UNIVERSITY of NORTHERN COLORADO

# Clarifying the Force Concept Inventory

Wendy K. Adams, Richard D. Dietz, Matthew R. Semak and Courtney W. Willis
University of Northern Colorado, Greeley, CO 80639

## Introduction

We have conducted 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 several questions to improve clarity and administered our revised FCI to two sections of introductory physics students. Here we show how and why we modified four questions and compare the consequent results with several years of archival data generated with the canonical FCI.

## Equivalent Populations

In order to demonstrate the effectiveness of our modifications to FCI questions we will compare results on the modified FCI to historical data. This kind of comparison obligates us to show that the new student population is similar in ability to past student cohorts.

First we compared the demographics of the two populations:

The historical data set includes four years of responses (N=431) collected in the fall semesters of 2007 – 2010. The modified FCI responses (N=139) were collected fall semester of 2012. All administrations were given during lab the first week of class to both the introductory algebra-based and introductory calculus-based courses.

Percentage of Students

| | original | modified |
|---|---|---|
| alg-based | 52.7% | 52.5% |
| calc-base | 47.3% | 47.5% |
| male | 50.5% | 52.5% |
| female | 49.5% | 47.5% |

The table above shows how the recent and historical populations were divided between gender and type of course. Clearly there is no remarkable difference between the two populations.

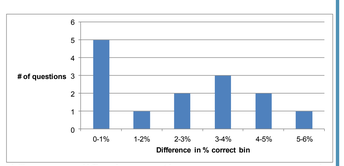
Second, we compared the pre-test results of the 15 unmodified questions using three methods.

1. We calculated the correlation coefficient between the percent of students in the new group choosing the correct answer to the percent of students in the historical group who chose the correct answer. The correlation between the modified questions is also shown for comparison.

   Correlations: unmodified questions 0.994
   modified questions 0.829

2. 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.

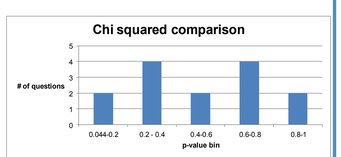
   **Per question**: Standard error was determined for individual questions assuming a binomial distribution: $\sigma_{historical} = 1.9\%$, $\sigma_{new} = 3.4\%$
   Difference in % correct ranges from: 0.16% to 5.9% which is within the 91% expected distribution range.




   **Total score:** An average score on the FCI for the 15 unmodified questions was compared between the historical data and the new data. Standard error was calculated from the standard deviation of the 15-question set of scores in this case.

   Historical 36.3 +/- 1.1%
   New 37.7 +/- 1.8%

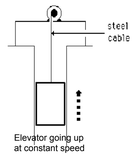
3. For each of the unmodified questions we constructed a histogram of each possible response vs. the percent of the students who selected that response. That gave us two histograms; one for the students taking the modified FCI and one for those who took the standard FCI. We then did a chi-squared comparison of those histograms and obtained an associated p-value. The p-value represents the probability that the two histograms, historical and new data, are the same. The plot shows that the histograms of all the unmodified questions are not remarkably different.




## 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).

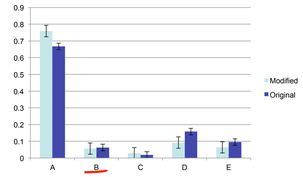



The point of confusion here involves frictional effects and the role played by air. Distracter D introduces air as a consideration, but it is not mentioned in the statement of the problem. Students wonder if air resistance is a frictional effect or something else.

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) 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 correct answer choice is underlined in red in all such plots.

### Our Thoughts

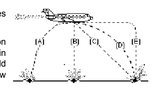
Now that the issue of air resistance has been somewhat clarified, student responses have migrated from the air resistance distracter to the very popular misconception that the upward force of the cable must be greater than that due to gravity for the elevator to move at a constant velocity.

## 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?



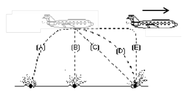

Interviews showed that this diagram was easy to misunderstand; probably because it is not correct. The plane is shown at the time the ball is released, but the ball is shown at the time it hits the ground. In addition, students put excessive and often incorrect value on the wording in the statement “As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

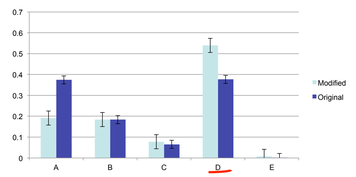
To clarify the situation we added a drawing of the plane in its position at the time the ball hits the ground. We also removed the wording “as observed by a person…”.

### 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?



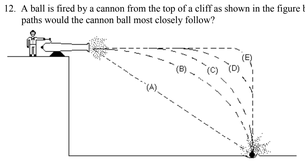

### Our Thoughts

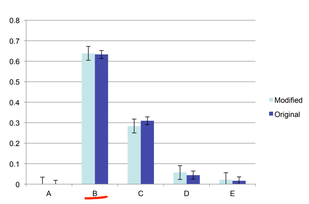
Nearly half of the students who had been choosing option A, now choose the correct answer. We believe both changes, but especially that concerning the diagram, were instrumental in bringing about this shift.

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?

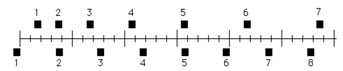



## Modifying Questions with Poor Representation

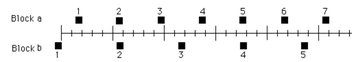
### Original Questions

19. The positions of two blocks at successive 0.20-second time intervals are represented by the numbered squares in the figure below. The blocks are moving toward the right.



Do the blocks ever have the same speed?
(A) No.
(B) Yes, at instant 2.
(C) Yes, at instant 5.
(D) Yes, at instants 2 and 5.
(E) Yes, at some time during the interval 3 to 4.

20. The positions of two blocks at successive 0.20-second time intervals are represented by the numbered squares in the figure below. The blocks are moving toward the right.




The accelerations of the blocks are related as follows:
(A) The acceleration of "a" is greater than the acceleration of " b".
(B) The acceleration of "a" equals the acceleration of "b". Both accelerations are greater than zero.
(C) The acceleration of "b" is greater than the acceleration of "a".
(D) The acceleration of "a" equals the acceleration of "b". Both accelerations are zero.
(E) Not enough information is given to answer the question.

Interviews suggested that some students were at a loss as to what the figures of Questions 19 and 20 physically represent. In particular, it was not clear how time and position were related. That the numbers next to the blocks were a proxy for time was a subtle point easily misunderstood.

To remedy this confusion we added a preliminary question and switched the order of the other two. The added question was intended to demonstrate, in an obvious way, how position and time were related in this style of representation.

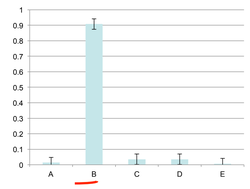
The order of the original questions was switched because we wished to present the problems in what the interviews indicated to be situations of increasing complexity.

### Modified Questions

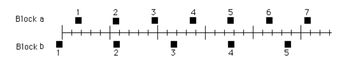
19. The position of one block at successive 0.20-second time intervals is represented by the numbered squares in the figure below. The block is moving toward the right.

(A) The block's speed is constant.
(B) The block's speed is increasing.
(C) The block's speed is decreasing.
(D) The block's speed is increasing and then constant.

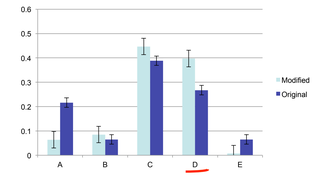
(E) Not enough information is given to answer the question.



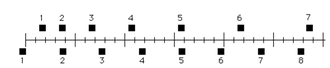

20. The positions of two blocks at successive 0.20-second time intervals are represented by the numbered squares in the figure below. The blocks are moving toward the right.



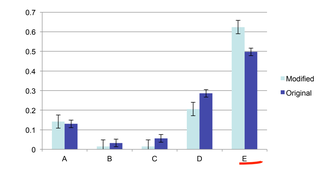

The accelerations of the blocks are related as follows:
(A) The acceleration of "a" is greater than the acceleration of " b".
(B) The acceleration of "a" equals the acceleration of "b". Both accelerations are greater than zero.
(C) The acceleration of "b" is greater than the acceleration of "a".
(D) The acceleration of "a" equals the acceleration of "b". Both accelerations are zero.
(E) Not enough information is given to answer the question.




21. The positions of two blocks at successive 0.20-second time intervals are represented by the numbered squares in the figure below. The blocks are moving toward the right.



Do the blocks ever have the same speed?
(A) No.
(B) Yes, at instant 2.
(C) Yes, at instant 5.
(D) Yes, at instants 2 and 5.
(E) Yes, at some time during the interval 3 to 4.




### Our Thoughts

The new question 19 is clearly very easy for students to interpret as we intended.

Clear improvement in correct responses is seen for both 20 and 21. Our supposition is that adding the easy question caused most of this change but interviews will be needed to support this idea.

## Conclusion

We have explored the consequences of modifying some FCI questions in order to achieve greater clarity in their presentation. Such modifications appear to have enhanced student understanding of the questions as evidenced by the response patterns. The modifications were not intended to make the questions easier. Indeed, the intent was to make the underlying physics more evident. We plan to conduct student interviews on the modified questions to find out if we have successfully removed non-physical difficulties such as wording and diagram confusion from the questions. That several FCI questions (even more than we investigated) would benefit from improved diagrams or wording remains a problematic aspect of the FCI.