

KINEMATICS

Learning gains in kinematics were generally good, particularly for velocity-distance-time relationships. For instance:

Velocity graph questions:

Pretest: 51%

Posttest: 87%

Acceleration graph questions:

Pretest: 13%

Posttest: 64%

HOWEVER, significant conceptual difficulties with acceleration remain . . .

Interviews with Students

Interview Format:

Students were interviewed ***after*** completing posttest diagnostic. A scenario was presented that was virtually identical to the “Force Sled” questions. *[A person wearing ice skates standing on a slippery frozen lake.]* Students were asked to respond to questions worded precisely the same as Force Sled Questions #1-5.

Following are excerpts from interview with student ranked 3rd in class of 11:

DEM: Suppose she is speeding up at a steady rate with constant acceleration. In order for that to happen, do you need to apply a force? And if you need to apply a force, what kind of force: would it be a constant force, increasing force, decreasing force?

STUDENT: Yes you need to have a force. It can be a constant force, or it could be an increasing force.

DEM: . . .She is speeding up a steady rate with constant acceleration.

STUDENT: Constantly accelerating? Then the force has to be increasing . . . Wait a minute . . .

The force could be constant, and she could still be accelerating.

DEM: Are you saying it could be both?

*STUDENT: It **could** be both, because if the force was increasing she would still be constantly accelerating.*

DEM: What do we mean by constant acceleration?

STUDENT: Constantly increasing speed; a constant change in velocity.

DEM: I need you to explain #3.

["The sled is moving to the right. Which force would slow it down at a steady rate (constant acceleration)?"]

Student: [reads answer she chose] "The force is toward the left and is decreasing in strength." . . . I was picturing the sled, and I was thinking that it would take less force once it started slowing down . . . I don't know . . .

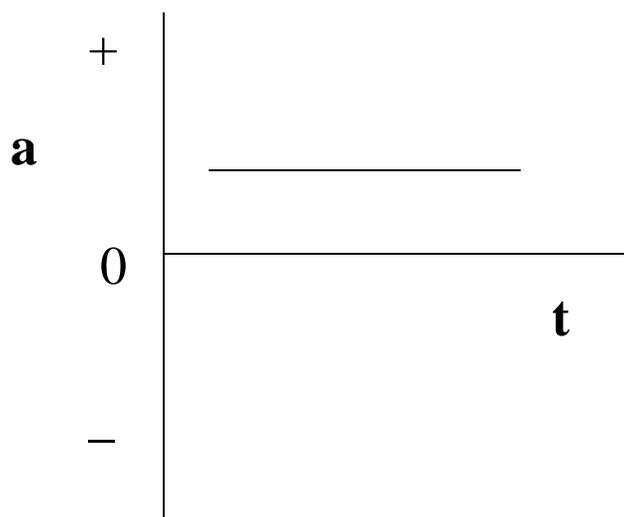
*You want it to slow down at a steady rate. So since it's moving towards me and I want it to slow down, I'm actually going to have to go with it . . . and I guess I would **increase** my force to slow it down, not decrease it. I don't know . . .*

DEM: Does the fact that it says "constant acceleration," does that help you to figure this out?

STUDENT: Only in so far as if the acceleration is constant, then the slope is zero . . .

DEM: The slope of what?

STUDENT: The slope of the acceleration, and so the slope of the force is going to be zero: they mirror each other. The force is going to be constant. [Draws graph to explain her reasoning.] When I think of constant acceleration, I think of this [horizontal line].



DEM: Now, if acceleration is constant, tell me what that tells you about force.

STUDENT: It tells me that the force is going to be constant . . . If I want to keep my acceleration constant, it seems like I would need to keep my force constant.

DEM: Now, on this one we've gone all the way around. At first you said less force was needed once it started slowing down, then you said maybe you have to increase the force. And now you're saying, "constant force."

STUDENT: Well, according to what I know, or what I think I know about graphs, I would say that the force had to remain constant because the acceleration is constant.

*According to the visual image I have in my head, if a skater was coming towards me and I wanted to slow her down at a steady rate, I don't think that my force would be constant. I don't know **why** I don't think that, I just think it would take less force towards the end.*

DEM: How about explaining [MBT #3] to me?

STUDENT: If there is no slope in velocity, it can not be accelerating . . . which means there can be no force.

This [middle segment] is constant and increasing, so that means it has a positive slope . . . velocity is constantly increasing, so acceleration is constant. It's the slope of the velocity . . .

Then here [first and last segments], there is no increase in velocity. There's no increase, there's no decrease . . . so it [acceleration] is zero. And with force mirroring acceleration, my force is going to be zero.

STUDENT (explaining MBT #21): Double the mass, double the time it takes.

DEM: How did you figure it out?

STUDENT: Because . . . I remember the force-motion worksheet we did where double the mass was double the . . . the formula, which I actually can't even recall.

DEM: Tell me again what you remember from the worksheet.

STUDENT: If the mass is doubled, if you want the speed to be the same, you'd have to double the force . . .

DEM: If there anything that would have allowed you to figure that out? From, like, mathematical formulas, or something else?

STUDENT: Yeah, there's the formula.

DEM: Can you write it down?

STUDENT: No . . . it's the mass, and it's force, and it's "this" equals "this over this." Then . . . "acceleration" equals "mass over force".

DEM: Now, that says that a bigger force gives you a smaller acceleration . . .

STUDENT: That's what it says.

DEM: So, if we had the same force, and we had the bigger mass, are we going to get the bigger acceleration?

STUDENT: If we have the same force, and we have more mass . . . Now you're going to have less acceleration. So that [her statement about bigger acceleration] is so wrong. So a is F over m .

DEM: Now, if acceleration is constant, tell me what that tells you about force.

STUDENT: It tells me that the force is going to be constant . . . If I want to keep my acceleration constant, it seems like I would need to keep my force constant.

DEM: Now, on this one we've gone all the way around. At first you said less force was needed once it started slowing down, then you said maybe you have to increase the force. And now you're saying, "constant force."

STUDENT: Well, according to what I know, or what I think I know about graphs, I would say that the force had to remain constant because the acceleration is constant.

DEM: Now, if acceleration is constant, tell me what that tells you about force.

STUDENT: It tells me that the force is going to be constant . . . If I want to keep my acceleration constant, it seems like I would need to keep my force constant.

DEM: Now, on this one we've gone all the way around. At first you said less force was needed once it started slowing down, then you said maybe you have to increase the force. And now you're saying, "constant force."

STUDENT: Well, according to what I know, or what I think I know about graphs, I would say that the force had to remain constant because the acceleration is constant.

(Some) Interview Findings

- Misunderstanding of “constant” rate of increase; misinterpretation of “constant” to mean “unceasing”
 - Shaky grasp on $a = F/m$
 - Much greater confidence with dynamics questions posed in graphical representation
 - Evidence of “pattern matching”

ELEMENTARY PHYSICS AT SOUTHEASTERN LOUISIANA UNIVERSITY (SLU)

Originally, this was a traditional lab-lecture course required of some students in the health professions.

One section of this course was taken over by an NSF-funded pilot project to create a new inquiry-based course targeted at elementary education majors.

Among the materials utilized (at one time or another):

- Homework sheets from **Tools for Scientific Thinking** (Thornton and Sokoloff)
- Worksheets from **Physics: A Contemporary Perspective (Workbook Vol. 1)** (Knight)
- Original materials developed at SLU.

INTERVIEW SUBJECT

- Ranked 3rd in class of 11
- Scored 100% on FMCE Velocity and Acceleration questions (Posttest)
- Meets Thornton and Sokoloff criteria for being at “transitional” stage of dynamics understanding
- Is representative of the “upper middle” of all eight classes

Force Sled Questions #1,2,4

“Which force would keep the sled moving . . . [1,4] . . . toward the right (left) and speeding up at a steady rate (constant acceleration)? [2] . . . toward the right at a steady (constant) velocity?”

[**Answers:** (1,4) toward the right (left) and of constant strength; (2) no applied force is needed.]

Pretest: 2% [3 samples]

Posttest: $37 \pm 4\%$ (range: 23-50%) [7 samples]

$g = 0.36$

All seven samples far lower than University of Oregon posttest.

Comparisons:

University of Oregon (non-calculus general physics class, Force Sled Questions #1-4,7):

Pretest: 17%

Posttest: 80%

$g = 0.76$

Force Sled Question #1,2, 4

*Which force would keep the sled moving . . .
[1] . . . toward the right (left) and speeding up at
a steady rate (constant acceleration)? [2] . . .
toward the right at a steady (constant) velocity?"*

Answers: (1,4) toward the right (left) and of constant strength; (2) no applied force is needed.]

Pretest: 2% [3 samples]

Posttest: $37 \pm 4\%$ (range: 23-50%) [7 samples]

$g = 0.36$

University of Oregon (non-calculus general physics class,
Force Sled Questions #1-4,7): Pretest: 17% Posttest:

$g = 0.76$

seven samples far lower than University of Oregon
test.

Comparisons: University of Oregon (non-calculus general
physics class, Force Sled Questions #1-4,7):

Pretest: 35%

Posttest: 92%

Force Sled Question #5

“The sled was started from rest and pushed until it reached a steady (constant) velocity toward the right. Which force would keep the sled moving at this velocity?”

[**Answer:** No applied force is needed.]

[This question is categorized as a “transitional” question by Thornton and Sokoloff, answered correctly by those who are just beginning to accept the Newtonian view.]

Pretest: 14% [3 samples]

Posttest: $48 \pm 7\%$ (range: 11-64%) [7 samples]

$g = 0.40$

***All seven samples** far lower than University of Oregon posttest.*

Comparisons:

University of Oregon (non-calculus general physics class):

Pretest: 35%

Posttest: 92%

$g = 0.88$

