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Development of an Alternative Statics Concept Inventory Usable as a Pretest

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My name is Wadson C Phanord, I'm a senior Civil Engineering student at the University of Puerto Rico, at Mayaguez campus. I'm a teaching assistant for Statics Engineering. I conduct research investigation in the area of Civil and Environmental Engineering, my current research focuses on how to develop a small Biosand Water Filter using Bamboo.

Development of an Alternative Statics Concept Inventory Usable as a Pretest

1. Introduction

Concept inventories (CI's) are now established means to measure students' qualitative understanding of basic concepts and principles. CI's typically consist of multiple choice questions with one correct answer and several "distractors" that reflect common misconceptions. The misconceptions are usually identified through formal research processes, such as using focus groups in which students answer questions and explain their reasoning in an expository manner.

A CI can be used to assess both individual student learning gains and effectiveness of pedagogical strategies, particularly by measuring differences in performance via pre-test (before instruction) and post-test (after instruction). If the CI is not appropriate as a pre-test, then its ability to measure learning gains might be established via other correlations, such as with exams.

The first CI that became widely deployed was the Force Concept Inventory (FCI)[1], developed to study the conceptual knowledge in basic mechanics among physics students. Since then, dozens of CI's have been deployed in various branches of engineering and science, including by organized efforts with sponsorship from the National Science Foundation[2]. However, efforts to perpetually deploy and collect data from CI's have proven difficult to sustain[3].

In Engineering Mechanics, the two most widely deployed CI's are the Concept Assessment Tool for Statics (CATS), originally named the Statics Concept Inventory (SCI)[4], and the Dynamics Concept Inventory (DCI)[5,6]. At least two independent efforts to create a concept inventory for Mechanics of Materials have been undertaken[7,8], but to the authors' knowledge, no standardized version has been widely adopted by the Engineering Mechanics community.

2. Concept Assessment Tool for Statics (CATS)

The CATS is a highly validated[9] and widely deployed CI, deployed to tens of thousands of students since its inception, and is currently maintained by its developer, Paul Steif[10]. The CATS consists of 27 questions, 3 questions each from 9 categories of Statics/basic mechanics, as summarized in Table 1. The authors have been using the CATS at the University of Puerto Rico, Mayagüez, for six years as a standard post-evaluation in Statics.

Table 1. Categories of Questions on the CATS
1. Forces on collection of bodies: Identifying forces acting on a subset of a system of bodies.
2. Newton's 3rd Law: Forces between two contacting bodies must be equal and opposite.
3. Static Equivalence: Static equivalence between forces, couples and combinations.
4. Roller: Direction of force between the roller and the rolled surface.
5. Slot: Direction of force between pin and slot of a member.
6. Negligible Friction: Direction of force between frictionless bodies in point contact.
7. Representation: Representing unknown loads at various connections.
8. Friction: Sorting out implications of equilibrium and Coulomb's Law on friction force.
9. Equilibrium: consideration of both force and moment balance in equilibrium.

A limitation of the CATS is that it does not work well as a pre-test. Historical data analyzed by Steif & Hansen shows that when administered to students prior to taking a Statics class, the results typically match what would be obtained by random guessing, and are such that the correctness of responses is unlikely to reveal strongly held pre-conceived ideas[11]. They explain this situation as follows [original references expanded in line]:

> Based on the successful application of the Force Concept Inventory, it has become an accepted practice to interpret post-test scores in light of the pre-test scores [Hake, 1998][12]. This makes sense when students have seen the concepts prior to the course in which the test is administered. However, for many subjects in engineering, while there are certainly concepts in previous courses that are relevant, a test that measures conceptual development adequately by the end of the course may not be a valuable measure at the beginning of the course. …
>
> In summary, while there can be correlations between the pre-test and exams for the [CATS], these are largely associated with students who score above the normal range for the pre-test. This is in contrast to the post-test, which is correlated to the final for all groups. This implies that the level of understanding of most students upon entering Statics is sufficiently low as to be inadequately captured by the inventory. While students who score significantly above levels explained by random guessing do tend to perform better in the remainder of the course, identifying likely high performers might be of little value to an instructor. Of much greater value would be a readiness test, which signals to the instructor weaknesses students have that will impede learning in Statics. The [CATS] certainly does not provide this function. However, it should be useful as a pre-test for following courses, such as Mechanics of Materials. As evidence, positive correlations have indeed been found between the [CATS] and exams in Mechanics of Materials [Steif & Hansen, 2006][13].

The authors do not take an absolute position on whether a CI should or should not be applicable as a pre-test. Indeed, the CATS itself is evidence that an instrument which is not appropriate as a pre-test can be very useful. Nevertheless, motivated by teaching practices in which the teacher would like to 'tap' the intuitive ideas of the students at the beginning of the class, the authors propose an Alternate Statics Concept Inventory (ASCI) that can complement the CATS and which can access student intuition prior to learning formal terminology and methods.

3. Development of the Alternate Statics Concept Inventory (ASCI)

The ASCI was developed as the result of a "eureka moment" experienced by the authors after returning from the previous ASEE conference and trying to decide what could be done to refresh their Statics course. A structured development process (such as a Delphi process) was not used to develop the instrument. Rather, the authors decided that it would be useful, and even fun, to "play around" with some questions that represent achievement in Statics, yet which can be stated in a manner that can access the intuition of a novice without any formal instruction. For this reason, the questions highly rely on common situations that can be easily visualized. The questions do respond to misconceptions that were observed repeatedly in other mechanics education research and teaching activities performed by the authors over the last several years.

Although the test is designed to be accessible to those without any formal training in Statics, we do, however, exploit words such as "friction" and "torque", on the assumption that these expressions exist in common parlance, and probably have been introduced to entering Statics students from prior physics courses. We suspect that such "bridge" words connect the intuition to the formal methodology, and we believe that it is precisely in this domain where student misconceptions can be usefully identified, exposed, discussed, and corrected.

In its present form the ASCI consists of 10 questions that span many of the traditional topics taught in Statics. The full instrument is provided in the Appendix. In its development, no attempt was made to associate the underlying concepts of the questions with the nine concept categories of the CATS. However, prior to any statistical analysis – so as not to bias the outcomes – the authors hypothesized associations between the ASCI questions and the CATS standard concepts. These associations are reported in Table 2.

Table 2. Hypothesized Associations between ASCI Questions and CATS Categories	
ASCI 1 Box held by flat hands	CATS 8/Friction, 9/Equilibrium
ASCI 2 Torque on signpost	CATS 1/Subsystem, 9/Equilibrium
ASCI 3 Beam FBD	CATS 7/Representation, 4 Roller
ASCI 4 Distribution of forces in truss	CATS 1/Subsystem, 9/Equilibrium
ASCI 5 Car parked on hill	CATS 8/Friction, 9/Equilibrium
ASCI 6 Brakes, ground, and bicycle wheel	CATS 2/Third Law, 8/Friction
ASCI 7 Pulley	CATS 1/Subsystem, 9/Equilibrium, 6/Negligible Friction
ASCI 8 Sag of taught cable	CATS 1/Subsystem, 9/Equilibrium
ASCI 9 Response of signpost to weight	CATS 1/Subsystem, 9/Equilibrium
ASCI 10 Torque wrench on tire	CATS 3/Static Equivalence

As an initial observation, the ASCI questions heavily included topics 1/Subsystem, 9/Equilibrium, and 8/Friction, as well as their coupling, revealing what the authors appear to emphasize. No questions directly addressed the CATS category 5/Slot.

4. Deployment and Results

The ASCI was deployed as a pre-test in August 2015 and was taken by a total of 165 students registered with four different instructors (A, B, C, D, where instructor A is one of the authors). It was later given as a post-test in December 2015 and taken by 62 students registered with three instructors (A, B, and C). Table 3 provides a summary of the pre- and post-test data for two cohorts, A and BC combined. The data consist of the average scores for each question (the score of each question ranges from 0 to 1), the average total scores (maximum score is 10), and the normalized gains $\langle g \rangle$, where $\langle g \rangle = (\text{Post} - \text{Pre})/(10 - \text{Pre})$[12].

Table 3. Average scores and normalized gains on the ASCI Pre-test and Post-test.

Cohort	Item	N	Total	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10
A	Pre	48	3.33	0.28	0.46	0.52	0.04	0.09	0.47	0.26	0.48	0.51	0.22
A	Post	44	4.34	0.27	0.68	0.80	0.52	0.07	0.56	0.30	0.51	0.43	0.20
A	<g>		0.15	-0.01	0.41	0.57	0.50	-0.02	0.18	0.05	0.06	-0.16	-0.02
BC	Pre	66	3.09	0.26	0.44	0.53	0.06	0.03	0.45	0.20	0.47	0.44	0.21
BC	Post	15	3.92	0.13	0.27	1.00	0.40	0.00	0.62	0.07	0.73	0.63	0.07
BC	<g>		0.12	-0.17	-0.31	1.00	0.36	-0.03	0.30	-0.16	0.50	0.35	-0.18

Note 1: unpaired *p*-scores for cohorts A and BC, pre-test vs. post-test total score, are 0.002 and 0.017, respectively.
Note 2: unpaired *p*-score for cohort A vs. cohort BC, pre-test total score, is $p = 0.374$.
Note 3: unpaired *p*-score for cohort A vs. cohort BC, post-test total score, is $p = 0.266$.
Note 4: data highlighted in green (red) indicate a normalized gain greater than 0.30 (less than –0.15).

The results show that for each cohort, there is a significant difference between the pre-test and post-test score, with $p = 0.002$ for cohort A, and $p = 0.017$ for cohort BC (Note 1, Table

3). This suggests that the instruction provided to each cohort was meaningful with respect to the concepts embedded in the ASCI.

The results also show that the difference in performance between the cohorts was not significant. In particular, the difference in performance between the cohorts on the pre-test yielded $p = 0.374$ (Note 2, Table 3), and visual inspection shows that the question-by-question averages on the pre-test have a similar pattern and magnitude for both cohorts. This suggests that students in both cohorts started with similar conceptual knowledge (although we have not yet investigated if the individual responses differ significantly). On the post-test, the comparison between the cohorts yielded $p = 0.266$ (Note 3, Table 3), indicating the overall difference in performance between the cohorts was not significant. However, for the post-test, both the normalized gains and the raw scores follow somewhat different patterns across the cohorts. This could possibly indicate that different instructors emphasized different concepts. We do observe similarity between the two cohorts in raw score and normalized gain on Questions 3, 4, and 5.

To probe the results further, each cohort was filtered to retain only students who took the pre-test, post-test, and the CATS. These subsets, A* and BC*, had 30 and 9 students, respectively. Analysis showed that there was a relatively weak correlation between the normalized gain on the ASCI and the CATS score. However, when the normalized gains and post-test scores for each question were compared with the CATS scores *restricted to the hypothesized associated categories* (cf. Table 2), reasonable correlations were found for cohort A*, but not for BC*. Table 4 provides the data corresponding to cohort A*.

Table 4. ASCI Post-test, Normalized Gain, Discrimination Index, and Comparison with CATS Associated Category Scores, Cohort A* (N = 30)

Item	Total	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10
ASCI Pre	3.31	0.27	0.43	0.47	0.07	0.03	0.48	0.23	0.53	0.53	0.27
ASCI Post	4.58	0.33	0.77	0.73	0.57	0.07	0.58	0.30	0.63	0.40	0.20
ASCI <g>	0.19	0.09	0.59	0.50	0.54	0.03	0.21	0.09	0.21	-0.29	-0.09
Discrimination Index		0.59	0.59	0.71	0.24	0.00	0.62	0.35	0.47	0.59	0.35
CATS associated categories		8 9	1 9	7 4	1 9	8 9	2 8	1 9 6	1 9	1 9	3
CATS average scores per respective associated category		0.17 0.27	0.30 0.27	0.36 0.42	0.30 0.27	0.17 0.27	0.17 0.17	0.30 0.27 0.36	0.30 0.27	0.30 0.27	0.15
CATS overall and average scores on associated categories	0.26	0.22	0.29	0.39	0.29	0.22	0.17	0.31	0.29	0.29	0.15

Note 1: Discrimination Index DI = (C1 – C4)/Q, where C1 (C4) is the number of correct responses from students in the upper (lower) quartile with respect to overall score, and Q is the average number of students in each quartile[14].
Note 2: Pearson Correlations: (ASCI Post, CATS-avg-assoc) = 0.525; (ASCI <g>, CATS-avg-assoc) = 0.451; (ASCI Post, CATS-overall) = 0.162; (ASCI Post, Final Exam) = 0.508; (CATS-overall, Final Exam) = 0.426.
Note 3: CATS scores are normalized to range from 0 to 1 for each category.
Note 4: data highlighted in green (red) indicate particularly favorable (unfavorable) results.

The moderate correlation coefficient for the ASCI post-test vs. the restricted CATS scores, $r = 0.525$ (Note 2, Table 4), suggests that the concepts embedded in the ASCI questions moderately correspond to several concepts embedded in the CATS. However, the overall correlation between the ASCI post-test scores and the total CATS scores was only 0.162 (Note 2, Table 4). It is also noteworthy that there is a mild correlation between the ASCI post-test and the course final exam score, 0.508 (Note 2, Table 4); reducing the correlation were several students with top final exam scores who had below average ASCI post-test scores, and vice-versa. In general, more work needs to be done to establish these relationships.

As this is a work in progress, a detailed item analysis of the question responses has not yet been conducted, either for purposes of validating the instrument or to understand common misconceptions. Nevertheless, some preliminary results stand out (and further commentary appears in the Appendix).

First, in looking at the results of Question 4, it appears that prior to Statics, most students think that an applied load at the joint of a truss will be relatively evenly distributed to in some or all of the joining members. We are encouraged that the relative normalized gain on this problem was consistently high among both cohort A (<g> = 0.50, Table 3) and BC (<g> = 0.36, Table 3), indicating that students are able to learn the concept of zero force member, and that this new knowledge can supersede some of their prior misconceptions. The discrimination index (DI) for this question is relatively low (DI = 0.24, Table 3), suggesting that this could be a relatively easy concept for students to understand.

Secondly, in Question 2, on the pre-test, about half of the students in both cohorts incorrectly believe that the internal torques are greatest at the top of the signpost where the wind pressure is greatest. This misconception was observed by the authors in a previous study[15]. Many students in cohort A corrected this misconception (<*g*> = 0.41, Table 3), whereas students in cohort BC migrated even more strongly toward this misconception (<*g*> = –0.31, Table 3). This difference might be explained by the fact that students in cohort A did a project related to a similar signpost system. Yet students in cohort A performed poorly on Question 9 (<*g*> = –0.16, Table 3), whereas students in cohort BC performed relatively well (<*g*> = 0.35, Table 3).

Third, it is clear that students learned the concept of basic reactions reasonably well, as the normalized gains for Question 3 indicate (A: <*g*> = 0.57; BC: <*g*> = 1.00; Table 3). Interestingly, the pre-test scores for this problem were reasonably high as well (A: 0.52; BC: 0.53; Table 3). Perhaps students can intuitively interpret symbols that represent reactions when presented in a "non-technical" manner.

Finally, three questions proved both difficult and poor discriminators: Question 5 (DI = 0.00, <*g*> = 0.03, Table 4), Question 7 (DI = 0.35, <*g*> = 0.09, Table 4), and Question 10 (DI = 0.35, <*g*> = –0.09, Table 4). Notably, Questions 5 (friction required to support car on hill) and 7 (limit of tension in cable as cable become horizontal) combine more than one topic, including topics that are somewhat beyond the immediate Statics topics. In particular, Question 5 requires students to accurately estimate the slopes of roads and hills, a task that the authors know to confound students. In the case of Question 10 (moment of a couple about a point), the topic is standard, but it is usually proves abstract and counterintuitive for many students in the authors' experience. While these questions may not effectively test conceptual knowledge in a discriminating manner, they nevertheless reveal much about students' limitations in qualitative mechanical reasoning. Whether this is due to a lack of conceptual understanding or problem solving skill (or patience) is an open question worthy of further investigation.

5. Conclusions and Future Work

The objective of this work is to develop an Alternative Statics Concept Inventory (ASCI) that can be effectively used as a pre-test. The primary reason for this is to engage both students and instructors in encountering students' (mis)conceptions early in a course. A key feature of the ASCI is the use of language that is accessible to the novice, yet which maintains integrity with accepted mechanical definitions and concepts. The immediate results demonstrate a mixture of learning gains with respect to some concepts (e.g., zero force members, cf. Question 4) and stubborn persistence of misconceptions (e.g., friction, cf. Question 1).

The results also suggest that the ASCI moderately embeds the core concepts as the CATS, as based on moderate correlations with sub-sections of the CATS (Table 4). However, the questions on the ASCI, in the authors' judgement (Table 2), typically embed two or more concepts from the CATS, particularly the combination of topics 1 (subsystems) and 9 (equilibrium). Indeed, while these topics are agreeably independent, they must be coupled in practice. Some will argue that the fact that the ASCI questions do not align to single CATS topics is a weakness, as it is generally accepted to conduct assessment on decoupled items. Yet the role for qualitative reasoning in research and practice is rarely restricted to a single isolated topic, and for this reason it is important to foster qualitative reasoning skills for this more complex environment. The question remains, however, if effective concept questions can be designed in this manner.

The authors intend that this work begins a new conversation on the use of concept inventories, particularly for Statics. We look forward to inviting others to collaborate to expand and refine the instrument, and to learn more about misconceptions – and how to overcome them – in mechanics education.

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Appendix: ASCI Instrument with Statistical Summaries and Commentary

The Appendix provides a complete description of the ASCI along with summaries of results and commentaries. Items denoted by *double asterisk* indicate correct answers. DNA = “did not answer”.

ASCI 1: A professor holds a box of mechanics textbooks by pressing both sides of the box with flat hands. If the professor presses harder, what happens to the friction force applied by the hands onto the sides of the box?

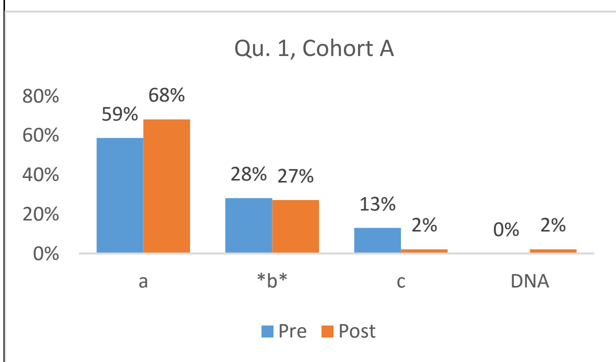
a. It increases
b. It remains the same
c. It decreases

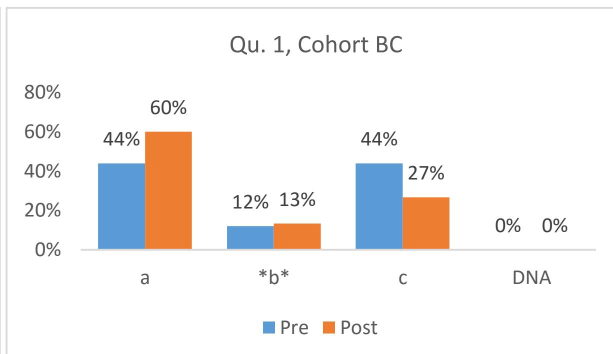
Corresponding CATS Categories: 8/Friction, 9/Equilibrium

Cohort A* Statistics (students who took both pre- and post- test, N = 30):

Pre: 0.27 Post: 0.33 <g> = 0.09 DI = 0.59 CATS (8, 9) = (0.17, 0.27)

Overall Statistics: Cohort A, N(Pre) = 46, N(Post) = 44; Cohort BC, N(Pre) = 66, N(Post) = 15

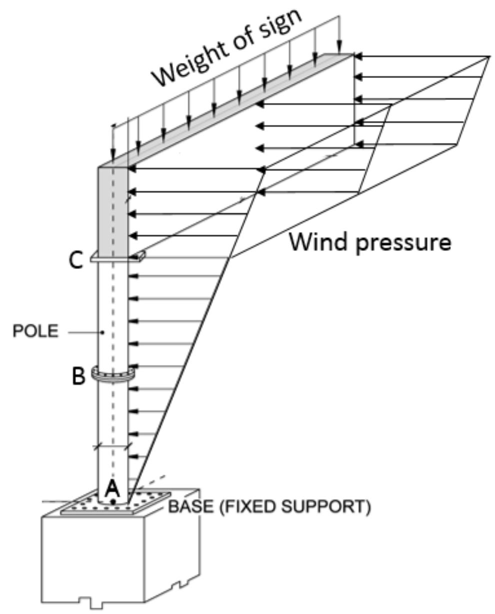




Commentary: On the pre-test, students demonstrate affinity to the misconception that the friction "increases" as the hands are pressed more tightly. The post-test performance showed essentially no gain on the correct answer, while modest gains were observed for the incorrect answer "increases", suggesting that this is potentially a strong misconception that is resistant to change. The weak averages on the CATS 8 and 9 are consistent with these results.

ASCI 2: A steel pole supports a sign (billboard). A horizontal wind blows onto the sign and the pole, and it is known that the wind pressure is greater at the top than at the bottom, as indicated by the lengths of the horizontal arrows. Which point on the pole experiences the greatest magnitude of torque?

a. The base A
b. The midpoint B
c. The top C

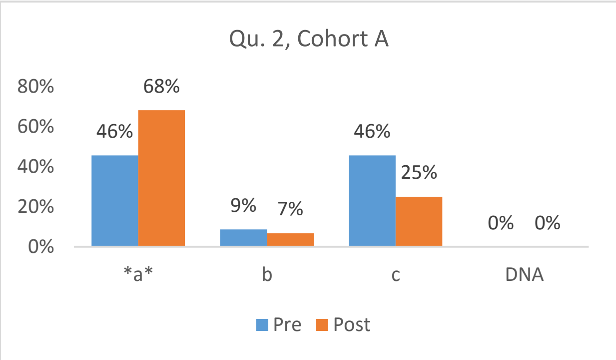


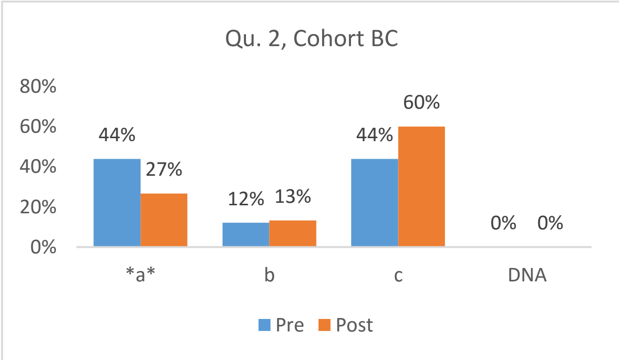
Corresponding CATS Categories: 1/Subsystem, 9/Equilibrium

Cohort A* Statistics (students who took both pre- and post- test, N = 30):

Pre: 0.43 Post: 0.77 <g> = 0.59 DI = 0.59 CATS (1, 9): (0.30, 0.27)

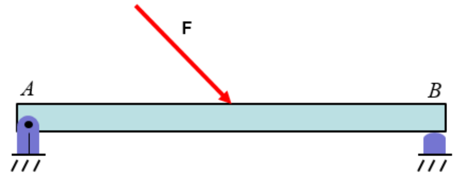
Overall Statistics: Cohort A, N(Pre) = 46, N(Post) = 44; Cohort BC, N(Pre) = 66, N(Post) = 15



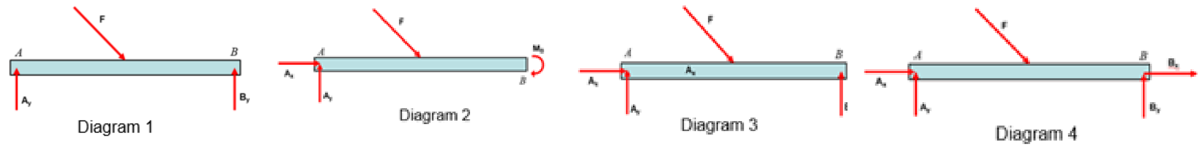


Commentary: A reasonable gain is observed for cohorts A and A*, while a loss is observed for cohort BC. This question was motivated due to the authors' observation that students often confuse the higher wind pressure near the top of the signpost with higher internal moment at that point. This misconception is reflected in the relatively high rate of response for choice "Top C" on the pre-test for both cohorts, and also on the post-test for cohort BC. Perhaps this misconception can be overcome by focused explanations in class, as was done in the case of Cohort A/A*.

ASCI 3: A diagonal force is applied to the center of a beam, as shown. The beam is supported as follows: the left end of the beam is attached to a smooth hinge at point A, and the right end of the beam rests on a smooth round surface at point B.



Which of the following diagrams best represents the equivalent forces and torques that are supplied by the supports? Note: straight arrows represent forces, and curved arrows represent torques.



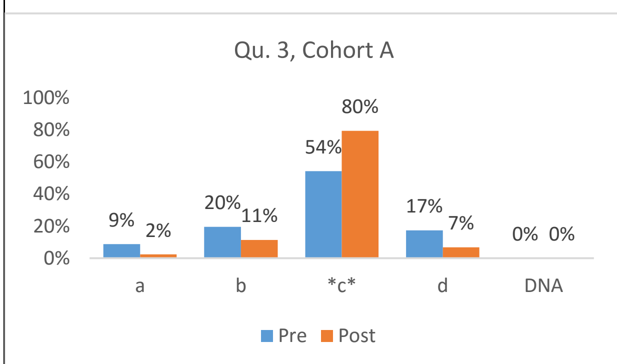
a. Diagram 1
b. Diagram 2
c. Diagram 3
d. Diagram 4

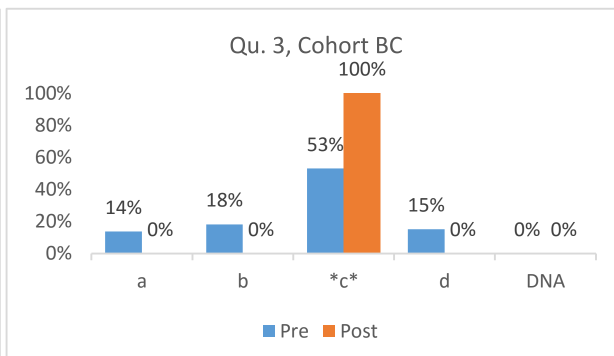
Corresponding CATS Categories: 7/Representation, 4/Roller

Cohort A* Statistics (students who took both pre- and post- test, N = 30):

Pre: 0.47 Post: 0.73 <g> = 0.50 DI = 0.71 CATS (7, 4): (0.36, 0.42)

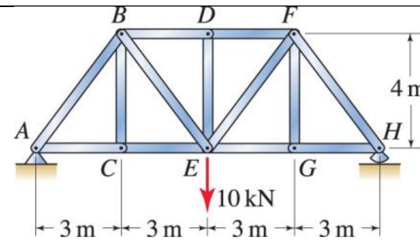
Overall Statistics: Cohort A, N(Pre) = 46, N(Post) = 44; Cohort BC, N(Pre) = 66, N(Post) = 15





Commentary: Somewhat surprisingly, the pre-test scores on this question were reasonably high, and they increased notably on the post-test for both cohorts. These results are consistent with the relatively stronger scores on the associated CATS questions. One possible explanation is that students have some intuition for the basic reaction types prior to learning them through formal instruction. The high discrimination index is also encouraging, and suggests that this type of question can be used as a benchmark for essential skills.

ASCI 4: A truss is a structure that is composed of straight bars that are attached to each other at points called joints. Trusses are often used to carry traffic, to support roofs, or to frame buildings. The truss shown rests on points *A* and *H*, and supports a vertical load of 10 kN (10,000N) at point *E*. Which of the following best describes the force carried by the bar *ED*?



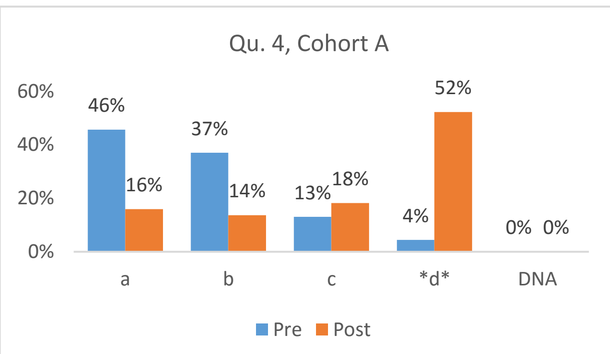
a. Bar *ED* carries the entire 10kN force because it is completely vertical (parallel to) the 10kN force.
b. Bar *ED* carries approximately one third of the 10kN force, because there are three bars at joint *E* that are at least partially vertical, and these bars share the load approximately equally; the two horizontal bars at joint *E* have no vertical component, and therefore do not carry any of the load.
c. Bar *ED* carries approximately one fifth of the 10kN force, because there are five bars at joint *E* to distribute the load approximately evenly.
d. Bar *ED* carries approximately zero force, because there is no load applied directly to joint *D*.

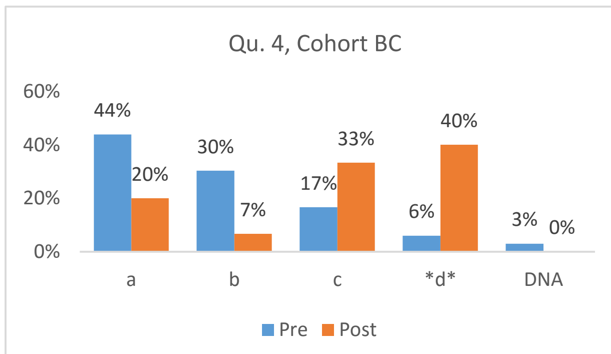
Corresponding CATS Categories: 1/Subset, 9/Equilibrium

Cohort A* Statistics (students who took both pre- and post- test, N = 30):

Pre: 0.07 Post: 0.57 <g> = 0.54 DI = 0.24 CATS (1, 9): (0.30, 0.27)

Overall Statistics: Cohort A, N(Pre) = 46, N(Post) = 44; Cohort BC, N(Pre) = 66, N(Post) = 15





Commentary: Not surprisingly, the pre-test results for both cohorts demonstrated that students have a basic institution to distribute the forces at a joint in a manner that is inconsistent with equilibrium. The post-test results show strong gains for both cohorts, suggesting that learning to recognize zero force members can overcome prior misconceptions.

ASCI 5: A car is parked on a steep hill. Which best describes the magnitude of the frictional force that prevents the car from sliding down the hill, as a percentage of the car's weight *W*?

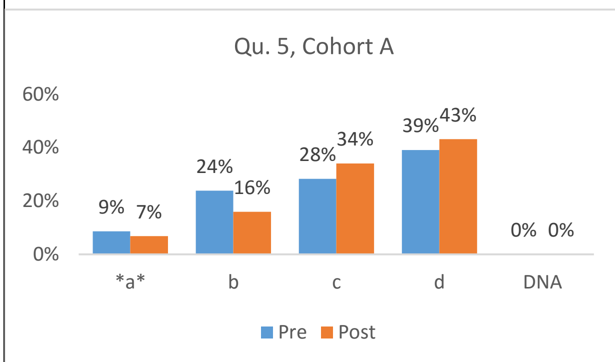
a. Approximately 5% of *W*
b. Approximately 25% of *W*
c. Approximately 50% of *W*
d. Approximately 100% of *W*

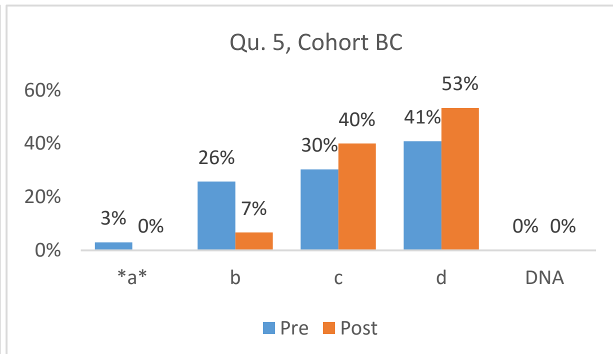
Corresponding CATS Categories: 8/Friction, 9/Equilibrium

Cohort A* Statistics (students who took both pre- and post- test, N = 30):

Pre: 0.03 Post: 0.07 <g> = 0.03 DI = 0.00 CATS (8, 9): (0.17, 0.27)

Overall Statistics: Cohort A, N(Pre) = 46, N(Post) = 44; Cohort BC, N(Pre) = 66, N(Post) = 15





Commentary: Both the pre- and post- test scores on this question were very poor, and the discrimination index was zero. While this may indicate that this is not a "good" question, the results do reveal some insight. Hidden in this question is the need to accurately estimate slopes of hills, which in the authors' experience, people tend to greatly exaggerate. It is not clear from the results if students simply guessed overall, or attempted a free-body & equilibrium analysis, and then guessed as to the effect of the slope; the authors suppose it to be the former. In either case, the results of this question suggest that developing standard skills from Statics is not sufficient for students to ascertain answers for many questions that are within their technical knowledge.

ASCI 6: A cyclist applies the brakes to the back (rear) wheel. Which of the following are true? Select all that apply.

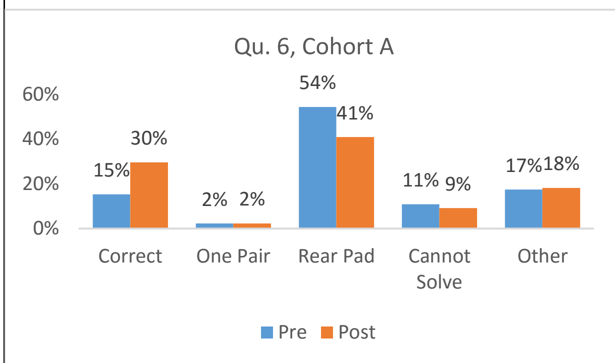
a. The rear brake pads apply friction to the rim of the back wheel.
b. The rim of the back wheel applies friction to the rear brake pads.
c. The ground applies friction to the bottom of the back tire.
d. The bottom of the back tire applies friction to the ground.
e. The question cannot be answered because it is not known whether the back wheel is rolling or skidding.

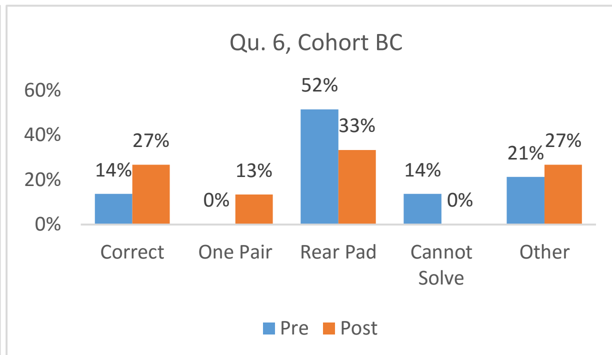
Corresponding CATS Categories: 2/Third Law, 8/Friction

Cohort A* Statistics (students who took both pre- and post- test, N = 30):

Pre: 0.48 Post: 0.58 <g> = 0.21 DI = 0.62 CATS (2, 8): (0.17, 0.17)

Overall Statistics: Cohort A, N(Pre) = 46, N(Post) = 44; Cohort BC, N(Pre) = 66, N(Post) = 15

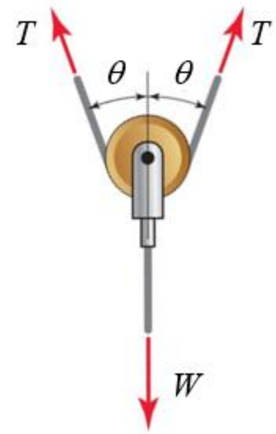




Note: "One Pair" refers to student who answered one complete action-reaction pair, but not both. "Rear Pad" refers to students who selected at least one answer with the "rear pad" referenced, but who did not answer completely correctly.

Commentary: This problem offered partial credit for each individual correct answer selected. A modest gain for students answering completely correctly was observed for both cohorts. Perhaps not surprisingly, the responses referencing "rear pad" received the highest frequency on the pre-test, and this persisted to some degree on the post-test. This suggests that students are more likely to associate "braking" with "brakes", and less with the "ground". The results show that instruction has some effect to correct this misconception, but the misconception appears to be reasonably robust.

ASCI 7: A weights W is attached to a pulley (wheel), and the pulley is supported by a cable that has a tension T. assuming that the cable is infinitely strong and will not break, which best describes the tension in the cable as the angle Θ is increased toward 90^o?



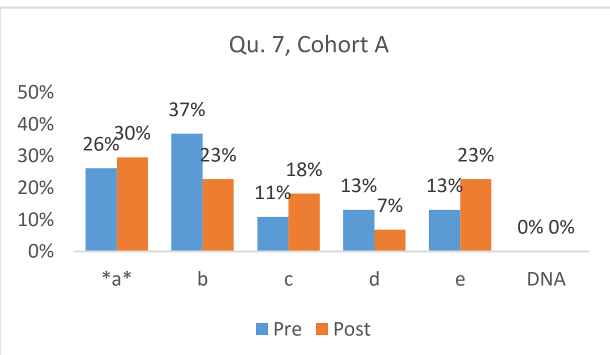
a. As the limit of the angle Θ goes to 90^o, the tension T will increase towards infinity.
b. As the limit of the angle Θ goes to 90^o, the tension T will increase towards a finite limit.
c. As the limit of the angle Θ goes to 90^o, the tension T will not change.
d. As the limit of the angle Θ goes to 90^o, the tension T will decrease to a limit that is greater than zero.
e. As the limit of the angle Θ goes to 90^o, the tension T will decrease to zero.

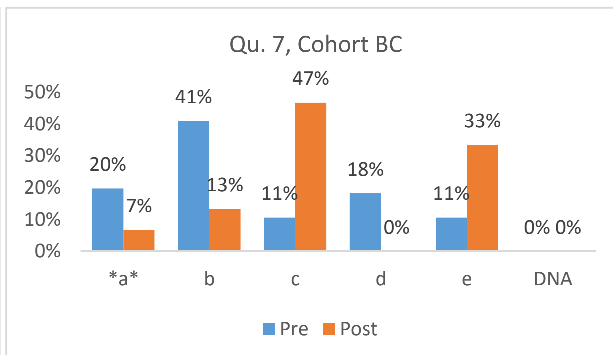
Corresponding CATS Categories: 1/Subsystem, 9/Equilibrium, 6/Negligible Friction

Cohort A* Statistics (students who took both pre- and post- test, N = 30):

Pre: 0.23 Post: 0.30 <g> = 0.09 DI = 0.35 CATS (1, 9, 6): (0.30, 0.27, 0.36)

Overall Statistics: Cohort A, N(Pre) = 46, N(Post) = 44; Cohort BC, N(Pre) = 66, N(Post) = 15





Commentary: The intent behind this problem was for students to draw a mental free body diagram and to consider the vertical components of the tension forces in equilibrium with the weight. In addition to this, the problem required some elementary pre-calculus reasoning (limits). Further investigation is necessary to understand the students' misconceptions on this problem, as there is only slight weight toward the correct answer "a" or the nearly correct answer "b".

ASCI 8: A thin wire is pulled tightly. Which of the following descriptions is most accurate?

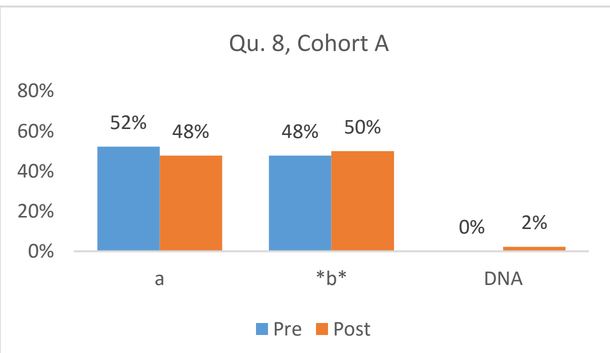
a. Even though the wire has some weight that will pull it downward, if the wire is pulled tightly enough, it can eventually become exactly horizontal.
b. No matter how hard the wire is pulled, the wire can never be perfectly straight because the wire has some weight, which will pull it downward by at least a slight amount.

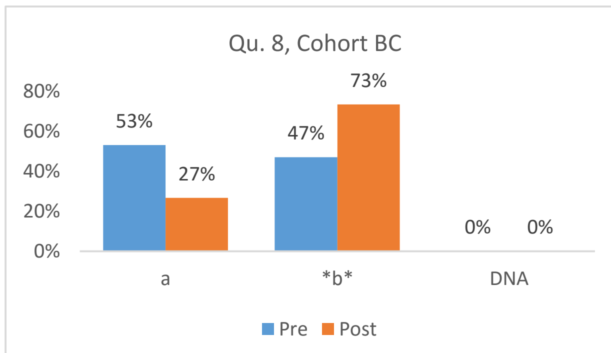
Corresponding CATS Categories: 1/Subsystem, 9/Equilibrium

Cohort A* Statistics (students who took both pre- and post- test, N = 30):

Pre: 0.53   Post: 0.63   <g> = 0.21   DI = 0.47   CATS (1, 9): (0.30, 0.27)

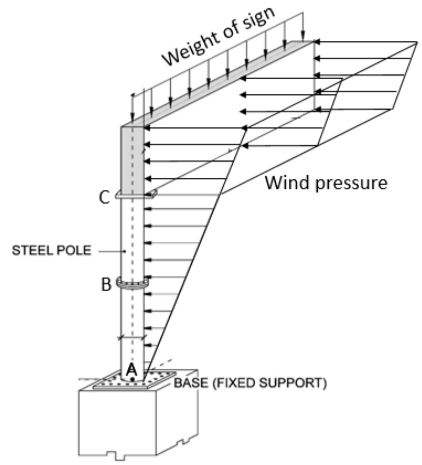
Overall Statistics: Cohort A, N(Pre) = 46, N(Post) = 44; Cohort BC, N(Pre) = 66, N(Post) = 15





Commentary: This question tacitly requires the student to mentally draw a free body diagram of a section of the cable, and reason that there must be at least some vertical component of tension. Although this problem refers to the concept of deflection, static equilibrium alone is sufficient to imply that the cable tension has a vertical component, implying that the cable cannot be exactly horizontal. The results on this problem appear to be mixed. Further investigation is required to determine if students were guessing or deducing their answers.

ASCI 9: A sign (billboard) is supported by a steel pole. Which of the following best describes the effect that the weight of the sign causes on the pole? Select all that apply.



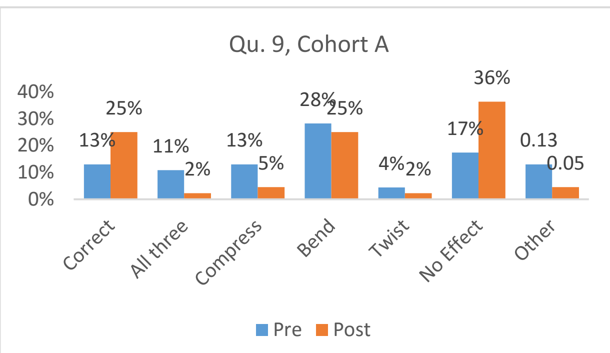
a. The weight of the sign causes the pole to compress.
b. The weight of the sign causes the pole to bend.
c. The weight of the sign causes the pole to twist.
d. The weight of the sign has no practical effect on the pole.

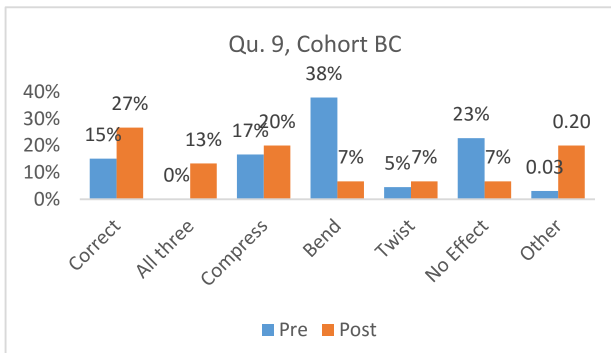
Corresponding CATS Categories: 1/Subsystem, 9/Equilibrium

Cohort A* Statistics (students who took both pre- and post- test, N = 30):

Pre: 0.53 Post: 0.40 <g> = -0.29 DI = 0.59 CATS (1, 9): (0.30, 0.27)

Overall Statistics: Cohort A, N(Pre) = 46, N(Post) = 44; Cohort BC, N(Pre) = 66, N(Post) = 15

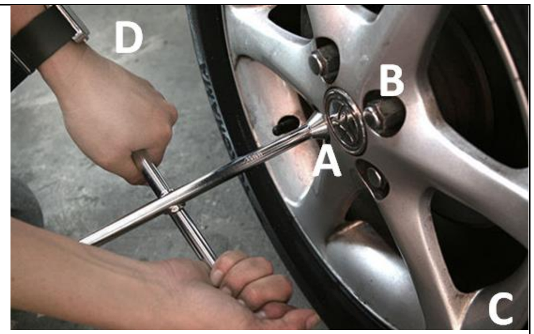




Note: This question allowed multiple responses. Responses were tabulated by selected categories.

Commentary: This problem offered partial credit for each individual correct answer selected. A modest gain for students answering completely correctly was observed for both cohorts. It is curious why cohort A shows and increase for “no effect”.

ASCI 10: A person applies a torque *T* to a wrench to unscrew the bolt at point A. Which of the following best describes the action of the wrench?



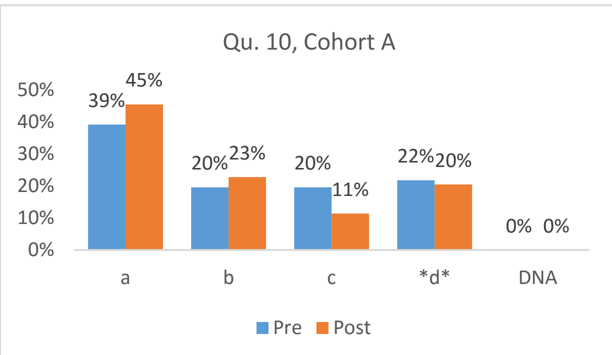
a. The action of the wrench causes a torque about point A, but about no other point.
b. The action of the wrench causes a torque about any point on the wheel, such as points A, B and C, but not about any point outside of the wheel, such as point D.
c. The action of the wrench causes a torque about any point, regardless of whether it is located on or off of the wheel, but the magnitude of this torque decreases as the distance from point A increases.
d. The action of the wrench causes a torque about any point, regardless of whether it is located on or off of the wheel, and the magnitude of this torque is the same, regardless of the location of the point.

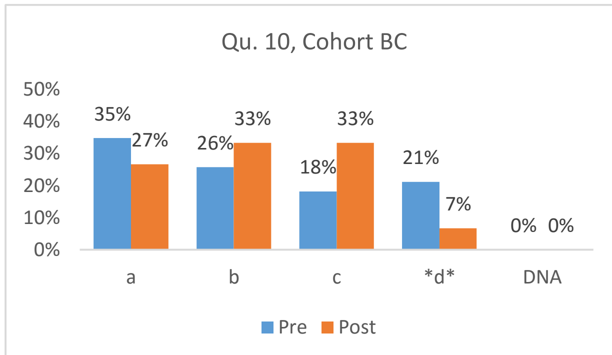
Corresponding CATS Categories: 3/Static Equivalence

Cohort A* Statistics (students who took both pre- and post- test, N = 30):

Pre: 0.27 Post: 0.20 <g> = -0.09 DI = 0.35 CATS (3): (0.15)

Overall Statistics: Cohort A, N(Pre) = 46, N(Post) = 44; Cohort BC, N(Pre) = 66, N(Post) = 15





Commentary: This problem was motivated by the authors' experience that students don't understand the concept of a couple with respect to a rigid system. As suggested by the high frequency of response "a", and not surprisingly, students appear to associate the moment caused by a torque only at the point where the torque is applied, despite the lesson on theory of couples. The results of this problem suggest that this misconception is rather robust.