AC 2008-2541: A STATICS SKILLS INVENTORY

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A Statics Skills Inventory

Abstract

Engineering faculty recognize the value of assessment instruments to measure student learning and to evaluate changes in teaching. As a result, a number of engineering subject assessment instruments formulated as "concept" inventories have been developed. Taking a different tack, the authors of this paper decided to focus on assessment of student **skills** in statics and this paper provides details of the development of a *statics skills assessment tool*. The use of only concept inventories to provide proof of student learning is an incomplete assessment as effective application of engineering knowledge consists of both a sound understanding of conceptual knowledge *and* skill intertwined. For instance, while demonstrating understanding of the concept of equilibrium is valuable, it is also important students are able to generate correct equations of equilibrium. A multi-step Delphi process involving statics educators was used to reach consensus on the important skills of statics. The Delphi rankings, including the importance of the skill as judged by the Delphi participants as well as an estimate of the proportion of students whom can perform the skill, were used to develop the final list of top ranked skills. Initial skill-based questions were developed to probe these areas and tested with students. The current status of the skill assessment instrument is discussed.

Introduction

Statics is usually the first in a series of courses within the broader body of knowledge commonly referred to as engineering mechanics. Virtually all engineering and engineering technology students take statics and it is a fundamental course prerequisite for other mechanics courses such as dynamics and strength of materials. Success in these latter courses is directly correlated to success in statics.

Demonstrated proof of student learning and mastery of engineering knowledge is now required by ABET's outcomes-based environment[1]. Additionally, engineering faculty need instruments for formative use in assessing implementation of new course design strategies and instructional practices intended to increase student learning. As in the physics community, the bulk of the development effort has focused on engineering subject concept inventories. Typically, these concept inventories focus on determining student understanding of a subject's fundamental concepts, usually through questions involving minimal calculation. Examples are a concept inventory for dynamics[2], a tool complementing the previously developed Force Concept Inventory[3], and for statics[4].

It can be argued that using only concept inventories to provide proof of student learning is an incomplete assessment as engineering knowledge consists of both conceptual knowledge and skill intertwined. For instance, while demonstrating understanding of the concept of equilibrium is valuable, it is also important to be able to generate correct equations of equilibrium. Thus, as a companion project to one investigating the concepts of statics, this paper reports on work towards assessment of student **skills** in statics and provides details of the development work towards a statics skills assessment tool.

Important Skills of Statics

In the same manner as those conducted for other engineering concept inventory development efforts, a multi-step Delphi process[5] involving a group of almost 20 engineering educators was used to reach consensus on the important skills of statics. Participants were recruited using a mechanics list serve and e-mail and included individuals from large public institutions (e.g., Pennsylvania State University, Virginia Tech), the Air Force Academy, and private universities (e.g., Rowan). The first round of the Delphi process asked participants to contribute their personal list of important statics concepts and skills. The original responses from the first round resulted in a list of 43 skill items.

After analysis, these 43 skills were subdivided and then expanded into a list of 53 skills with the items clearly delineating the task being addressed. For example, calculating the area moment of inertia appears twice, once by the composite method and once by integration. The 53 skills were grouped into ten basic categories. These were:

- algebra and geometry (three skills),
- properties of areas and volumes (eight skills),
- vector manipulation (seven skills),
- modeling and free body diagrams (eight skills),
- equilibrium equations (five skills),
- manipulation of forces and force systems (nine skills),
- plane trusses (four skills),
- frames and machines (three skills),
- friction (four skills), and,
- "general" (two skills).

This expanded skill list was then the subject of a second Delphi round with participants asked to rank both the average importance of the skill and their judgment of the typical proportion of their students (e.g., eight out of ten) whom can perform the skill. This latter estimate provided an indicator of student mastery of the skill. The results from this second Delphi round were analyzed using the ratings of perceived importance and student mastery as a primary and secondary ranking system. The perceived importance of the skill was the primary ranking method. Then, within the importance rankings, the student mastery data provided a way to rank skills within a similar importance ranking (for instance, there were six skills with an average importance ranking of 9.5). A difference was created by subtracting the student mastery score from the importance score. For instance, a skill with an importance of 10 and an average student mastery score of 8 would show a difference of 2.0. This result was called the Student Mastery Indicator and was used as the secondary ranking procedure. It provided a way to distinguish between important skills that students typically master as compared to important skills in which students typically may not obtain a high level of proficiency. The 24 top-ranked skills using this methodology are shown in Table 1 below. This approach provided a mechanism where an important skill could be eliminated from the assessment tool simply because most students

Table 1. Top Ranked Statics Skills

Sorted Skill Rank	Skills	Average Importance of Skill (10 Point scale)	Student Mastery Indicator
1	Construct a correct free-body diagram of a 3-dimensional "real world" situation.	10.0	2.7
2	Generate correct independent equations of equilibrium when given a free body diagram, i.e., trusses, frames, machines, friction, pulleys and other situations.	10.0	2.2
3	Apply force and/or moment equilibrium equations based on a correct free-body diagram.	9.8	2.0
4	Construct a correct free body diagram of a two dimensional object.	9.8	1.6
5	Calculate the (scalar) moment of a 2-D force about a point.	9.6	1.3
6	Determine support reaction magnitudes and directions using the equations of static equilibrium.	9.6	1.3
7	a) Given a vector, determine its magnitude and direction; and b) Write a vector, knowing its magnitude and direction.	9.6	1.3
8	Apply equilibrium equations to individual parts or sub-system of a larger object in static equilibrium	9.5	2.0
9	Determine the rectangular components of a vector using the magnitude and a), the unit vector, or b), the direction cosine.	9.5	1.8
10	Associate various support systems with the correct reaction forces and moments as needed on a 2-D or 3-D free body diagram.	9.5	1.5
11	Analyze a friction problem when the force of friction is less than the normal force times the coefficient of friction.	9.3	2.2
12	Calculate the centroid of a 2-D shape using the composite shapes method	9.1	1.6
13	Determine a 3-D *unit vector* based on geometric information in a Cartesian co-ordinate system	9.1	1.3
14	Calculate a distributed load's equivalent concentrated force and location.	9.1	0.9
15	Analyze a friction problem when the force of friction is equal to the normal force times the coefficient of friction.	9.1	0.9
16	Disassemble a frame or machine to determine internal forces in its members.	8.9	2.5
17	Analyze a truss using method of sections.	8.9	1.5
18	Identify and analyze two-force members.	8.9	1.3
19	Calculate the moment of a 3-D force using the vector cross product.	8.9	1.1
20	Solve for three unknowns using three simultaneous equations.	8.9	0.9
21	Analyze a truss using method of joints.	8.9	0.9
22	Describe the steps necessary to analyze a frame.	8.7	1.6
23	Calculate the forces applied to an object that is held between the jaws of a tool, (i.e., pliers, wire cutter, or crimping tool).	8.7	1.6
24	Determine a moment's direction using the right hand rule.	8.7	1.1

obtain mastery of the skill. Also, questions probing these high mastery skill areas may be impacted by a ceiling effect, thus limiting their value as a discriminator of students' statics skill masteries. However, to keep the test completion time for the skills assessment tool to a reasonable amount, it was decided that not all of these 24 skills can be probed. Narrowing this list of skills even further, it is interesting to note the distribution of the top 12 ranked skills by importance within the broader skill categories. These are:

- vector manipulation (three of top 12 skills),
- modeling and free body diagrams (two of top 12 skills),
- equilibrium equations (four of top 12 skills), and,
- manipulation of forces and force systems (two of top 12 skills).

While questions were developed to probe skills 12 through 15, solution time estimates and the drop in importance and mastery numbers shown in Table 1, led to the decision to only probe the top 11 skills in the prototype version of the skill assessment tool. These skills had importance rankings of 9.3 and above, with mastery scores ranging from 1.3 to 2.7. As can be seen in the table, one of the two top-ranked skills by importance also has the highest student mastery indicator (2.7). So, while this skill is rated as very important, students struggle to perform it well. Such a skill is an ideal target probe for the assessment tool.

Skill Assessment Instrument Development

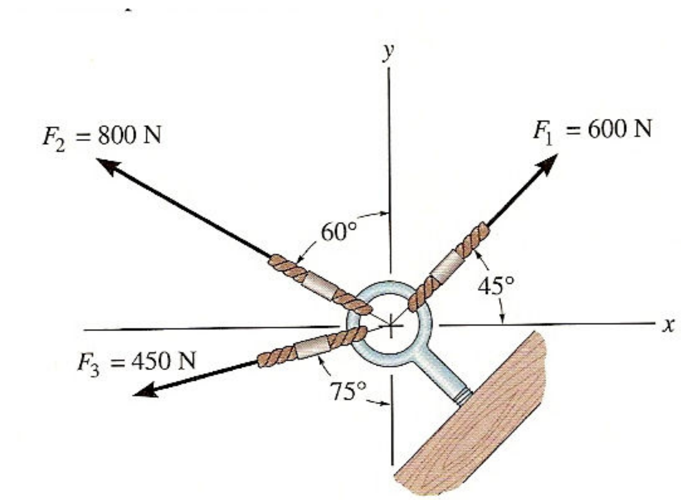
Skill-based questions were developed to probe the top 11 ranked skills. Unlike concept inventory probes, the skill assessment questions require calculation and use of formulas. However, the initial development philosophy is that the student would not have access to any formula "aids" but have to generate all required formulas. This stance will be evaluated during the development process and could be modified if students appear to be failing skill probes due to simple formulation mistakes.

Development of the skill probes required a mental adjustment from the typical engineering problem development faculty typically employ when creating quizzes or tests. *Each question has to focus on only the skill being probed*. For instance, for skill 19, calculate the moment of a 3-D force using the vector cross product, the student has to be given the two vectors. Otherwise, if a student fails to identify the correct answer, the failure may have been in writing one or both of the vectors (involving skills 9 and 13), not in doing the cross product.

The probe development focused on questions extracted from typical statics homework or exam problems. The complete problem could not be used since, in typical statics problems, multiple skills are required to solve the problem. In a skills assessment setting, such a problem would cloud the instrument's ability to assess student mastery of specific skills unless a cascading problem format was used. Cascading would entail students being asked to complete individual steps of a multi-probe problem solution in sequence. Since a mistake in executing a step in the solution sequence could cause a subsequent solution step to generate an incorrect answer *even when that step is executed correctly*, solution "trees" would have to be developed. Thus, while cascading questions were initially developed, they were abandoned due to the complexity of tracking solution trees.

Whenever possible, the discrete skill probe was couched within a realistic statics problem format (for example, see Figure 1). In terms of the desired skill assessment, it was important to have the probe mimic what students see in a typical statics problem setting. As shown below, such a problem statement may include much of what is typically asked of the student in terms of task performance. At this stage of the development process, students are being asked to write out their solution to the questions. These solutions are then analyzed to determine typical mistakes and the resulting incorrect answers. These typical mistakes and associated incorrect answers are being used to determine the distracter (incorrect) answers that will be used when the assessment tool is transitioned into a multiple choice format for either a web or paper-based medium.

Three forces act on an eye anchor, as shown below.



The resultant force $\boldsymbol{F}_R = \boldsymbol{F}_1 + \boldsymbol{F}_2 + \boldsymbol{F}_3$ is:

$\boldsymbol{F_R} = -703\hat{\boldsymbol{i}} + 708\hat{\boldsymbol{j}}$ [N.]

Determine (1) the *magnitude* of $\boldsymbol{F}_R$ and (2) its *direction*, measured as a counterclockwise angle from the positive x axis.

Figure 1. Probe for Skill #7a[4]

For instance, the common failures demonstrated by students for the problem in Figure 1 are: 1) incorrect third quadrant angle calculation, 2) no third angle calculation, 3) incorrect use of the Theorem of Pythagoras in doing the resultant force magnitude calculation, and 4) not using the theorem for the resultant force magnitude calculation.

The alpha version of the statics skills inventory with questions probing the top 11 ranked skills was completed and used in a statics class of 27 students as a part of their fall semester 2007 final exam. The students were given a maximum of 70 minutes to complete their work. Table 2 below shows student performance on these questions (Note: the problem number is *not* related to the skill numbers shown in Table 1). The students were scored using a 1 to indicate successful completion and a 0 for unsuccessful completion of the problem. First, notice that Question 8 had only one student correctly complete the problem. In this case, the instructor (not one of the assessment tool developers) had not covered the skill area in his class.

Table 2. Skills Assessment Tool Alpha Test Scoring

Problem	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11	#12
Student												
1	0	1	0	1	1	0	0	0	0	0	1	1
2	0	0	0	0	1	0	0	0	0	0	1	0
3	1	1	0	1	1	1	1	0	0	0	1	1
4	0	1	0	1	0	0	0	0	1	0	0	1
5	1	0	0	1	0	1	0	0	0	0	1	1
6	0	1	0	0	0	0	0	0	0	0	0	1
7	1	1	1	1	1	1	1	0	1	1	1	1
8	1	1	1	1	1	1	1	0	1	1	1	1
9	0	1	1	1	1	0	0	0	0	0	1	1
10	1	1	0	1	0	1	0	1	1	1	0	1
11	0	0	0	1	1	0	0	0	0	0	1	0
12	0	1	1	1	0	0	0	0	1	0	0	1
13	0	0	0	0	1	1	0	0	0	0	1	1
14	1	1	0	1	0	1	0	0	0	0	0	1
15	0	1	0	1	1	1	0	0	1	0	0	0
16	0	1	1	1	1	0	0	0	1	0	0	0
17	1	0	0	1	0	0	0	0	0	0	0	0
18	0	1	1	1	0	0	0	0	0	0	1	1
19	0	0	0	1	1	0	0	0	0	0	1	1
20	0	1	0	1	1	0	1	0	0	0	0	0
21	0	1	0	1	0	0	0	0	0	0	0	0
22	1	1	1	1	1	0	1	0	1	0	0	0
23	0	0	1	0	0	0	0	0	0	0	0	1
24	1	0	1	0	1	0	0	0	0	1	0	1
25	0	1	1	0	0	0	0	0	0	0	0	1
26	0	0	1	0	0	0	0	0	0	0	0	0
27	1	1	0	0	1	0	0	0	0	0	1	0

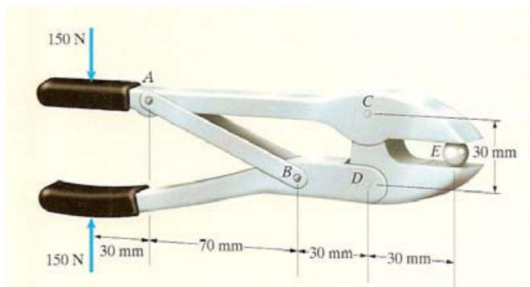
Of more importance to the development effort, a statistical discrimination index was used to look at each item's ability to discriminate between those students who know the material and those that who don't. (The discrimination index scores are shown in Table 3 below.) As the material required for problem 8 was not taught, it was excluded from the analysis. Problem 3 (probing skill #6) was shown to be a poor discriminator with problems 9 (probing skill #2) and 10 (probing skill #3) showing marginal discrimination. However, less than 30 per cent of the students successfully completed problems 9 and 10 and this may have impacted the discrimination index. Currently, the errors made by the 27 students are being investigated to see if there are clues to any potential issues with the problem statements or if other issues that may have contributed to poor performance. Problems 9 and 10 were not trivial problems (see problem #9 designed to probe Skill #2: "generate correct independent equations of equilibrium when given a free body diagram, i.e., trusses, frames, machines, friction, pulleys and other situations" - see Figure 2 below), and consequently students may have struggled with their solutions. It is also important to note that there is no "partial credit", - students either solved the problem completely correct, scored as a "1", or they scored a "0".

Table 3. Discrimination Index Scores

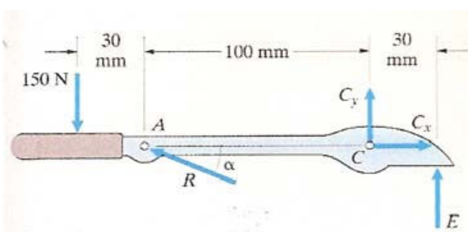
Question	1	2	3	4	5	6	7	9	10	11	12
Discrimination Index	0.67	0.67	0.33	0.67	0.67	0.67	0.67	0.50	0.50	0.50	0.50

As the development effort continues on the skills assessment tool, a parallel development is beginning on the web-site that will host the instrument. Two graduate students in Arizona State University's Division of Computing Studies are building a site that will be database driven and provide support for all usage aspects of the assessment tool. A site management component will allow instructors to request use of the tool for their class and permit them to exercise control over the components of their skills test. For instance, if a skill is not taught in their class, the instructor will be able to exclude that skill from their version of the assessment tool. The overall length of the assessment tool will be controllable as the instructor will be able to select the number of skills probed (the current plan is to develop questions for the top 24 skills shown in Table 1).

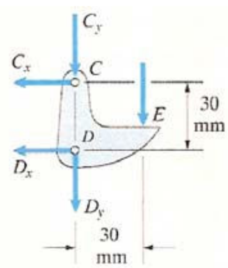
PROBLEM #9



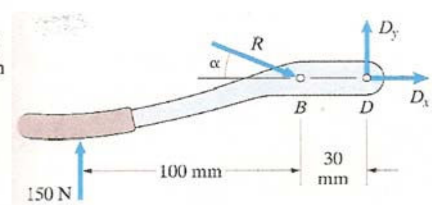
Shown below are **3** free-body diagrams for (1) the **upper handle/jaw**, (2) **lower jaw**, and (3) the **lower handle** of these pliers. Take a moment to study these FBD's.



FBD (1)



FBD (2)



FBD (3)

The force applied to the handles of these pliers is 150 N, as shown. *Write the equilibrium equations you would need* to determine the force ***E*** exerted on the bolt at point E between the jaws. **DO NOT compute this force – just write the equilibrium equations you would use**.

NOTES: 1) You may have to use more than one of the FBD's. (2) The only *known* forces are the 150 N forces applied to each handle. (3) We want you to indicate the order in which you would use the equations, e.g., "I would first write this equilibrium equation for FBD (2), then this equation for FBD (2)", etc..

Figure 2. Problem 9[5]

The web-site is also being developed to allow tracking of student performance in various ways. The instructor will receive a report of how their class performed, both by skill and individual. In addition, the meta-data regarding student performance for each skill will be available. This will allow the instructor to compare their students' performance to *all* students completing the question. These data will also inform the developers about the test item, including its viability within the skills test.

Conclusions

While statics concept inventories may be useful tools for engineering educators, a statics skills inventory is potentially also of measurable value. Development of such a tool is underway and the work done to date includes a Delphi process involving experienced engineering mechanics educators to establish the important skills within statics. These skills were also ranked by two different measures. These skill rankings could be used to shape instructional efforts, i.e., reduce instructional time on skills judged to be less important.

Skill assessment questions have been developed for the top-ranked 11 skills and are being tested. The resulting data are being analyzed to ensure tests with questions that are good discriminators. Student errors are being analyzed to help with improvement of currently identified questions that are poor discriminators as well as to establish appropriate "distracter answers" for the multiple choice version of the assessment tool. Also, a web-site to host the assessment tool is under development.

Developing a statics skills assessment tool recognizes the importance of those skills, both the actual student accomplishments and its subsequent measurement, to engineering education. Such a tool will complement assessment via statics concept inventories.

Acknowledgment

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