Math-Statics Baseline (MSB) Test: Phase I

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Abstract

Assessing student learning is important to engineering educators for a number of well-known reasons. While methodologies exist, they are often either time intensive or provide only aggregate data at the end of a degree program. While physics instructors have access to several assessment tools validated for introductory physics, none have been identified for engineering science subjects. This paper describes a Math-Statics Baseline Test that probes math topics typically used in statics as well as specific statics topics. Pre- and post-course test data for over 240 statics students and pre-course data for 250 dynamics and strength of materials students are reported and discussed. Several surprising results are discovered.

Introduction

Engineering and engineering technology educators face a significant task in adjusting to an outcomes-based environment, one, in part, driven by the new accreditation requirements adopted by the Accreditation Board of Engineering and Technology (ABET, 2000). Demonstrated proof of student learning and mastery of engineering concepts are now required. As one response, significant effort is being made to assess student outcomes via faculty teams reviewing capstone course materials or student portfolios. Another common approach has been to use relatively broad and generalized results from licensure or certification, e.g., the Fundamentals of Engineering exam, administered by various organizations. Unfortunately, these tests have been developed for other purposes and results are available only in aggregate fashion (typically by school). In addition, they are administered at the end of the educational process and do not provide any immediate feedback to either students or engineering faculty. Also, not all students take these exams so the sample group has limitations.

Also, there are no published tools available for assessing student learning in critical engineering courses. While there are more subject specific tests available, they do not work well for engineering faculty. For instance, the Force Concept Inventory and the Mechanics Baseline probe student understanding of Newtonian physics (Hestenes, Wells, & Swackhamer, 1992; Hestenes & Wells, 1992). These tools have seen much use by physics educators to assess student learning and knowledge retention. Of more interest to engineering educators, two tests are reported (Snyder & Meriam, 1978; Negahban, 1998) for assessing the mathematics preparation of students in engineering mechanics classes. Development of well-designed and validated engineering specific subject tests is an important issue for assessment within engineering education. Such tools have two major uses within education.

First, such tools allow assessment of individual student knowledge at the beginning and end of a class and at the beginning of other classes for which the class is prerequisite. Students, faculty, departments, and institutional administrators will all receive benefits from this direct measurement of student learning. Such tools provide knowledge "profiles" of students. Thus, the feedback loop for both the individual student and instructor is completed on a shorter timeline, one allowing more immediate action by the student, faculty member, or department administrator.

Thus, if an instructor finds that a large number of students have failed to understand a particular topic or topics, they can address the problem immediately in their next offering of the course. This is in contrast to the long time required for feedback when using an end-of-the-educational-process test like the aggregated results of the Fundamentals of Engineering. Additionally, use of the test will allow faculty in a follow-on course to pinpoint where learning difficulties originate. For instance, if a student struggles in a mechanics of materials course (for which statics is always a prerequisite) but demonstrates good understanding of the concepts of statics, both the student and faculty member know the issue lies in the current topic, not the prerequisite course!

Second, engineering faculty members need an instrument for formative use in assessing implementation of new course design strategies and instructional practices intended to increase student learning. For example, such a tool may be used to compare the performance of experimental and control groups by recording pre- and post-instruction performance. Eric Mazur in his *Peer Instruction* guide (Mazur, 1997) used the Force Concept Inventory to assess student learning in his introductory physics for both experimental and control group settings by recording pre- and post-instruction performance. His powerful data showing the value of peer instruction and the use of concept questions to increase student learning would not have been possible without an instrument like the FCI. Emphasizing this point, Richard Hake (2001) in his recent article, "Lessons From the Physics-Education-Reform Effort," writes as follows.

> "So great is the inertia of the educational establishment that three decades of physics-education research demonstrating the futility of the passive-student lecture in introductory courses were ignored until high-quality standardized tests that could easily be administered to thousands of students became available. These tests are yielding increasingly convincing evidence that interactive engagement methods enhance conceptual understanding and problem solving abilities far more than do traditional methods…. In my opinion, all disciplines should consider the construction of high-quality standardized tests of essential introductory course concepts."

Statics is the first course in what is typically a series of important courses within the broader subject area of engineering science. Since virtually all engineering and engineering technology students take statics, an assessment tool to gage student learning would impact large numbers of faculty and students (estimated to be over 100,000 per year based on 1997-98 Engineering Workforce Commission Report). As a first step in developing such an assessment tool for statics, a web-based multiple-choice test called Math-Statics Baseline (MSB) test has been developed. This paper describes the development of the first phase of such a test. The preliminary results from over 400 NDSU students are included.

The MSB Test

The MSB Test consists of ten math questions and ten statics questions. The math portion probes algebra, geometry, trigonometry, vector algebra, and calculus topics typically used in statics. The statics portion probes knowledge of equilibrium of a particle and a rigid body, structures, friction, internal forces, centroids, and moments of inertia (please see Table 1 for additional description of the questions). The questions are intended to be straightforward and require only simple calculations. Students are allowed to bring a calculator, paper, and pencil to the test and there is no time limit. Typically, it takes between 20 to 60 minutes to complete the test. The web-based quiz program initially records the student's name and a college code assigned by the instructor. During the actual test, one question is displayed at a time. The student is asked to select the correct answer as well as their confidence level (low, medium, or high) in that answer. In addition, the program records the time taken to answer each question. Student performance is graded and all results are stored in a database. The program manager can add or delete the college codes, and view or download the results file. This results file can then be imported in Excel™ for further analysis.

Table 1. Description of the MSB Test Questions

Question #	Brief Description of the Question
1	Solve a simple linear equation (Algebra)
2	Solve an equation with fractions (Algebra)
3	Solve two simultaneous linear equations (Algebra)
4	Determine an angle (Geometry)
5	Use of similar triangles (Geometry)
6	Use of a simple trigonometric relationship (Trignometry)
7	Use of a simple trigonometric relationship (Trignometry)
8	Definite Integral of a simple expression (Calculus)
9	Dot product of two vectors (Vector algebra)
10	Minimization of a simple function (Calculus)
11	Addition of forces using Cartesian Vectors
12	Equilibrium of a particle in 2-D
13	Determining equivalent force system in 2-D
14	Equilibrium of a rigid body in 2-D
15	Determining zero-force members in a truss
16	Moment of a force about an axis in 3-D
17	Determining friction force on a simple block
18	Determining internal force in a beam that has a distributed load
19	Determining centroid of an area using composite areas
20	Use of the parallel-axis theorem

Preliminary Results

About 240 students in two sections of statics classes and another 250 students in dynamics and mechanics of materials were asked to take the MSB test in the first week of the fall 2001 semester. The students were told that their performance on the test would not impact their grade for the class but that the test could help them determine their strengths and weaknesses to help them prepare for the class. Approximately 93% of the students took the test. In the last week of the fall 2001 semester, the statics students were asked to take the test (as a post-test) to assess what they had learned and to help them prepare for the final examination.
Each question is worth one point and the confidence level had three possible values: low (1), medium (2), and high (3). The results of the average scores for each question and the average confidence level for each question are given in Table 2. The standard deviation for the scores and confidence levels for each question are given in Tables 3. The statics post-test results are compared with the results of the statics pre-test data for statistical significance ($\alpha < 0.01$ marked by * and $\alpha < 0.001$ marked by +). Similarly, the dynamics and mechanics of materials results are compared with the statics post-test results and are shown in Table 2.

On the math portion students did well, scoring above 77 percent on all questions except one. There were few statistically significant differences in the performance scores across the three different test groups. Pre- and post-test results for the statics' group showed statistically significant increases for only three math questions (3, 8, and 10). For questions six to ten confidence levels were higher at $\alpha < 0.01$ or $\alpha < 0.001$. The overall statics' group math confidence level was also higher in the post-test (moving to 2.89). The dynamics and mechanics of materials pre-test group showed a significant decrease in confidence level for three questions (6,7, and 10) compared to the statics post-test group.

The worst math score was for question number nine (dot product of two vectors). This score was consistently low for all three groups. Surprisingly, the average score for this question is lower (although not statistically significant) for the statics' post-course group even though the topic is taught in the statics class (negative learning!). Interestingly, the course raised the student's confidence levels but not the actual score. This area can be a focus of an instructor seeking to make improvements.

The statics post-test scores showed significant gains for all questions except for the friction question (#17). This could be because of the misuse of the friction equation $F = \mu_s N$ by students. Students often don't remember that this equation gives the maximum possible friction force and the friction force can be lower depending upon the application. The second lowest test score was for the question about zero-force members in a truss (#15). The statics scores also show that the averages are not very high compared to the math scores. Thus, teachers and students both have the potential to make improvements. The confidence levels reported on all statics questions went up significantly (as expected).

Table 2. Average Scores and Average Confidence Levels For Each Question
($\alpha < 0.01$ marked by * and $\alpha < 0.001$ marked by +)

Test Type (N) →	Pre-Test in Statics (222)		Post-Test in Statics (191)		Pre-Test in Dynamics and Mechanics (232)	
Question Numbers	Average Score	Average Conf. Level	Average Score	Average Conf. Level	Average Score	Average Conf. Level
1	0.97	3.00	0.97	2.99	0.97	2.97
2	1.00	2.97	0.98	2.98	0.99	2.95
3	0.92	2.89	0.98*	2.94	0.97	2.92
4	0.91	2.86	0.92	2.91	0.91	2.89
5	0.95	2.85	0.95	2.92	0.93	2.86
6	0.91	2.78	0.91	2.93+	0.84	2.79+
7	0.89	2.74	0.87	2.92+	0.85	2.78*
8	0.83	2.51	0.92*	2.85+	0.96	2.80
9	0.40	2.37	0.36	2.55*	0.46	2.58
10	0.77	2.52	0.87*	2.80+	0.80	2.63*
Math Total	**8.55**	**2.79**	**8.73**	**2.89+**	**8.68**	**2.85**
11	0.70	2.36	0.81*	2.60+	0.69*	2.35+
12	0.30	1.71	0.70+	2.55+	0.70	2.52
13	0.45	1.39	0.74+	2.74+	0.73	2.60
14	0.21	1.36	0.59+	2.54+	0.60	2.57
15	0.11	1.25	0.30+	2.17+	0.21	1.85+
16	0.27	1.18	0.55+	1.83+	0.41*	1.61*
17	0.26	1.46	0.30	2.41+	0.19*	2.01+
18	0.19	1.19	0.68+	2.29+	0.65	2.42
19	0.29	1.51	0.59+	2.69+	0.44*	2.12+
20	0.24	1.35	0.59+	2.43+	0.22+	1.86+
Statics Total	**3.02**	**1.57**	**5.86+**	**2.43+**	**4.84+**	**2.23+**

Table 3. Standard Deviations of Scores and Confidence Levels For Each Question

Test Type (N) →	Pre-Test in Statics (222)		Post-Test in Statics (191)		Pre-Test in Dynamics and Mechanics (232)	
Question Numbers.	S.D. of Score	S.D. of Conf. Level	S.D. of Score	S.D. of Conf. Level	S.D. of Score	S.D. of Conf. Level
1	0.16	0.00	0.17	0.07	0.18	0.21
2	0.00	0.20	0.14	0.23	0.11	0.30
3	0.28	0.40	0.14	0.35	0.18	0.35
4	0.29	0.48	0.27	0.36	0.28	0.39
5	0.22	0.36	0.21	0.34	0.25	0.48
6	0.32	0.56	0.29	0.26	0.36	0.54
7	0.31	0.54	0.34	0.31	0.20	0.56
8	0.39	0.74	0.27	0.45	0.20	0.56
9	0.50	0.77	0.48	0.64	0.50	0.70
10	0.41	0.80	0.34	0.46	0.40	0.68
Math Total	**1.49**	**0.26**	**1.23**	**0.17**	**1.31**	**0.26**
11	0.40	0.75	0.39	0.66	0.46	0.82
12	0.46	0.75	0.46	0.67	0.46	0.76
13	0.50	0.72	0.44	0.51	0.44	0.69
14	0.41	0.59	0.49	0.67	0.49	0.72
15	0.25	0.63	0.46	0.67	0.41	0.74
16	0.47	0.54	0.50	0.78	0.49	0.76
17	0.42	0.80	0.46	0.65	0.40	0.76
18	0.41	0.53	0.47	0.73	0.48	0.79
19	0.47	0.75	0.49	0.57	0.50	0.79
20	0.43	0.63	0.49	0.74	0.41	0.82
Statics Total	**1.42**	**0.36**	**2.28**	**0.39**	**1.91**	**0.46**

Conclusions

The pre-test data for the dynamics and mechanics students showed, as many instructors know, that students tend to forget much of what they covered in course prerequisites, raising the question of how much student actually learn over the longer term. Five questions out of ten showed a statistically significant decline in scores accompanied by a statistically significant decrease in confidence level for six of the ten questions. Overall, there was decline in both the total score and the total confidence level. This test gives numerical evidence of a common instructor experience.

The specific question results point out the danger of making assumptions about what student's have learned and the quality of that learning. The data regarding the dot product question was both surprising and distressing. Obviously, an assessment tool has value in demonstrating student learning or the lack of learning.

These results also point to another of the advantages of a subject-specific assessment tool. Instructors can use such tools to test alternative pedagogies to measure improvements in student knowledge gain and retention. For instance, Mehta and Danielson (2000) have developed strategies and teaching resources (Danielson & Mehta, 2001) based on what they refer to as Next Generation Principles to enhance student learning. The MSB test data can help provide an initial measure of their impact on learning. The MSB data from students involved in this effort will be reported in the future.

The MSB test will also be given in the spring 2002 semester to students in statics, dynamics, and mechanics of materials classes. The results from the spring semester are not in this paper but will be presented at the ASEE Annual Conference. Input from other mechanics instructors will be solicited and the MSB test can be given at their institutions. Hopefully, this process will begin to raise awareness and interest in working towards deliberate assessment of student learning in engineering science classes.

It is important to note that the MSB test is not a complete assessment tool for learning of statics. Half of the instrument is devoted to mathematics and, while providing useful information, does not serve to measure learning of all statics topics. Also, the MSB test probes only a representation of topics usually taught in statics. In addition, the test does not allow detailed information to be gleaned about what the students actually don't understand. In other words, the test doesn't provide insight into the student misconceptions that caused them to select wrong answers.

These issues along with the validity and reliability of the test will be the focus of future work. Meantime, the web-based MSB test is a starting point and one, to the authors' knowledge, not available for any other engineering subjects. Mechanics educators have the potential to begin a new chapter in mechanics-education research with the development of a high-quality standardized test for statics.

References

1. ABET (2000). See http://www.abet.org and follow the accreditation link to both the engineering and engineering technology criteria for the new accreditation criteria.

2. Danielson, S., & Mehta, S. (2001). "Teaching Resources for the New Millennium: Statics as an Example," *Journal of SMET Education: Innovations and Research*, Vol. 2, Issues 1&2, pp. 37-45.

3. Hake, R. (2001). "Lessons From the Physics-Education-Reform Effort," *Conservation Ecology*, a free on-line journal at http://www.consecol.org/Journal/, a "peer-reviewed journal of integrative science and fundamental policy research.

4. Hake, R. (1998). "Interactive-engagement versus traditional methods: A six thousand-student survey of mechanics test data for introductory physics courses," *Am. J Phys., 66* (1), pp. 64-74.

5. Hestenes, D., M. Wells, & G. Swackhamer (1992). Force Concept Inventory. *Phys. Teach.* 30:141-158.

6. Hestenes D. & M. Wells (1992). A mechanics baseline test. *Phys. Teach.* 30:159-166.

7. Mazur, Eric (1997). *Peer Instruction*. Prentice Hall, NJ

8. Mehta, S. & Danielson, S. (2000). "Next Generation Principles for Enhancing Student Learning," *Proceedings*, *ASEE National Conference*, St. Louis, MO.

9. Negahban, M. (1998). "Results of Implementing a Mechanics Readiness Program in Statics," *Proceedings*, *Workshop on Reform of Undergraduate Mechanics Education*, Pennsylvania State University, University Park, PA.

10. Snyder, V. & Meriam J. (1978). "A Study of Mathematical Preparedness of Students: The Mechanics Readiness test," *Engineering Education*, pp. 261-264.

Biographies

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