UNIVERSITY of NORTHERN COLORADO

# Force Concept Inventory Interviews

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**Abstract:** For several years we have investigated the well-known gender gap in performance on the Force Concept Inventory (FCI) which is certainly seen with our students. Indeed, our incoming female population has much lower pre-test scores (26%) than do their male counterparts (42%). This difference is not consistent with course performance, and we would like to account for this discrepancy. Our students represent the full range of possible pre-test scores. To investigate how our students think, we conducted think-aloud student interviews on a specific subset of FCI questions. Our subjects had previously taken the FCI twice. Preliminary results indicate that students who score 20% or lower are not guessing; they have reasons for their answers. Furthermore, particular incorrect answers are selected for a variety of reasons.

## Introduction

The Force Concept Inventory has been administered to high school and college students for over 25 years. The resulting scores have been analyzed in a multitude of ways. Gains in the FCI have been used to support the efficacy of various teaching strategies. Yet, despite its familiarity, the FCI remains problematic. For example, there is still no satisfactory explanation for the fact that males routinely outperform females on the FCI.

As part of our continuing effort to understand student performance on the FCI, we have begun to conduct think-aloud interviews with physics students as they grapple with some of the questions on the FCI. The initial dozen interviews have been revealing. We found that some students have ways of looking at some questions that would never have occurred to us. We, as experienced physics instructors, are effectively oblivious to difficulties that beginning students can have with test questions. The nuanced wording of the questions we create is lost on some students for whom the question might just as well be written in Sanskrit. To some students our carefully constructed diagrams resemble the entrails of a goat. When presented with such questions, students try to engage in sense-making by grasping at whatever straws appear.

We are here not dealing with what are commonly known as misconceptions. To be a misconception there has to exist some coherent mental construct that can be so-labeled. What we observe could better be called misunderstandings. We here draw attention to some of the misunderstandings revealed during the interviews.

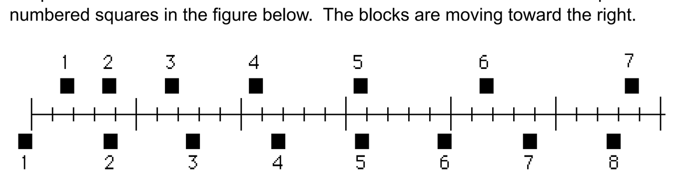
## Interview Protocol

**Key:**
Phase 1 student comment
*Phase 2 student comment*

- 20 FCI questions
- ~1 hour
- Think aloud in two phases
  - Phase 1: The student is asked to answer each question and think out loud.
  - Phase 2: The student is told the "physicist's answer" for each question and asked to explain that choice and how reasonable it seems.

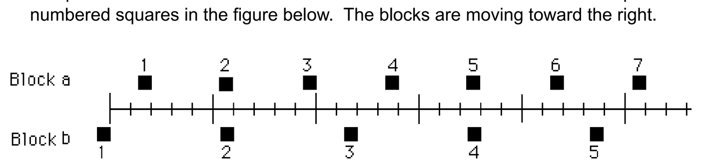
## Poor Representation

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.

As the interviews suggest, some students were at a loss as to what the figures of Questions 19 and 20 are physically representing. Specifically, from the student input, one may ask if Question 19 has certain students confused as to what role time plays in relation to position. Some students seemed to look for a point at which the blocks pass one another and wanted to focus on points 2 and 5 as they are lined up for both blocks indicating, to these students, that they have the same speed, at least, momentarily.

"Yes, at instant 5." (*Seems to want them to be lining up still.) "It's at the point where the bottom one passes the first one."*

As they grappled with the figure, interviewees seemed to lose sight of the problem statement and how time is implicitly included. In this sense, one might see this overall method of posing this problem to be a distraction in itself. (One student lost sight of the problem statement and saw the blocks as moving in opposite directions.)

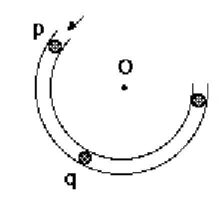
Interestingly, interviews revealed that certain students having problems with Question 19 seemed to interpret Question 20 correctly – they saw consecutive squares equally spaced over equal time intervals and reasoned that the speed for each block is constant, and, therefore, the accelerations are both zero. However, this wasn't always the case. Some students still appeared to have a general problem of seeing how to handle time, and, thus, speed and acceleration, properly, given the figure.

Overall, this way of presenting Questions 19 and 20 seems, given the students' responses, to have left students unclear as to how the motion in question is to be interpreted. This would suggest that, for some students, their simplest understanding of kinematics could not be employed, thus, having one ask what these questions are ultimately testing. As one student put it (after being made aware of the correct answer), *"It's just a number line with blocks. No, I don't understand."* At least Question 20 labels the blocks (Question 19 does not) in the figure allowing students to more immediately grasp the figure's intent.

## Question/Diagram Confusion

**USE THE STATEMENT AND FIGURE BELOW TO ANSWER THE NEXT TWO QUESTIONS (5 and 6).**

The accompanying figure shows a frictionless channel in the shape of a segment of a circle with center at "O". The channel has been anchored to a frictionless horizontal table top. You are looking down at the table. Forces exerted by the air are negligible. A ball is shot at high speed into the channel at "p" and exits at "r."

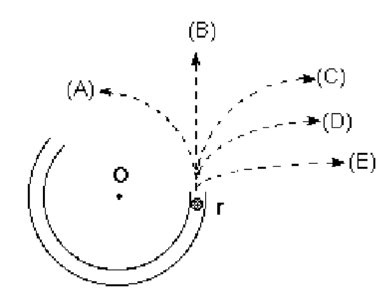



5. Consider the following distinct forces:
   1. A downward force of gravity.
   2. A force exerted by the channel pointing from q to O.
   3. A force in the direction of motion.
   4. A force pointing from O to q.

Which of the above forces is (are) acting on the ball when it is within the frictionless channel at position "q"?

(A) 1 only.
(B) 1 and 2.
(C) 1 and 3.
(D) 1, 2, and 3.
(E) 1, 3, and 4.

6. Which path in the figure at right would the ball most closely follow after it exits the channel at "r" and moves across the frictionless table top?




➢The format of the print version of the FCI places Question 5 between two diagrams, the upper associated with Question 5 and the lower with Question 6. Some students (21%) see the second diagram as more closely connected with Question 5 perhaps because it is physically close to the answers to Question 5. The most egregious source of confusion between the two questions is that the same letters of the same alphabet label the answers to Question 5 and the paths in the diagram for Question 6. It so happens that path "B" is the correct answer to Question 6, and "B" is the correct answer to Question 5. Thus a student could give the correct answer to Question 5 for a completely wrong reason. One of the interviewees clearly changed his answer to B because of the second diagram even though his reasoning supported option C.

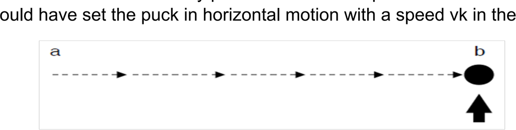
Reads the question out loud while pointing to the correct diagram. "So it still has 1 it always has gravity. q to O um so it would be 1 and 3 a force pointing in the direction of motion. O to q umm I'm going to go with C 1 and 3. A downward force of gravity and a force in the direction of motion. But then there's also (points to next diagram) wait 1 and 2 actually I'm going to go with B 1 and 2 force exerted by the channel from q to O because it's going to go like this (points along path B of second figure) unless the channel is still going around so B".

➢Many students were overwhelmed by the question. Several had to write notes or arrows while working out the answer. Two students chose different options from their reasoning. It appeared this was simply an error due to the load necessary to translate the description of the forces to a force, then identify the correct number associated with each force and then to identify an answer option that contained only the numbers for the forces they had identified.

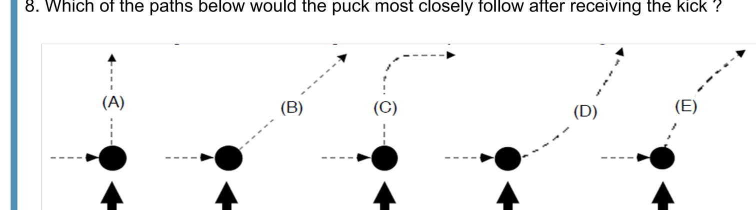
## Perplexing Notation

**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 vo 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 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 "$v_o$" it had before it received the kick.
(B) equal to the speed "$v_k$" resulting from the kick and independent of the speed "$v_o$".
(C) equal to the arithmetic sum of the speeds "$v_o$" and "$v_k$".
(D) smaller than either of the speeds "$v_o$" or "$v_k$".
(E) greater than either of the speeds "$v_o$" or "$v_k$", but less than the arithmetic sum of these two speeds

With this question, we were only able to get insight into students' physical reasoning with half the interviewees. All but one of those got the question correct. The others who answered incorrectly misunderstood some part of the question terminology or description, so their physical reasoning could not be analyzed. The good news is that all correct responses came with correct reasoning.

➢Students were confused by the notation making it impossible to understand their difficulties with the physics. We postulate that this may be more of an issue for the pre-test than the post-test.

*"$v_o$ is velocity constant and $v_k$ …and I don't know. Well $v_o$ is initial… I'm trying to remember back to what he taught me. We used $v_i$ and I guess…"*

*"…the original speed, o for original."*

➢30% of interviewees chose option B. Their descriptions *could be considered* consistent with the understanding that the final velocity was given in the problem as $v_k$.

"B. Equal to the speed you're hitting it with because if you have a frictionless surface."
"I'm going to go with B. Just cause it's motion is independent and all that junk on a frictionless path."

➢Students combined part of the distracter information with the question. "$v_k$ and $v_o$ are independent," which is only suggested in option B and is not part of the question.

*"Now if it asked for the resultant vector then it would be E but it says independent so I would not concur."*

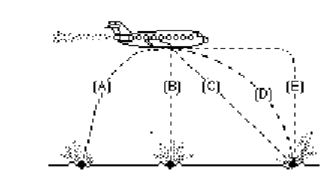
➢At least one student did not know what "arithmetic sum" meant.

"Equal to the arithmetic sum. Oh Wait. It has the initial and it gets another and they don't add. Yea I'm going to go with C."

## Incorrect Diagram

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?




Most students did not understand the diagram. 2 of 5 correct responses came with correct reasoning. All other responses, correct and incorrect, were convoluted with misunderstanding the diagram so physical reasoning could not be interpreted.

➢The diagram is incorrect and was misinterpreted by the majority of students. The plane is shown at the time the ball is released; however, the ball is shown at the time it hits the ground.

"A Because it's going to appear as the plane's moving. *Are they watching it from the plane. That's just a confusing question in my opinion. With D I would see it as if the plane is at a standstill. I guess if the plane continued and the ball dropped out of the back."*

"Is the plane still moving?" She had correct reasoning but talked herself into B because of the diagram. "Not possible for the ball to land ahead of the plane."

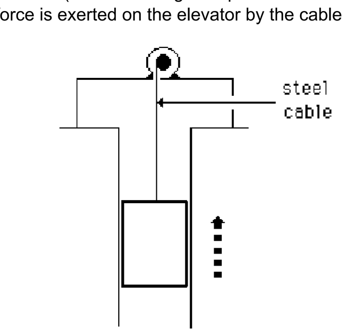
➢50% of correct answers were based on intuition and not the physics.

"I'd probably say D. It looks right."

"It's going this direction so that force… (used one hand horizontal -plane continuing on - and one the ball.) D."

## Confusing Wording

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).




Elevator going up at constant speed

Students all used physical reasoning to answer the question and interpreted the question and the diagram as a physicist would with the exception of "all frictional effects are negligible." If the question said, "all frictional effects including air resistance are negligible," then the question would clearly focus on the physics of having no net force when velocity is constant.

➢The predominant idea is that for the elevator to go up, there must be a net force in the upward direction.

*"They're saying they are equal. But if it's moving shouldn't the force upward be greater? If it were just sitting there they would equal each other. I think they're full of it."*

*"But it's going up! Maybe because the upward force of the cable is like the normal force. They have to equal each other. The cable is shortening maybe? All the forces are equal..."*

➢A couple of students, when faced with the correct response, wondered if a motor could explain this strange answer.

*"Maybe a motor?" or "They're just one constant speed that's being moved by some motor or whatever."*

➢The majority of students understood "no frictional effects" to mean no air resistance as well as no friction on the elevator. However, 30% of interviewees interpreted air resistance as being different than friction.

"And friction is negligible but air can still play a role."

"I feel like there's a downward force of air and an upward force due to air so they would cancel."

"All right I don't really see anything about air. So I don't think the question is worded very well. Um we're going to neglect air, the force of the cable is greater than the force of gravity. They don't say anything specifically about air but I think it's such a moot point it won't even matter anyway."

## Conclusion

The results of these interviews call into question the validity of some of the FCI questions in that misunderstandings, arising from flaws in their presentation, prevent them from accurately measuring physical understanding.