Correlating Engineering Statics Student Performance with Scores of a Test over Pre-requisite Material Involving Problem Solving

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Abstract

A test over pre-requisite Physics material involving problem solving was developed for use at the semester's start in Engineering Statics. This test is different from a Concept Inventory test which emphasizes student understanding of concepts through a series of multiple-choice questions. The new "pre-test" involves the application of concepts and knowledge through problem solving rather than multiple-choice questions *alone*. This pre-test was administered to almost 750 students in 13 sections taught by four different instructors over 2½ years at Wichita State University. Results show that pre-test scores correlate reasonably well with the semester grade point where the Pearson correlation coefficient was +0.45.

Introduction

In today's increasingly technology-driven world, nations and states must increase the number of workers with the appropriate Science, Technology, Engineering, and Math (STEM) skills that are necessary to remain competitive. This viewpoint is confirmed by, "a number of studies [that] have shown that 50 to 85 percent of the growth in America's GDP is attributable to advancements in Science and Engineering."[1] As another example of the need for more workers with STEM skills, the state of Delaware's STEM Council recently found that "for every unemployed person in Delaware, there are 3.8 open jobs in STEM fields, and for every non-STEM job there are 1.7 people in the state."[2] According to a report from Georgetown University, "STEM occupations [in the United States] will grow far more quickly than the economy as a whole (17 percent versus 10 percent)."[2] In order to address this need for more workers with STEM skills, many states are beginning to increase spending on STEM-related degree programs. In the state of Kansas, a recent STEM initiative added 10½ million dollars per year to the three state universities with Engineering programs (i.e., 3½ million dollars per year to each university) in order to increase Engineering graduation numbers by 60% over the next ten years.[3]

One roadblock to initiatives for increasing Engineering graduation numbers is the issue of student retention. It is well-known that Math and Physics have a tremendous impact on Engineering student retention. According to assessment of freshman courses at Purdue University,[4] the main reason many students gave for leaving Engineering was "difficulty with Calculus, Chemistry, or Physics." At Pennsylvania State University,[5] the best predictor of freshman year Engineering student retention was grades in Physics I, Calculus I, and Chemistry I. Thus, student performance in Math and Science during the first year together with an understanding of this material content is critical to Engineering student retention.

In order to address this retention issue, a pilot program was begun at Wichita State University to teach the Calculus-based Physics in-house within the College of Engineering. At Wichita State, one common complaint heard from Engineering students is the disconnect between Math and Physics courses which are taught with a "theoretical" emphasis and the applications-oriented Engineering courses. In order to help with this issue, a number of different universities have incorporated a revised first year Math and/or Physics curriculum where students are provided with "increased relevance between the material being studied and student perception of their career needs. As a result, students [were] more highly motivated to master material being presented"[6] and increased student retention followed. A similar approach was taken in a pilot program at Wichita State where Engineering applications were incorporated within Engineering Physics in order to motivate students and improve their performance. Prior to the pilot program, the traditional Physics course was taught in large (~70+ student) class sizes which resulted in relatively large numbers of D, F, and W grades in that course. For the pilot program, the traditional Physics course continued to be taught in the Liberal Arts and Sciences along with the Engineering Physics course, but both were taught in smaller (~35-40 student) class sizes.

Engineering students who pass Physics must then go on to take Engineering Statics. However, student performance in Statics is typically lower by 1 to 1½ letter grades. Preliminary data from the pilot program indicated that the grade reduction was better (i.e., less of a reduction) by about half letter grade for the applications-oriented Engineering Physics course compared to the traditional Physics course. For example, a student who achieved a B in Engineering Physics would perform at a C+ level in Statics while a student who achieved a B in the traditional Physics course would perform at a C- level in Statics. One notable similarity between Engineering Physics and the traditional Physics courses was that the pass rate was the same in both courses. This is probably due to the similarity in class sizes. The Engineering Physics pilot program was recently phased out, but the Liberal Arts and Sciences now teach their traditional Physics course in smaller class settings.

Once past the freshman year, a "bottleneck" affecting student retention is Statics. At Wichita State University, all Engineering students must take and pass Statics before graduating with an Engineering degree. However, what constitutes passing is somewhat different depending upon the major. Aerospace, Manufacturing, and Mechanical Engineering majors must pass the course with a grade of (flat) C which is equivalent to a 2.0 grade point because Statics is a pre-requisite to subsequent Engineering courses taken in these majors. On the other hand, Computer, Electrical, and Industrial Engineering as well as Bio-engineering majors must pass at a D- rate which is equivalent to a 0.7 grade point because no subsequent course with Statics as a pre-requisite is required. (Of course, all students must maintain an overall 2.0 grade point *average*.) Although there is a grade requirement difference between majors, "passing" will be considered to be grades of A, B, or C (i.e., down to C-) for the sake of simplicity. Based on this criterion, approximately 64% of the students during the last 2½ years (including repeaters) "passed" the Statics course at Wichita State. This is similar to the pass rate at California State Polytechnic University in Pomona during the mid-2000's where the pass rate was 56%.[7]

Test for Pre-requisite Knowledge and Skills Associated with Statics

In order to determine what types of knowledge and/or skills are associated with passing Statics, a test over pre-requisite material involving problem solving was incorporated into the Statics course. The original motivation behind this "pre-test" in Statics was to use it as an outcomes assessment of Engineering Statics-type knowledge gained by students in the Engineering Physics and traditional Physics classes. For many years, the Physics Department has utilized a Force Concept Inventory[8] type of test as a part of the final exam in the traditional Physics course. According to the Physics faculty, the students in their classes "perform well" in the Force Concept Inventory test. Nevertheless, the Engineering students who go on to take Statics perform 1 to 1½ letter grades lower than in the Physics course. In order to investigate the reason behind this discrepancy, a different type of outcomes assessment was sought as a pre-test in Statics.

Although the Force Concept Inventory was originally devised for the Physics material, a similar type of Concept Inventory test was developed by some faculty at Carnegie Mellon University for Statics.[9,10] One distinct feature of the Concept Inventory test is the emphasis on conceptual understanding through simple multiple-choice type questions, which makes it relatively easy to grade the test. Nevertheless, the Statics Concept Inventory test given near the *end* of the semester has been shown to correlate well with the semester grade (where Spearman's rank correlation coefficient is -0.55),[9] and with individual exams given throughout the Statics course.[11] Another type of test (or "tack") taken by some faculty at Arizona State University is a Statics Skills Inventory test.[12] Here, the emphasis is on the skills required to *apply* the engineering knowledge rather than a simple test of students' understanding of the basic concepts. Since the Force Concept Inventory test used by the Physics department did not provide any insight into why students under-perform in Statics, a test utilizing a different "tack" (i.e., something other than simple multiple-choice questions *alone*) was sought. Since the Statics Skills Inventory test at Arizona State University was still under development at the time, a new / different pre-test was developed at Wichita State University.

Statics Pre-test Format and Conditions

The Statics pre-test developed at Wichita State consists of six problems over material covered in the pre-requisite Physics course. In fact, the questions are problems directly from or are quite similar to problems in a standard Physics textbook. However, they have direct applications to Engineering problems in Statics, and are in a simpler basic form. The topical areas covered by the six problems are: (1) vector magnitude, (2) vector resultant, (3) friction, (4) dot product, (5) torque (i.e., moment), and (6) force equilibrium. Many of the problems involve multiple parts where the answer for part (b) depends on the answer from part (a). The exceptions are those for dot product which only has one part and vector magnitude which has two independent parts (i.e., effectively two separate questions "rolled" into one). These questions are posed in multiple-choice format with some wrong "answers" that could be part-way to the final correct answer or are the answer to a different version of the pre-test. Also, the friction problem's part (a) is conceptual in nature and given in multiple choice format, but only has an indirect role in solving part (b).

In order to allow comparison from semester to semester as well as from instructor to instructor, the problems in the pre-test were essentially the same from one administration of the pre-test to the next. The main difference was a change in the given values to the problems (e.g., magnitude or angle) and order of the answers in multiple-choice questions. Additional details about the pre-test problems are unfortunately not included in the paper. The reason is to prevent students from obtaining too much information which can change the results in future administration of the pre-test. The oral presentation during the conference, however, will include further details.

Each Statics instructor used a standard process for the pre-test. Students were informed about what topical areas were involved (i.e., the list of six topics discussed earlier). The pre-test was given one week after the start of the semester, without any direct review of the pre-requisite Physics material. Students were asked to bring a scientific calculator with the ability to perform calculations involving trigonometric functions. The pre-test was closed book, closed notes, without the use of self-generated crib sheets. However, an equation sheet consisting of a copy of the inside front cover of the Statics textbook (Hibbeler's *Engineering Mechanics: Statics*) was provided. Students were cautioned that the notation used in the Statics textbook may not be the same as the Physics textbook they used. Irrespective of the amount of class time available, students were given a fixed length of 50 minutes maximum to take the pre-test. It should be noted that roughly half of the students were finished in about 30 minutes during any given administration of the pre-test. Thus far, the first author graded all of the pre-tests. This ensured a consistent grading process and methodology. Although students were informed about their overall score in the pre-test, the graded tests were not returned nor were students allowed to view them again. The only minor variation from instructor to instructor was the value given for the pre-test which ranged from 3% to 5% of the semester grade.

Results and Analysis

Table 1 presents the results correlating average pre-test score against semester grades in major groupings of A, B, C, D, and F as well as W for withdrawal. The results are for 733 students in 13 sections of Statics from spring 2012 through spring 2014. Although 749 students took the pre-test, 733 students received letter grades or withdrew from the course by the tenth week out of the fifteen week semester and received a "grade" of W - the remaining 16 students never registered. It should also be noted that there are a few students who show up more than once due to repeating the course in a subsequent semester. Wichita State has a 12-point grading scale with + or – discriminators in A through D grades, except that an A+ is not given. The letter grades correspond to the following grade points: A = 4.0, A- = 3.7, B+ = 3.3, B = 3.0, B- = 2.7, C+ = 2.3, C = 2.0, C- = 1.7, D+ = 1.3, D = 1.0, D- = 0.7, and F = 0.0. No grade points are given for withdrawal (i.e., a "W" grade is not part of the grade point average calculation). Figure 1 present the results for the same 733 students, but with + or – discriminators included in the grade.

Table 1. Average pre-test score for each major grade category.

	A's	B's	C's	D's	F's	W's
Average pre-test score	78.4%	67.8%	65.2%	56.2%	53.9%	50.3%
Number of students	147	172	160	98	110	46

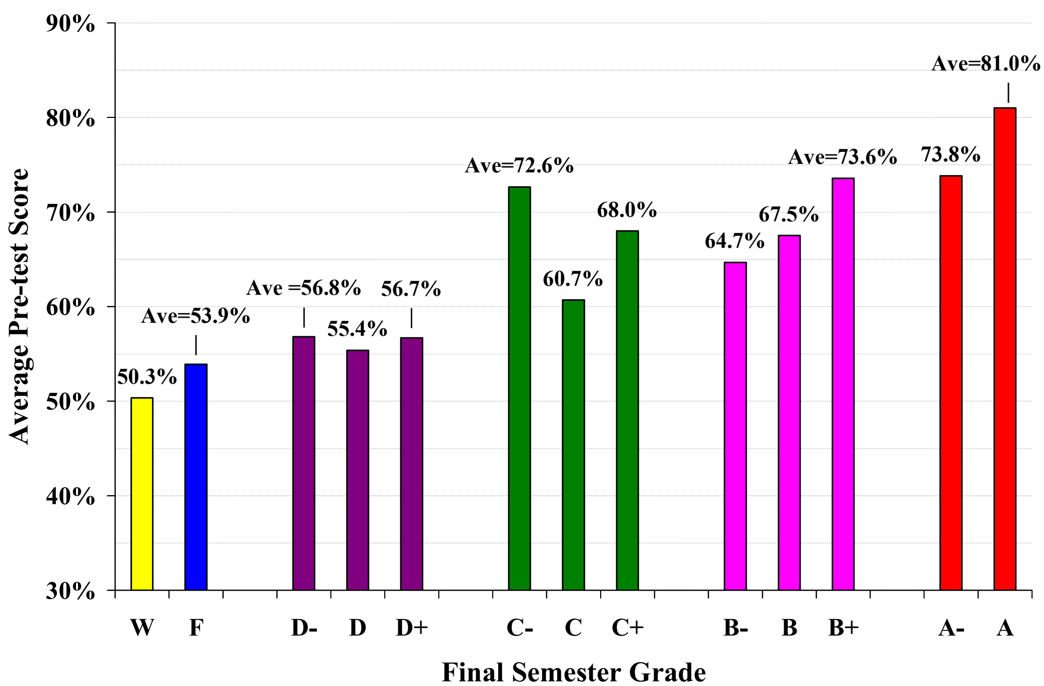

Figure 1. Semester grade as a function of average pre-test score.

Results show that students who earned an A achieved a pre-test score on average of ~78%, B students had ~68%, C students had ~65%, D students had ~56%, F students had ~54%, and those who withdrew had ~50%. This suggests that students with pre-test scores below 65% were in danger of not passing the course, and instructors warned such students in the second week of the semester to obtain tutoring or other support.

In order to determine how well correlated the pre-test scores were to semester grades, the Pearson correlation coefficient was determined for the data. In the present study, the grades were converted to grade points (A = 4.0, A- = 3.7, etc.) and then correlated with the pre-test scores. The analysis shows that pre-test scores and grade point correlate reasonably well with a Pearson correlation coefficient of +0.45. A Pearson correlation coefficient of -1 would be anti-correlation (i.e, low pre-test scores correlate with high grade points) while a coefficient of 0 would indicate no correlation at all and a coefficient of +1 would indicate perfect correlation. A somewhat similar correlation was obtained in the study about Statics Concept Inventory test,[9] where a Spearman's rank correlation coefficient of -0.55 was obtained. The Spearman's rank correlation coefficient is effectively the same type of measure as the Pearson correlation coefficient. However, integer ranking values (with "ties" allowed) of A = 1, B = 2, and C = 3 were associated with the semester grade in their study. Thus, a negative correlation coefficient is to be expected because a "lower" rank value (i.e., closer to A) should correspond to a higher Concept Inventory score. It should be noted that their study did not appear to include test results for students who received grades of D or F whereas the present study includes those grades as well as + or – discriminators.

The results shown in Figure 1 and Table 1 relate to averages for the entire 733 students from spring 2012 through spring 2014. Figure 2 presents more detailed results for each grade category. Here, 13% of the students who earned A's or A-'s had pre-test scores in the 0 to 59% range while 27% of A and A- students had pre-test scores in the 90 to 100% range with the overall average pre-test score being 78% for A's and A's as indicated by Table 1. Figure 2 also shows that a higher proportion of A and A- students had pre-test scores in the 90 to 100% range compared to students with lower grades. Conversely, a higher proportion of students who failed the course with an F had pre-test scores in the 0 to 59% range compared to students with higher grades. These results are not surprising at all. However, it shows that individual students perform quite differently depending on workload, tutoring support, etc. Thus pre-test scores should not be used as a predictor of an *individual* student's performance.

As mentioned earlier, the Statics pre-test consisted of questions from six different topical areas. Figure 3 presents the average score achieved in each of the six topical fields by all 749 students who took the pre-test. The questions on vector magnitude and dot product were multiple-choice in format, and more of a mathematical tool type of problem rather than Physics in nature so it is shown in the figure in pink shading. The problem on friction involved questions in multiple parts, but the answer in part (b) did not depend upon the answer in part (a) so it is shown in a different shade of blue compared to the other Physics-related multiple-part problem solving type questions. Broadly-speaking, students performed better in questions that did not involve multiple parts (i.e., in vector magnitude, dot product, and friction) where the answer for part (b) did not depend upon the answer for part (a). More complex problems (i.e., those for vector resultant, moment, and force equilibrium) resulted in substantially lower average scores. This anecdotal observation applies to student performance later in the course as well.

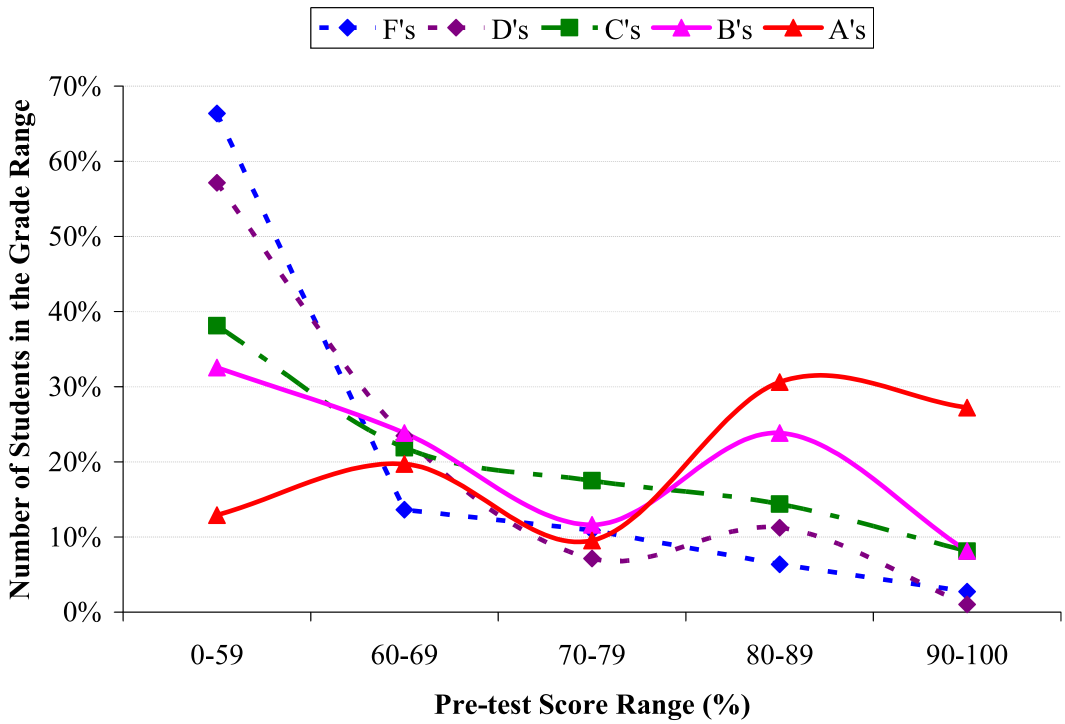

Figure 2. Pre-test score distribution as a function of semester grade.

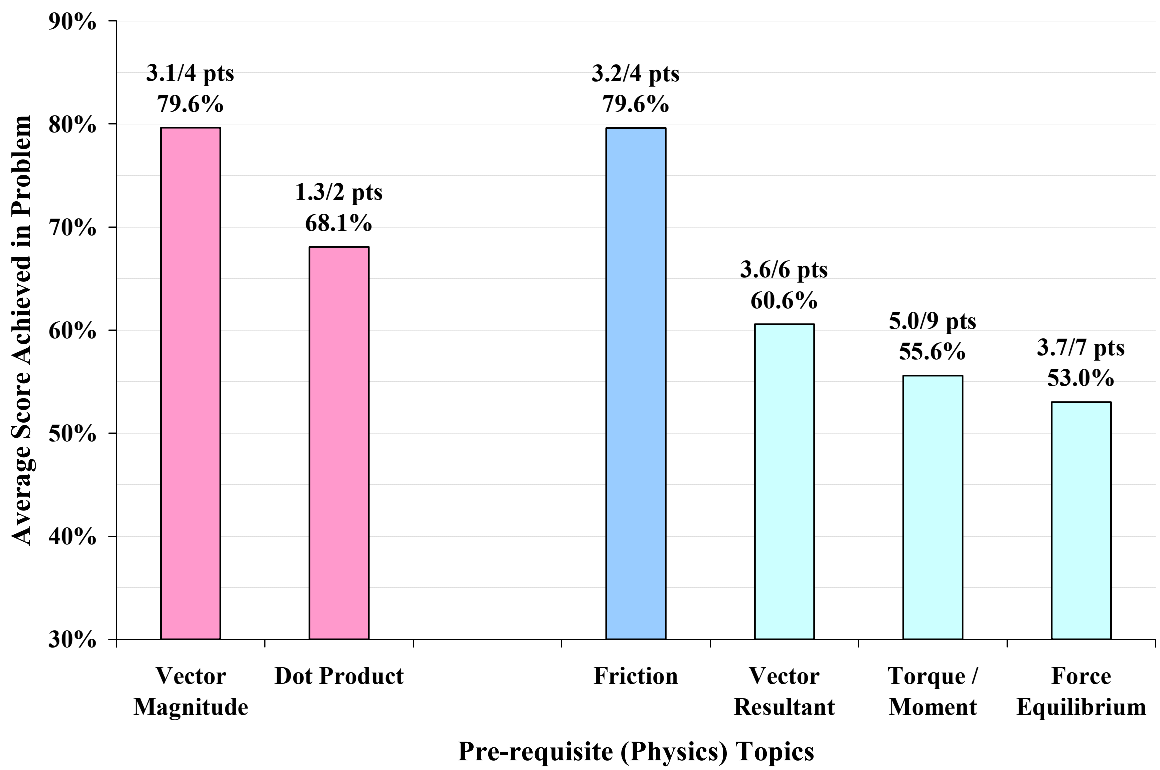

Figure 3. Average score in each pre-test topical area.

An attempt was made to see if there was a correlation between student performance in the individual pre-test questions and problems throughout the rest of the semester in Statics. One example of this is the dot product mathematical tool which is used to determine the force along a line as well as the moment along a line. Although this mathematical tool is used in both types of problems, there are significantly more steps / skills associated with solving problems of these types. Consequently, students who can perform a dot product properly may not necessary be able to perform the appropriate process to get to the point of determining the correct values to use in the dot product operation. Thus, the correlation was not very good between performance in the individual pre-test questions and later problems in the Statics course. This suggests, once again, that pre-test scores should not be used as a predictor of *individual* student's performance.

Conclusion and Potential for Future Work

A test over pre-requisite Physics material was developed for use in Statics. The pre-test consisted of problems over six different topical areas: (1) vector magnitude, (2) vector resultant, (3) friction, (4) dot product, (5) torque (i.e., moment), and (6) force equilibrium. Many of the problems involved multiple parts where the answer for part (b) depended on the answer from part (a). This test is different from a Concept Inventory test which emphasizes student understanding of concepts and knowledge through a series of multiple-choice questions. Rather, the new "pre-test" involved the application of concepts and knowledge through problem solving rather than multiple-choice questions *alone*.

The newly developed pre-test was administered to almost 750 students in 13 sections taught by four different instructors over 2½ years at Wichita State University. Results show that pre-test scores correlate reasonably well with the semester grade point where the Pearson correlation coefficient was +0.45. This is a reasonably good correlation, especially in light of the fact that the pre-test is given towards the beginning of the semester. Most Concept Inventory tests are typically correlated between semester grade and test scores conducted towards the end of the semester.

Pre-test results show that students who earned an A achieved a pre-test score on average of ~78%, B students had ~68%, C students had ~65%, D students had ~56%, F students had ~54%, and those who withdrew had ~50%. This suggested that students with pre-test scores below 65% were in danger of not passing the course. Instructors were able to use this assessment instrument as a way to warn students in the second week of the semester to obtain tutoring support if their score was below 65%. Possibilities for future work include creating a formal process of connecting low scoring students with tutoring support as well as "post-testing" of the same test towards the end of the semester.

Bibliography

1 Norm Augustine, "America's Education Problem Isn't Money, It's How We Spend It," *U.S. News and World Report*, 8 June 2012. Available WWW: www.usnews.com/opinion/articles/2012/06/08/americas-education-problem-isnt-money-its-how-we-spend-it .

2 John Sununu and Maria Cardona, "STEM fund key to U.S. global competitiveness," *The Hill Congressional Blog*, 12 June 2013. Available WWW: http://thehill.com/blogs/congress-blog/education/305061-stem-fund-key-to-us-global-competitiveness .

3 Tim Carpenter, "Governor signs KPERS, engineering bills," *Topeka Capital-Journal*, May 25, 2011.

4 Dan Budny, Goranka Bjedov, and William LeBold, "Assessment of the Impact of Freshman Engineering Courses," *Journal of Engineering Education*, vol. 87, pp. 405-411, October 1998.

5 J. Levin and J. Wyckoff, "Identification of Student Characteristics that Predict Persistence and Success in a Engineering College at the End of the Sophomore Year: Informing the Practice of Academic Advising," *Pennsylvania*

State University Division of Undergraduate Studies Report No. 1990.1, 1990.
6 N. Al-Holou, N.M. Bilgutay, C. Corleto, J.T. Demel, R. Felder, K. Frair, J.E. Froyd, M. Hoit, J. Morgan, and D.L. Wells, "First-Year Integrated Curricula Across Engineering Education Coalitions," *Proceedings from the 28th Annual Frontiers in Education Conference*, Tempe, AZ, November 1998.
7 Amir Rezaei, Kyu-Jung Kim, Jawaharlal Mariappan, and Angela Shih, "Lessons Learned from a Newly Developed Hybrid Vector Statics Course Based on Fundamental Concepts and Hands on Experiments." *Proceedings of the 2007 American Society for Engineering Education Pacific Southwest Annual Conference*, 2007.
8 David Hestenes, Malcolm Wells, and Gregg Swackhamer, "Force Concept Inventory," *The Physics Teacher*, Vol. 30, pp. 141-158, March 1992.
9 P.S. Steif and J. Dantzler, "A Statics Concept Inventory: Development and Psychometric Analysis," *J. Engineering Education*, Vol. 33, pp. 363-371, 2005.
10 P.S. Steif and M. A. Hansen, "New Practices for Administering and Analyzing the Results of Concept Inventories," *J. Engineering Education*, Vol. 96, pp. 205-212, 2007.
11 P. S. Steif and M. Hansen, "Comparisons Between Performances In A Statics Concept Inventory And Course Examinations," *Int. J. Engineering Education*, Vol. 22, pp. 1070-1076, 2006.
12 S. Danielson and R. Hinks, "A Statics' Skills Inventory," *Proceedings of the 2008 American Society For Engineering Education Annual Conference*, Pittsburgh, PA, June 2008.

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