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 these think-aloud interviews, we modified a subset of questions to improve clarity. Also, for the same purpose, some new questions have been modified and now we have 9 questions to compare.

Revised FCI Methodology

- Interviews with algebra- and calculus-based introductory physics students after instruction in physics
- V. 3 Revised FCI administered to both algebra- and calculus-based courses
- Interviews with algebra- and calculus-based physics students before instruction
- V. 2 Revised FCI administered to algebra-based course
- V. 1 Revised FCI administered to both algebra- and calculus-based courses

Comparing Populations

<table>
<thead>
<tr>
<th>Population Demographics</th>
<th>Percentage of Students</th>
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<tr>
<td></td>
<td>Original</td>
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<tr>
<td>alg-based</td>
<td>53%</td>
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<tr>
<td>calc-based</td>
<td>47%</td>
</tr>
<tr>
<td>male</td>
<td>51%</td>
</tr>
<tr>
<td>female</td>
<td>49%</td>
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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 2013 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?” 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: \( \text{SEM} = \sqrt{\frac{pq}{n}} \), where \( p = 0.5 \) and \( q = 0.5 \). Difference in \( \% \) correct ranges: 0.04% to 7.1% 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.

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<tr>
<td></td>
<td>32.94 +/- 1.00%</td>
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<tr>
<td>New</td>
<td>32.48 +/- 1.72%</td>
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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: A force exerted by the air.

Modified Question Statement: A force exerted by the air on a soccer ball after it has left contact with the ground.

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 that the big difference in the student performance (36% 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

1. Consider the following forces: (A) the upward force by the cable (B) the downward force of gravity. Which path would the bowling ball most closely follow?

Original Question

Modified Question

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

Question 30

30. Consider the following forces: (A) the upward force by the cable (B) the downward force of gravity. Which path would the bowling ball most closely follow?

Our Thoughts: During interviews we found that each of these questions elicits 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.