Listening to Students: How We Investigate the FCI

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Abstract

We have been investigating the Force Concept Inventory (FCI) since 2005 so that we may better understand what the FCI tells us about our teaching. In 2012 we turned to think-aloud student interviews on a subset of questions. Doing so showed us that the difficulties they had with some questions had nothing to do with their understanding of physics. These difficulties involved diagrams, notations, and vocabulary that make perfect sense to physics teachers but can easily confuse beginning students. Based on these interviews, we attempted to clarify some of the FCI questions and then conducted more think-aloud sessions. After two iterations, the third set of interviews revealed student difficulties which clearly centered on the physics. Here we focus on two particular conceptual difficulties that arose consistently – definition of the word "force" and coherent tracking of events in time.

Introduction

Typically, the result of administering the Force Concept Inventory (FCI)[1] is a bubble sheet with marks on it. Those marks can be translated into a numerical score which supposedly becomes a measure of how well a student understands the concept of force. While it is a simple matter to determine if the student selects the correct answer, the bubble sheet is silent on the question of WHY the student selected the answer he or she did.

Many researchers have studied the FCI via statistical analysis or by modifying question context[2]. Curiously the think-aloud interview approach[3] seems not to have been used in investigations of the FCI since the 1992 paper in which Hestenes et al. introduced the Inventory. In their studies interviews revealed that students offered correct answers for incorrect reasons suggesting limited value for scores lower than 80%.

Our think-aloud interviews with the FCI revealed student difficulties concerning nonphysical issues such as a question's wording or diagram. After addressing some of these issues by modifying certain questions, we conducted a third set of interviews. Here, we present the results of these latest think-aloud sessions.

Interview Protocol

Based on interviews, we attempted to modify several of the FCI questions that our interviews found particularly problematic and then conducted more think-aloud sessions. After two iterations of revisions, the third set of interviews revealed student difficulties which clearly centered on the physics and correct responses were rarely chosen for incorrect reasons.

We conducted interviews with students from both algebra and calculus-based introductory physics courses. Pre-test scores for this population, averaged over four years, are 28% and 41% respectively. Therefore this population is especially well suited for interviews since they are attracted to the incorrect distracters. Fourteen students were interviewed using the original FCI, six interviews were conducted using our first revision and nine interviews using our second revision. The third set of interviews was conducted during the first week of class before instruction on force and motion.

In all cases the protocol was identical. As an introduction, students were told that these were validation interviews to determine if students interpreted the questions the same way that physics teachers do. The interviews had two parts:

1. A strict think-aloud protocol was followed as students answered a subset of 20 FCI questions;
2. The students were told, "we will be going back through the same questions, but this time you'll be told the physicist's answer. Your job is to tell me why you think the physicist might have said that and if it makes sense for the question as stated."

The Clarity of the Revised FCI

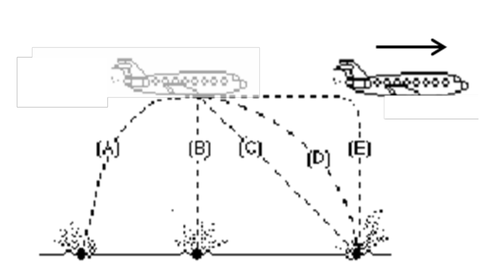
An indication of the clarity of the revised questions was seen by the reduced time required for the third iteration of interviews. This third set using the "clarified FCI", averaged 41 minutes compared to interviews using the original FCI which lasted one hour. Students in the third set quickly understood the scenario and worked out an answer. With the original set of questions, students spent more time quietly thinking or on false starts.

Student Responses to a Modified Question

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?



Student responses from this question on the original were very vague and limited. The revised question revealed some very interesting, and unexpected reasoning.

Max - chose path D (correct): He comments that this problem as similar to the cannon problem, *"… forward motion from the plane and gravity acts immediately."*

Elise - chose path A (incorrect): *"immediately I can disclude C, D and E because direction of airplane moving won't affect a ball dropping out of it."* she thought these were silly. *"A plane causes the air around it to go in the opposite direction"* (used her hand to show air flow away from plane's motion) *"You can see this in skydiving. When you jump out of a plane you go backwards because the air around the plane blows you back."*

Definition of the word "Force"

During interviews the same students who demonstrated the common alternate conception[4] "motion requires a force" also correctly used the concept of inertia on other questions.

Elise, for example, consistently identified "motion requires a force" for Q5 – ball in channel, Q11- hockey puck and Q13 – ball toss; however, on Q10 she says *"If it's a frictionless surface there's nothing that's going to cause it to decrease so I can disclude D and E. Um … and C. But um, there's nothing that's making it continuously accelerate either so I can disclude B so I choose A, it's constant."*

The cause of this seemingly inconsistent behavior was not immediately clear; however, using Q30 – tennis ball over net – as a peer-discussion question in Adams' class shed some light. During a heated debate, it slowly became clear that many of the students were using the word force for two different phenomena – what we call force and what we call momentum. Students were clear that these were different but called both force.

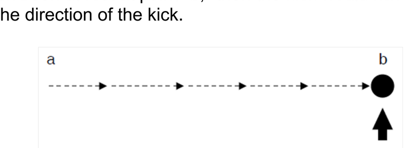
We tested this possible source of confusion, in the 3rd round of interviews. During the second part of each interview, the physics definition of force and momentum were discussed with students who used "motion requires a force" on Q5 – ball in channel.

The interviewer used Q30-the tennis ball, to define force and momentum for Elise. She quickly jumped in and transferred the idea to Q5, *"Ohhhh, okay. So it doesn't make sense for there to be like …, because there's nothing pulling the ball around the channel."* I: "*whatever kicked it in there…"* E: *" it's done."* Elise went on to apply this definition to Q11 and Q13 successfully.

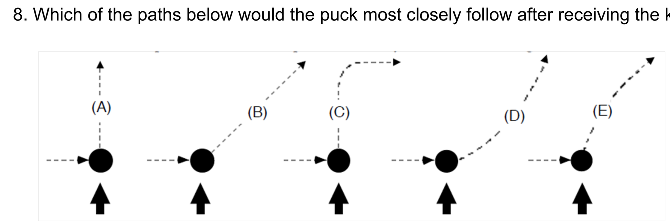
When Max is told that the answer to Q11 is 'a downward force of gravity and an upward force by the surface.' Max quickly responded, *"because there's nothing touching it anymore, that makes sense…. It's just the momentum"* I: *"right,"* and then he extends this idea to acceleration, *"not force. So then a force would cause an acceleration if there's no other..?"*

Original Questions

USE THE STATEMENT AND FIGURE BELOW TO ANSWER THE NEXT FOUR QUESTIONS (8 through 11).
The figure depicts a hockey puck sliding with constant speed v0 in a straight line from point "a" to point "b" on a frictionless horizontal surface. Forces exerted by the air are negligible. You are looking down on the puck. When the puck reaches point "b," it receives a swift horizontal kick in the direction of the heavy print arrow. Had the puck been at rest at point "b," then the kick would have set the puck in horizontal motion with a speed equal to vk in the direction of the kick.



8. Which of the paths below would the puck most closely follow after receiving the kick?



9. The speed of the puck just after it receives the kick is:
   (A) equal to the speed it had before the kick.
   (B) equal to the speed, vk, and not related to the speed it had before the kick.
   (C) equal to the sum of the speed before the kick and vk.
   (D) smaller than either the speed it had before the kick or vk .
   (E) greater than either the speed it had before the kick or vk , but less than the sum of these two speeds.

10. Along the frictionless path you have chosen in question 8, the speed of the puck after receiving the kick:
   (A) is constant.
   (B) continuously increases.
   (C) continuously decreases.
   (D) increases for a while and decreases thereafter.
   (E) is constant for a while and decreases thereafter.

11. Along the frictionless path you have chosen in question 8, the main force(s) acting on the puck after receiving the kick is (are):
   (A) a downward force of gravity.
   (B) a downward force of gravity, and a horizontal force in the direction of motion.
   (C) a downward force of gravity, an upward force exerted by the surface, and a horizontal force in the direction of motion.
   (D) a downward force of gravity and an upward force exerted by the surface.
   (E) none. (No forces act on the puck.)

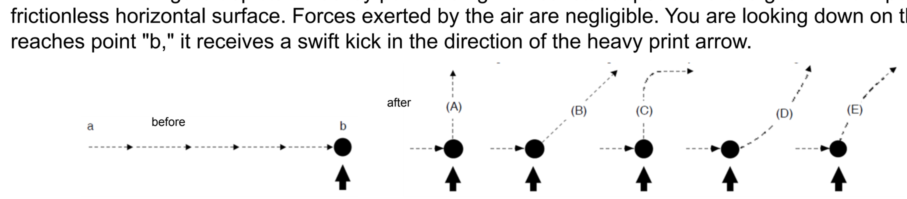
These questions were modified so that students can quickly connect the before and after situations.

During interviews the original Q9 was not eliciting physical discussion. Additionally, vector addition could be argued to be extraneous to other concepts addressed by the FCI.

Surprisingly after removal of Q9, clearer descriptions of the students intuitions about the puck's speed after the kick emerged, while describing answers to the other questions, including it was slower, stayed the same or faster.

Modified Questions

USE THE STATEMENT AND FIGURE BELOW TO ANSWER THE NEXT THREE QUESTIONS (8 through 10).
The figure depicts a hockey puck sliding with constant speed in a straight line from point "a" to point "b" on a frictionless horizontal surface. Forces exerted by the air are negligible. You are looking down on the puck. When the puck reaches point "b," it receives a swift kick in the direction of the heavy print arrow.



8. Which path would the puck most closely follow after receiving the kick?
9. The speed of the puck after receiving the kick:
   (A) is constant.
   (B) continuously increases.
   (C) continuously decreases.
   (D) increases for a while and decreases thereafter.
   (E) is constant for a while and decreases thereafter.
10. The main force(s) acting on the puck *after* receiving the kick is (are):
   (A) a downward force of gravity.
   (B) a downward force of gravity, and a horizontal force in the direction of motion.
   (C) a downward force of gravity, an upward force exerted by the surface, and a horizontal force in the direction of motion.
   (D) a downward force of gravity and an upward force exerted by the surface.
   (E) none. (No forces act on the puck.)

Coherent Tracking of Events in Time

As physicists, we tend to think of the temporal evolution of a system in terms of a flow of successive moments in time. Then we can analyze what is happening to the system at a particular instant by carefully coordinating all events that occur at that instant.

During interviews, certain students had difficulty doing this on Q5 ball in channel, Q10 hockey puck speed after kick, Q13 ball toss, Q17 elevator, Q22 & Q24 rocket speed when engines on and after burst, and Q26 doubling the force on the box.

Original Questions

25. A woman exerts a constant horizontal force on a large box. As a result, the box moves across a horizontal floor at a constant speed "vo".
   The constant horizontal force applied by the woman:
   (A) has the same magnitude as the weight of the box.
   (B) is greater than the weight of the box.
   (C) has the same magnitude as the total force which resists the motion of the box.
   (D) is greater than the total force which resists the motion of the box.
   (E) is greater than either the weight of the box or the total force which resists its motion.

26. If the woman in the previous question doubles the constant horizontal force that she exerts on the box to push it on the same horizontal floor, the box then moves:
   (A) with a constant speed that is double the speed "vo" in the previous question.
   (B) with a constant speed that is greater than the speed "vo" in the previous question, but not necessarily twice as great.
   (C) for a while with a speed that is constant and greater than the speed "vo" in the previous question, then with a speed that increases thereafter.
   (D) for a while with an increasing speed, then with a constant speed thereafter.
   (E) with a continuously increasing speed.

27. If the woman in question 25 suddenly stops applying a horizontal force to the b that is constant and greater than the speed in the previous question, ox, then the box will:
   (A) immediately come to a stop.
   (B) continue moving at a constant speed for a while and then slow to a stop.
   (C) immediately start slowing to a stop.
   (D) continue at a constant speed.
   (E) increase its speed for a while and then start slowing to a stop.

Modified Questions

Use the statement below to answer the next three questions (25 through 27).

A large box is pulled with a constant horizontal force. As a result, the box moves across a level floor at a constant speed.

25. The pull:
   (A) has the same magnitude as the weight of the box.
   (B) is greater than the weight of the box.
   (C) has the same magnitude as the total force which resists the motion of the box.
   (D) is greater than the total force which resists the motion of the box.
   (E) is greater than either the weight of the box or the total force which resists its motion.

26. If the pulling suddenly stops, then the box will:
   (A) immediately come to a stop.
   (B) continue moving at a constant speed for a while and then slow to a stop.
   (C) immediately start slowing to a stop.
   (D) continue at a constant speed.
   (E) increase its speed for a while and then start slowing to a stop.

27. If, *instead*, the horizontal force pulling the box is doubled, the boxes' speed:
   (A) continuously increases.
   (B) will be double the speed but still constant.
   (C) is greater and constant, but not necessarily twice as great.
   (D) is greater and constant for a while and increases thereafter.
   (E) increases for a while and constant thereafter.

During interviews on the original set of questions, some students were not reading all the distractors; and others were changing their interpretation of the question as they read the options.

We determined that the text was too complicated. Also these questions are very similar to the hockey puck and rocket so should look similar. This way we can be more confident that differences are not due to question wording only the physical situation. Q26 is harder than Q27 so we switched the order.

The clarified questions functioned well during interviews providing much new information on student difficulties with force. These questions require a deeper understanding than previous questions.

Students insisted on considering the process of *getting to* the moment that the question describes. With the double force on the box, the force could not just be doubled, it was important to them to describe the speed while the force was becoming double and then after.

Jerome thinks, *"I guess it would depend on how it's applied. Is it immediately, you know. … The force applied increases but not a gradual over time increase."*

Elise says *"Since in real life things don't just jump up a graph and move at an increased rate [of force], it can't just be… it'll have to reach that speed."*

With Question 27 many students were unhappy with the indefinite end to this question.

When presented with the correct answer for the double force on the box, Shane expresses his disbelief, *"continuously increases? Theoretically forever and ever?"*

Elizabeth was also bothered, *"I don't know. Wouldn't it like eventually level out?"*

This difficulty with the coherence of events in time, could be related to visualization skills and the very important physicist' technique of simplifying and focusing only on the basic cause and effect of an isolated scenario.

Conclusion

We have explored the consequences of modifying some FCI questions in order to achieve greater clarity in their presentation. The results of the latest iteration of think-aloud interviews suggests a certain level of success in this regard as student interviews indicated a focus on the physics of the questions with minimal distractions arising from non-physical features. In fact, students were able to convey information so as to allow us to discern the underlying problems. We presented two of those here - definition of the word "force" and coherent tracking of events in time.

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