   $h = \frac{v_i \sin(\theta) t}{2} - \frac{gt^2}{4}$
2. Draw a free-body diagram for the system described in problem 1. Show the free-body (1) at the start, (2) final distance, and (3) maximum height.
3. If you push a heavy chair by its back starting from rest in one location to a new location on a flat floor, what would the free body diagram look like during the action of pushing it?
4. Explain the situation and forces on each block with a written answer:

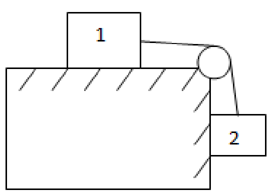

FIGURE 5:
SAMPLE SURVEY

Grading of Surveys

In order to evaluate the surveys in a consistent manner, a grading rubric was created. This is shown in FIGURE 6:. The surveys were comprised four questions and each question was worth a maximum of two points. Furthermore, the questions were then graded on a scale to allow for partial credit, with a completely incorrect or blank question receiving 0 points, a question containing partial answers receiving 0.5, 1.0, or 1.5 points depending on the level of understanding shown, and a correct answer receiving the full 2 points.

Rubric	2 Points	1.5 Points	1 Point	0.5 Points	0 Points
Question 1	Drew a visual representation showing the motion of the object		Only drew initial conditions		No work or Incorrect
Question 2	Three FBDs with proper forces labeled	Included forces as well as velocities on each FBD	Some FBDs have errors	Only provided one FBD or had significant amount of errors	No work or Incorrect
Question 3	FBD with proper forces labeled and assumptions		Errors in assumptions or forces labeled		No work or Incorrect
Question 4	Explained all assumptions and forces	Missed explanation of force or did not provide assumption	Errors in assumptions or forces explained	Answer was not written	No work or Incorrect

FIGURE 6:
SURVEY GRADING RUBRIC

Survey Results and Discussion

A total of one hundred sixty-seven (167) students were surveyed. Of the students, sixty-two (62) of them were freshman engineering students and one hundred five (105) were senior engineering students. The freshman engineering students were made up of engineering students that have not yet selected their specific discipline; all engineering students at Binghamton University share a common first year and are asked to declare their majors at end of the second semester. The senior students that participated in the survey were students in Mechanical Engineering, Electrical Engineering, or Computer Engineering who all share a single Senior Projects class at Binghamton University. The data collected from the surveys provided some unexpected results. Approximately 20% of students taking the survey scored above a 75%. However, the results showed that there was no significant difference between the capabilities of senior and freshman engineering students. FIGURE 7 shows the small difference between the freshman and senior average scores.

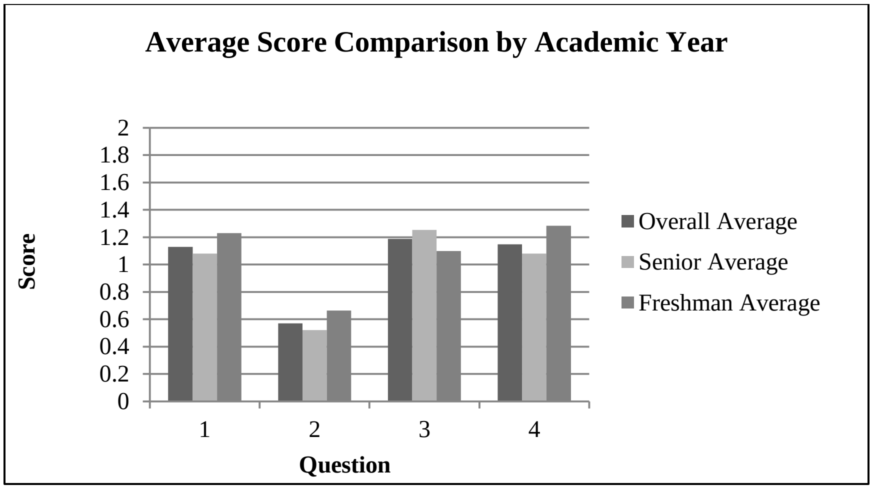

FIGURE 7:
SURVEY COMPARISON BY ACADEMIC YEAR

However, there was a significant difference between the students when it came to the level of physics they had taken. In FIGURE 8 you can see that students who had taken Advanced Placement physics scored much higher on average than students having taken High School physics.

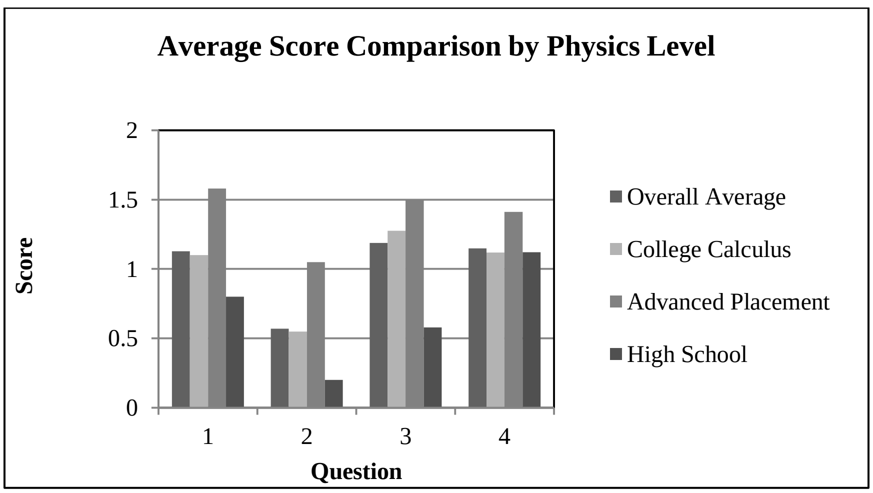

FIGURE 8:
SURVEY COMPARISON BY PHYSICS LEVEL

All senior students had taken a calculus based college physics course. The freshman students were about evenly split between Advanced Placement and High School physics. For most of the questions the students who took Advanced Placement physics scored double the average of students having taken High School physics.

One possible explanation for such unexpected results is that the surveys were presented in the students' classes but were anonymous and students were informed that they would have no effect on their grades. This led to many of the surveys containing blank answers, some of which only had a single attempted question. Whether these were due to the students not knowing the correct response, or due to the student skipping the questions to save time or effort is unknown.

Conclusion

Results showed that there was no significant difference between the capabilities of senior and freshman engineering students. It was determined that the primary factor affecting performance was the level of physics taken in high school. There was a significant difference between the students when it came to the level of physics they had taken. Students who took Advanced Placement physics scored much higher on average than students having taken non AP high school physics.

The results of the survey were unexpected, and further study will be needed in order to fully investigate the impact of the method of using free-body diagrams in high school physics had on later student performance in college mechanical engineering.

References

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