AC 2009-579: NO NUMBERS: CONCEPTS-BASED TESTING IN ENGINEERING

Joseph Walchko, United States Military Academy

No Numbers -- Concepts Based Testing in Engineering

Abstract

Emphasis on conceptual learning, instead of fact storing and memorization, is prominent in engineering curricula. A "no numbers" methodology is presented and discussed with focus on conceptual instruction and testing. This "no numbers" methodology is used and evaluated in an undergraduate dynamics course. Student feedback and examination scores suggest that this methodology is an excellent means to stress and then test concepts within a dynamics course. The students agree that their conceptual knowledge increases when both course instruction and exams utilize the "no numbers" methodology. Exam scores also increase when this methodology is applied throughout the entire course (classroom instruction, in-class example problems, homework problems, and exams). While the "no numbers" methodology is successful in an undergraduate dynamics course, further application of the methodology to other engineering courses seems promising.

1. Introduction

Conceptual learning is commonplace in current engineering education curriculum. Students taught to develop a conceptual understanding of various aspects within a particular engineering course will be more proficient at problem solving and abstract reasoning. They will be able to generalize their knowledge to new situations and more likely to make connections to related information [1]. Contrary to conceptual learning is rote, or non-meaningful learning, which emphasizes a skill acquisition approach with few provided relationships between skills[2]. Prince and Vigeant noted that students are frequently able to solve problems that have been explicitly taught, but are unable to apply course concepts to solve real problems not seen in class[3]. The majority of engineering educators, given the choice, should prefer that their students understand the engineering concepts and relationships which could be applied to a vast number of designs and problems and across multiple disciplines within engineering.

From the learning theory of constructivism and ideas of Swiss psychologist, Jean Piaget, comes a theory of how to teach science, known as the scientific learning cycle. The scientific learning cycle consists of three phases: exploration, term introduction, and concept application[4]. Considerable evidence is present stating that this scientific learning cycle is more effective in teaching science than other traditional methods. This same learning cycle is applied in engineering curriculum as well. In the third phase, concept application, students apply knowledge across a variety of problems and disciplines.

Many in the engineering education community adopt and use conceptual learning techniques to enhance the students' understanding in a particular discipline. Darmofal, Soderholm, and Brodeur applied concept maps and concept questioning to enhance conceptual understanding in aeronautics and astronautics courses at the Massachusetts Institute of Technology[5]. Yap and Wong assessed conceptual learning at the Nanyang Technological University, Singapore [6]. Brodeur, Young, and Blair utilized problem based learning as a form of conceptual learning in the aeronautics and astronautics curriculum at the Massachusetts Institute of Technology[7].

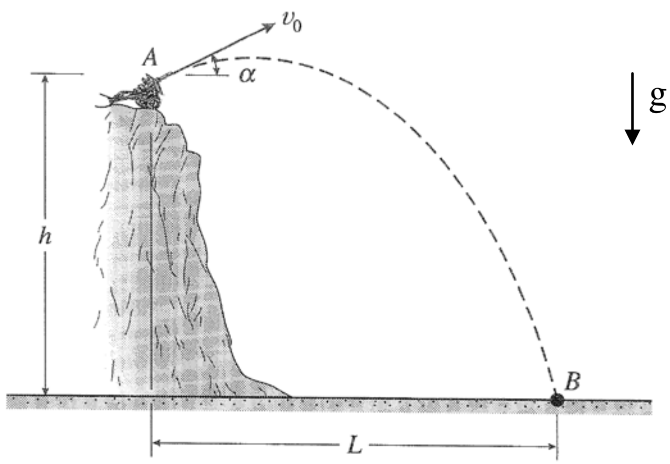
This paper presents a methodology for instruction and testing in an engineering course based on conceptual learning techniques. The examinations within an undergraduate dynamics course (and many of the homework problems) contain no numbers, only variables, forcing the student to prove their knowledge of the concept and thus eliminating the need to do extensive math calculations. The genesis of using only variables in the exam questions stemmed from the fact that the exam was administered in a standard 55 minute class. To alleviate the student from spending time doing math calculations, the exam questions were written in such a way, that the student was only required to provide the necessary equations to solve the dynamics problem, but not actually solve it.

2. The Process

Undergraduate dynamics lends itself to utilization of a "no numbers" methodology for testing where only variables instead of numbers are present in the questions. In dynamics, a particular concept is presented that can be applied across multiple facets. An example of this is uniformly accelerated motion (U.A.M.). One can use U.A.M. in the analysis of particle dynamics, systems of particle dynamics, and rigid body dynamics. The principle concept remains the same throughout; the acceleration of the particle (or center of mass for a system of particles / rigid body) remains constant. A particular example of U.A.M. or constant acceleration is found in projectile motion problems. The concept is that acceleration in the vertical direction (y-direction) is constant at the acceleration due to gravity, g, while the acceleration in the horizontal direction (x-direction) is zero. While the initial and final conditions of each specific example of projectile motion may change (release elevation, impact elevation, initial release velocity and orientation), the underlying concepts of acceleration due to gravity in the vertical direction and zero acceleration in the horizontal direction don't change. The student need only to understand this concept, and he or she should be able to apply these concepts to any projectile motion problem, regardless of initial / final conditions and geometry of the problem. The student will be able to obtain an independent equation from the vertical direction and another independent equation from the horizontal direction. This system of equations can be solved for two unknowns utilizing a mathematical solving routine (by hand or computer software).

Using the instruction and testing methodology presented in this paper, a projectile motion question is written with variables in place of numbers (Figure 1). The student is instructed to write only the necessary equations to solve for a particular aspect of the problem, but not to solve the mathematics. This evaluates the students' conceptual knowledge of the dynamic aspect of uniformly accelerated motion but does not use precious exam time evaluating his or her ability to solve a system of equations, which is better served in a mathematics class.

An artillery piece at *A* launches a round with initial velocity v_o at an angle α from the horizontal. The height of the artillery piece (h), is known. Write all the necessary equations you would use to solve for the range (L) to the impact point at point B. DO NOT SOLVE.



[8] (Picture only)

Figure 1. Example projectile motion examination question utilizing the "no numbers" methodology

In addition, follow on questions can be used to further emphasis the concept. For the particular problem in Figure 1, a logical follow on question is… "An answer found is that $L = [v_o \cos(a)] / gh$. Provide one reason why you believe this answer to be correct or not." This type of questioning, forces the student to synthesize the concept and given information in order to decide if the answer is correct. The student can do a units check, magnitude check, mathematics relationships, etc. to evaluate correctness.

This "no numbers" methodology was used throughout the dynamics course to enhance the students' conceptual knowledge of a particular subject. The emphasis of concepts (and at the same time, de-emphasis of numbers) in multiple problems forced the students to apply concepts across a broad range of problems, instead of simple relying on rote memorization of a particular fact or problem set-up.

3. Study Results

This "no numbers" methodology was implemented in an undergraduate dynamics course without any laboratories, only lecture style classes. At first, only a partial "no numbers" concept teaching method was use. That is, only the examinations were created and administered in the "no numbers" format. The homework problems and in class examples still had numbers and forced the students to utilize some type of solving routine to determine a final numerical answer to a given dynamics problem. As time and computer access were not an issue on homework problems, it was determined that a "complete" analysis of a particular dynamics problem was beneficial to the students learning and understanding. The "no numbers" exams were considered easier by the instructors because they only consisted of determining equations and removed the need for extensive mathematical analysis. However, students did not feel the exams were fair with respect to homework problems and in-class examples. Student feedback from an end-of-course assessment in a year *before* the “no numbers” methodology was fully integrated, highlights this sentiment (five such examples):

1. Put numbers in the exams so we can more easily check answers.
2. Lessen the difficulty of the exams a little. Include values in the question.
3. I would make the problems on the exams have numbers. I couldn't tell if I was getting an accurate answer because the answer didn't have much meaning in the context of the problem.
4. A practice exam before the real one so students know what to expect. I think the lowest grades came from the easiest exam because students were just unsure of the format. Also, make homework problems sets and the exams the same types of questions instead of using just numbers for one and just letters for another
5. I would provide more problems similar to the exams and I wouldn't change the final from the style of the exams.

In subsequent academic terms, attempts were made to reduce this student perception of unfairness in exams. The “no numbers” concept methodology was fully implemented throughout the entire course. The homework problems and in-class example problems were modified to resemble the exam style. That is, instead of adding numbers to the exam questions, the numbers in the homework problems and in-class example problems were removed in lieu of variables. The “no numbers” methodology was extended throughout the course, honing the students’ conceptual knowledge and understanding about a particular topic in dynamics. Additionally, emphasis during classroom instruction was placed on understanding the concept versus understanding a specific example.

Tabulated student feedback from end-of-course surveys shows the promising aspect of a fully implemented “no numbers” concept methodology. Figure 2 compares the response scores on an end-of-course survey *before* the “no numbers” concept was fully implemented, to response scores on the same end-of-course survey *after* the “no numbers” concept was fully implemented. The “*before*” numbers are an average of three semester’s survey data. The “after” numbers are from an average of two semester’s survey data. The surveys use an opinion scale (Answers: [5] Always [4] Frequently [3] Sometimes [2] Rarely [1] Never).

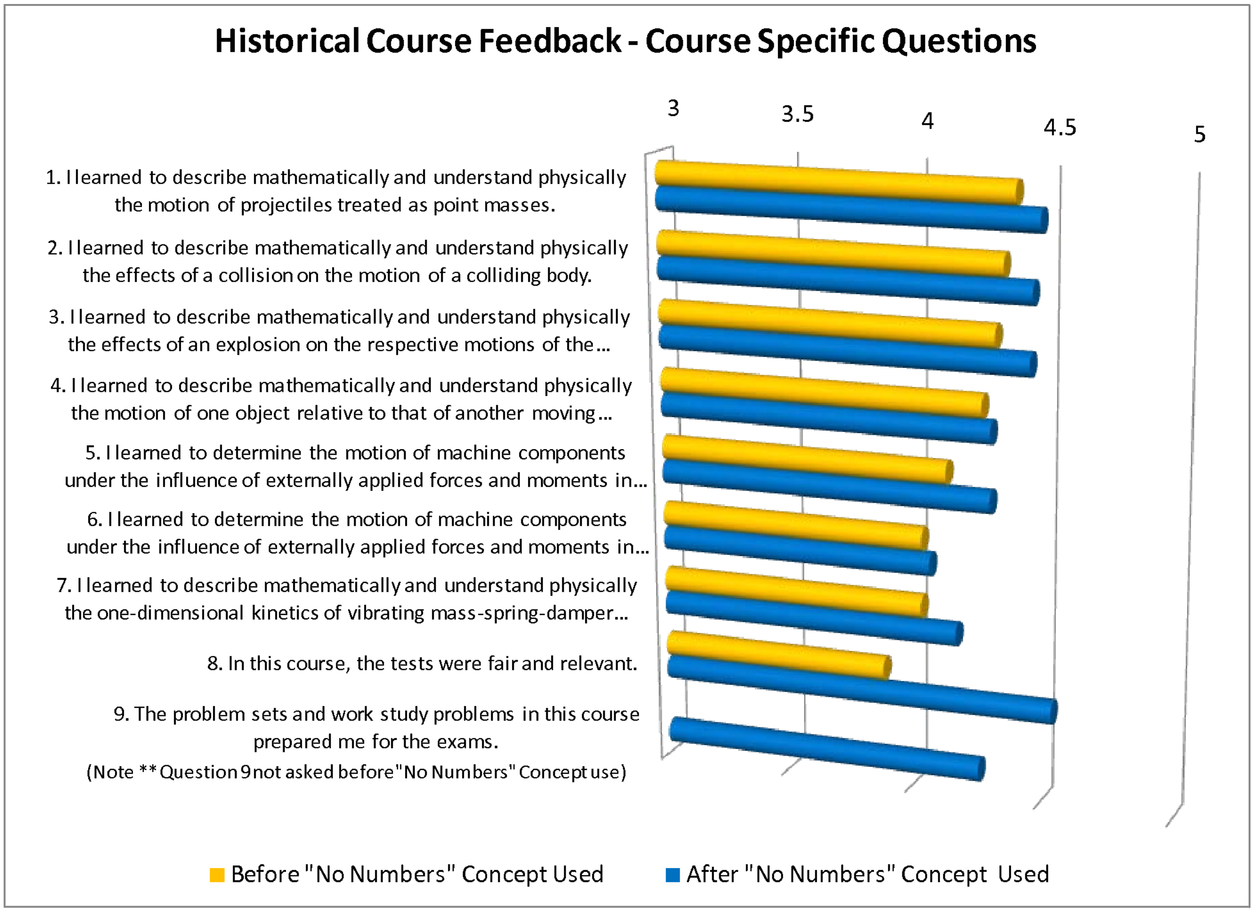


Figure 2. Historical Course Feedback – Course Specific Questions

The results of the “no numbers” methodology are promising. When specifically queried about the fairness of course exams during end of course surveys (Question 8 in Figure 2), the students responded with much higher marks after the “no numbers” concept methodology was fully implemented. The students became familiar with not seeing numbers in in-class problems and homework problems, and consequently felt more at ease with the exam problems that also had no numbers.

At the end of the course, the students also felt more confident in their conceptual understanding of key course objectives after implementation of the full “no numbers” concept (Figure 2 – Questions 1-7). Furthermore, student feedback from the “no numbers” instruction and testing made little or no mention of the fact that the exams had no numbers.

In addition, students were surveyed concurrently at three different times during the course (after each testing block) and again at completion of the course after the full “no numbers” implementation. The students were asked to comment on their confidence in their conceptual knowledge of the aspects of dynamics in the block just completed (after taking the exam and results provided back to the student). They were also asked to comment on the homework problems, in class problems, and the exam of the previous dynamics block. Figure 3 displays the graphical results of these concurrent surveys. Again, the scale used for questioning was an opinion scale (Answers: [5] Strongly Agree [4] Agree [3] Neither Agree nor Disagree [2]

Disagree [1] Strongly Disagree). While the student's confidence in their conceptual knowledge was lower concurrently during the course than at the end of the course (comparing to results in Figure 2), this could be attributed to a level of discomfort in a teaching style unfamiliar to them at the onset of the course. The students did agree more with the statement that the homework problems prepared them for the exam, and that the exam was fair because the questions asked were similar in nature to the problems they had seen throughout the course (Figure 3, Questions 2 and 3). The "no numbers" concept, when fully implemented throughout the course, was a positive experience from the student's perspective. Consequently, as the course progresses the student's confidence in conceptual knowledge increases and by the end-of-course survey, they rate their confidence with higher marks (Figure 2).

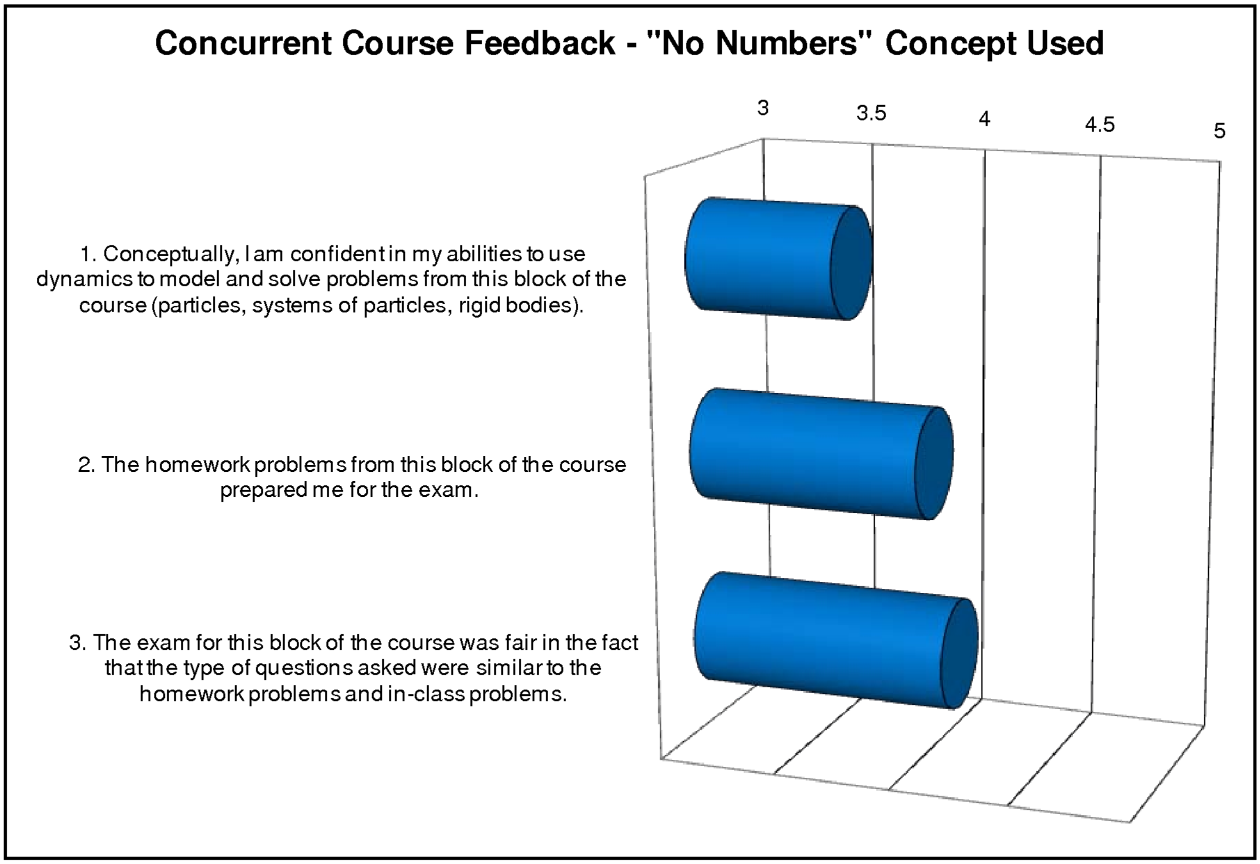


Figure 3. Concurrent Course Feedback when "No Numbers" methodology used

While the students generally felt better about their conceptual knowledge and abilities on the exams as they had in previous terms, did their performance on exams change at all? Comparing students' graded events scores of those academic terms before the "no-numbers" method was fully integrated throughout the course, to the scores after adoption of the "no-numbers" methodology throughout the course, exam scores increased in every case (Figure 4). Although the questions on each exam were slightly different, the concepts and material covered was the same for all academic years' exams. It appears that the student's conceptual knowledge in the course increased. This is in agreement with their own assessments on student feedback mentioned earlier in this paper.

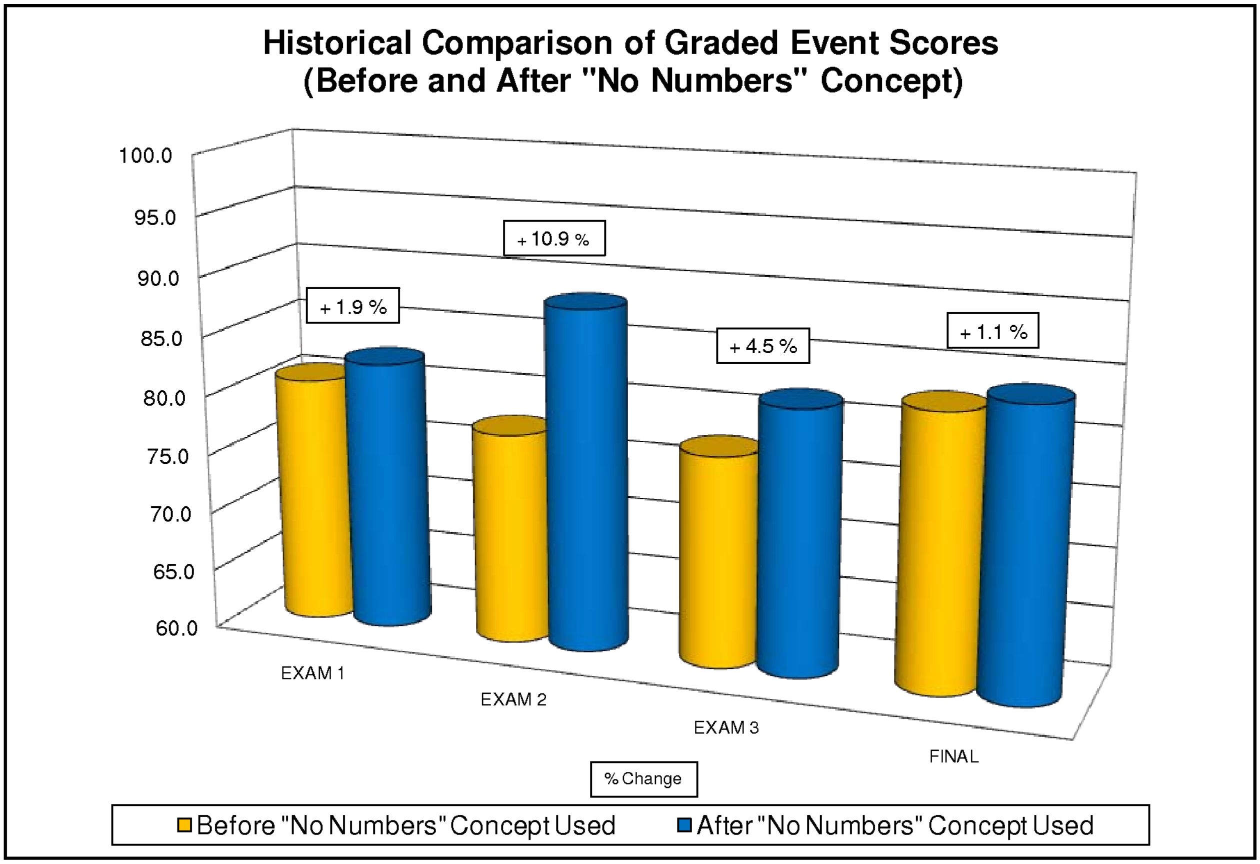


Figure 4. Historical Comparison of Graded Event Scores (with percentage increase using "No-Numbers" methodology)

One may suggest that these increases in exam scores may be the result of fewer places for the student to make an error due to the reduction in mathematic calculations. However, in all exam utilized in this research, the "no numbers" concept was used in creating the exams. That is, even the "before" exams had the numbers left out in the interest of shortening exam completion time. Therefore, the exams themselves "before" and "after" were generally equal. The students just performed better when the "no numbers" concept was fully implemented throughout the course, not just for the examinations.

While the fully implemented "no numbers" concept increased student understanding and conceptual knowledge in this course, it may have some drawbacks. Mathematically, the skills of the student are less likely challenged and reinforced using this "no numbers" concept. The undergraduate education in engineering is facilitated by fostering and application of mathematics learned in the first few semesters of undergraduate education. These skills are most certainly perishable without continued emphasis in an engineering curriculum. This "no numbers" concept may lead to this degradation of math skills in the undergraduate student.

4. Conclusions

Conceptual learning continues to be emphasized in engineering curricula. The “no-numbers” methodology is a means to focus students on the particular concepts of a given engineering course by removing numbers from examples and exam questions and replacing them with variables. This forces the student to understand the concept and worry less about getting the correct numerical answer. This “no-numbers” methodology was used and evaluated in an undergraduate dynamics course. Student feedback and examination scores and results suggest that this methodology is a very adequate means to stress and then test concepts within a dynamics course. While there may be some degradation in math skills from implementing a “no numbers” methodology, there does not appear to be any long term implications of using such instruction and testing style. The students agreed that their conceptual knowledge increased when both course instruction and exams utilized the “no-numbers” methodology. Exam scores also increased when this methodology was applied throughout the entire course (classroom instruction, in-class example problems, homework problems, and exams). The “no-numbers” methodology was successful in an undergraduate dynamics course, and further application of the methodology to other engineering courses seems promising.

Bibliography

1. Ormrod, J., “Human Learning, 5th Ed.,” New Jersey, Merrill-Prentice Hall, 2008, pp 249-307.
2. Snowman, J. and Biehler, R., “Psychology Applied to Teaching, 6th Ed.” Boston, Houghton Mifflin, 2003, pp. 430-446.
3. Prince, M. and Vigeant, M., “Using Inquiry-Based Activities to Promote Understanding of Critical Engineering Concepts,” *Proceedings of the 2006 ASEE Annual Conference & Exposition*, Chicago, IL, 2006.
4. Wankat, P. and Oreovicz, F., “Teaching Engineering,” New York, McGraw-Hill, Inc., 1993, pp. 284-288.
5. Darmofal, D., Soderholm, D., and Brodeur, D., “Using Concept Maps and Concept Questions to Enhance Conceptual Understanding,” *Proceedings of the 32nd ASEE/IEEE Frontiers in Education Conference*, Boston, MA, 2002.
6. Yap, K., and Wong, C., “Assessing Conceptual Learning from Quantitative Problem Solving of a Plane Mirror Problem,” *Physics Education*, Vol. 42, No. 1, January 2007, pp. 50-55.
7. Brodeur, D., Young, P., and Blair, K., “Problem-Based Learning in Aerospace Engineering Education,” *Proceedings of the 2002 ASEE Annual Conference & Exposition*, Montréal, Quebec, Canada, 2002.
8. Das, B., Kassimali, A., Sami, S., “Engineering Mechanics: Dynamics,” Burr Ridge, Richard D. Irwin, Inc., 1994, p. 57.