Force Concept Inventory Clarifications

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Introduction

Over the past two years we have conducted three iterations of think-aloud interviews with students as they grappled with questions on the Force Concept Inventory (FCI). Doing so has shown us that the difficulties they have with some questions have nothing to do with their understanding of physics. These difficulties involve diagrams, notations, and vocabulary that make perfect sense to physics teachers but can easily confuse beginning students. Informed by those think-aloud interviews, we modified a subset of questions to improve clarity. Also, for the same purpose, some new questions were added. Modifications were made after each round of interviews, and then the latest version of the clarified FCI was administered to students in two introductory physics courses. Here we present an overview of our efforts by discussing some specific changes made and how students responded to them.

Revised FCI Methodology

- **Spring 2012** • Interviews with algebra- and calculus-based introductory physics students after instruction
- **Fall 2012** • V. 1 Revised FCI administered to both algebra- and calculus-based courses
- **Spring 2013** • Interviews with algebra- and calculus-based physics students after instruction
- **Summer 2013** • V. 2 Revised FCI administered to algebra-based course • Interviews with algebra-based physics students before instruction
- **Fall 2013** • V. 3 Revised FCI administered to both algebra- and calculus-based courses

Comparing Populations

Population Demographics

The historical data set includes four years of responses (N=431) collected in the fall semesters of 2007 – 2010. The most recent modified FCI responses (N=157) were collected fall semester of 2013. All administrations were given during lab the first week of class to both the introductory algebra and calculus-based courses.

Percentage of Students

	original	modified
alg-based	53%	61%
calc-based	47%	39%
male	51%	49%
female	49%	51%

The table above shows how the recent and historical populations were divided between gender and type of course. There is a noticeable difference between the two populations due to the fact that the calculus-based course has not grown but the algebra-based course has increased in size by 25%.

Comparison of Response Profiles for the Unmodified Questions

We previously reported at AAPT W2013 the comparison between our first revised FCI V. 1 to answer the question, "Are the percentages of correct responses statistically different between the historical and new data set?". We compared correct responses on unmodified questions both by individual question and as a whole. A few additional questions have been modified and now we have 9 questions to compare.

Per question: Standard error was determined for individual questions assuming a binomial distribution: $\sigma_{historical}$ = 1.9%, σ_{new} = 3.2-3.8%
Difference in % correct ranges from: 0.04% to 7.5% which is within the 90% expected distribution range.

Total score: An average score on the FCI for the 9 unmodified questions was compared between the historical data and the new data.

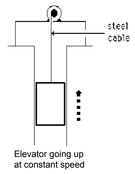
Historical: 32.94 +/- 1.00%
New: 32.48 +/- 1.72%

Chi-squared We used Chi-squared to compare the pre-test responses of the recent and historical response profiles of each of the unmodified FCI questions. A p-value greater than 0.10 indicates differences in the profiles are likely due to chance. The profiles for question 2, which is now question 1, show significant variations. However, the other questions have response patterns that are statistically similar with p-values ranging from 0.180 – 0.777.

Modification of a Question with Confusing Wording

Original Question

17. An elevator is being lifted up an elevator shaft at a constant speed by a steel cable as shown in the figure below. All frictional effects are negligible. In this situation, forces on the elevator are such that:
(A) the upward force by the cable is greater than the downward force of gravity.
(B) the upward force by the cable is equal to the downward force of gravity.
(C) the upward force by the cable is smaller than the downward force of gravity.
(D) the upward force by the cable is greater than the sum of the downward force of gravity and a downward force due to the air.
(E) none of the above. (The elevator goes up because the cable is being shortened, not because an upward force is exerted on the elevator by the cable).



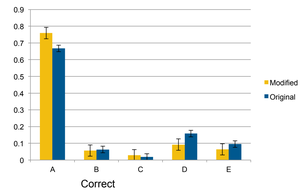
The point of confusion here involves frictional effects and the role played by air. Distracter D introduces air as a consideration, but it is not mentioned in the statement of the problem. Students wonder if air resistance is a frictional effect or something else.

Our modification was simply to add the words "including air resistance" to the original question.

Modified Question Statement

17. An elevator is being lifted up an elevator shaft at a constant speed by a steel cable as shown in the figure below. All frictional effects including air resistance are negligible. In this situation, forces on the elevator are such that:
(A) the upward force by the cable is greater than the downward force of gravity.
(B) the upward force by the cable is equal to the downward force of gravity.
(C) the upward force by the cable is smaller than the downward force of gravity.

(D) none of the above.



Our Thoughts

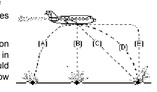
Now that the issue of air resistance has been somewhat clarified, student responses have migrated from the air resistance distracter to the very popular misconception that the upward force of the cable must be greater than that due to gravity for the elevator to move at a constant velocity.

Modification of a Question with an Incorrect Diagram

Original Question

14. A bowling ball accidentally falls out of the cargo bay of an airliner as it flies along in a horizontal direction.

As observed by a person standing on the ground and viewing the plane as in the figure at right, which path would the bowling ball most closely follow after leaving the airplane?



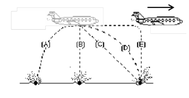
Interviews showed that this diagram was easy to misunderstand; probably because it is not correct. The plane is shown at the time the ball is released, but the ball is shown at the time it hits the ground. In addition, students put excessive and often incorrect value on the wording in the statement "As observed by a person…".

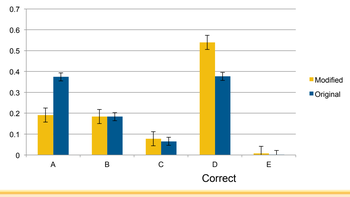
To clarify the situation we added a drawing of the plane in its position at the time the ball hits the ground. We also removed the wording "as observed by a person…".

Modified Question

14. A bowling ball accidentally falls out of the cargo bay of an airliner as it flies along in a horizontal direction.

Which path would the bowling ball most closely follow after leaving the airplane?





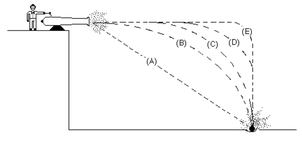
Our Thoughts

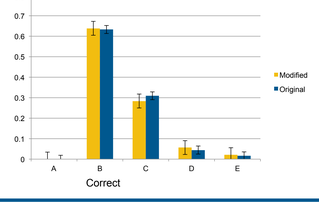
Nearly half of the students who had been choosing option A, now choose the correct answer. We believe both changes, but especially that concerning the diagram, were instrumental in bringing about this shift.

It is also interesting to note that the percent correct on this question (54%) is closer to the percent correctly answering #12, the cannon question (64%), shown below. One might have thought the big difference in the student performance (38% and 64%) between these two questions on the original FCI was due to different physical reasoning. Now it seems that this is not necessarily so.

Unmodified Question

12. A ball is fired by a cannon from the top of a cliff as shown in the figure below. Which of the paths would the cannon ball most closely follow?

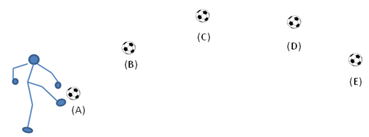




A New FCI Question to Consider

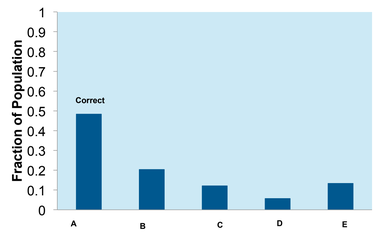
New Question 31

31. A soccer player kicks a ball on a calm day.



At which of the points shown is the ball moving the fastest?

Response Profile for New Question 31 on FCI Pre-test Fall 2013



This question was inspired by a conversation with a person during a soccer game. After a player in the game was kicked in the face with a soccer ball, the person said, "Good thing he wasn't standing further back or he would have been hurt worse." Further conversation found that this person felt that the ball needed more distance to "get up to speed."

During class, a video was shown to students depicting a similar situation and students were asked where they would stand if they were to be kicked in the face by the ball. Students responded with a variety of answers, similar to the FCI response profile. There were similar arguments for the ball getting up to speed. Also, there was a strong argument against standing further away because "gravity would cause the ball to accelerate."

In an interview with a student, they were able to correctly identify the best place to stand; but, could not identify where the ball was travelling the fastest. This was because the student was using the conservation of energy along with thinking about the x- and y-components separately, but forgot about gravitational potential energy.

Although 48% of the student population answered this question correctly, the other 52% surprised us by picking the other distracters. In particular, 20% gave response B which fits with the getting up to speed reasoning.

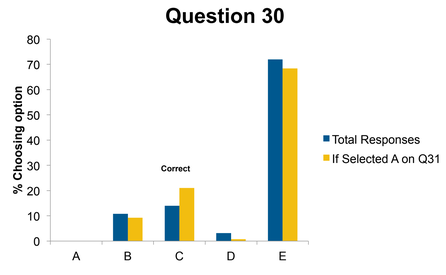
A physicist uses similar reasoning to answer both questions 30 and 31. Because of this we looked at students who correctly answered question 31 to see if they are more successful on question 30.

30. Despite a very strong wind, a tennis player manages to hit a tennis ball with her racquet so that the ball passes over the net and lands in her opponent's court.

Consider the following forces:
1. A downward force of gravity.
2. A force by the "hit".
3. A force exerted by the air.

Which of the above forces is (are) acting on the tennis ball after it has left contact with the racquet and before it touches the ground?

(A) 1 only
(B) 1 and 2
(C) 1 and 3
(D) 2 and 3
(E) 1, 2, and 3



During student interviews, the three most prevalent student alternate conceptions made it clear that students were confusing force with momentum, students also had difficulty isolating or focusing a specific moment in time, they could analyze the hit, but had trouble focusing on a specific moment. It wasn't completely clear but it seemed a few students may have thought there was a force still acting on the ball.

Our Thoughts

During interviews we found that each of these questions elicit multiple student alternate conceptions. So it is not unexpected to find that students who correctly answer question 31 are no better at answering question 30 than the students who missed question 31.

Conclusion

We have conducted several iterations of student interviews, modifications and data collection with the FCI as we corrected the weakest questions. We've also added a few questions to help clarify student misconceptions. At this point, further changes would likely constitute a whole new test so we find ourselves at the conclusion of this project. To obtain a copy of the Clarified FCI please email wendy.adams@unco.edu.