Toward a comprehensive picture of student understanding of force, velocity, and acceleration

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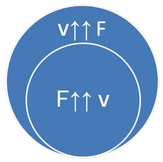
Introduction

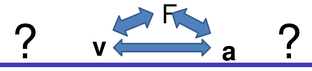
Students' difficulties with conceptual questions about force, velocity and acceleration have been well documented.

However, there has been no single systematic study of student understanding of all paired relations among the concepts of force, velocity and acceleration.

Does a student who thinks that a moving object must have a force, v ↑↑ F also think that an object with a force necessarily has a velocity, F↑↑ v?



What about force and acceleration? Velocity and acceleration?



Performance differences between tests

A group of workers is pushing a car in a driveway. The net force on the car is toward the street. What can you say about the acceleration of the car?

Test Type	N	F ↑↑ a	F (↑↑,↑↓, ↑ 0) a	F (↑↑, ↑↓) a	F (↑↑, ↑ 0) a	Other
Test 1	78	89%*	9%			2%
Test 2	40	35%*	13%	15%	20%	17%
Test 3	119	56%*	13%	4%	20%	7%

F ↑↑ a means the student says the acceleration is aligned with the given net force.
F ↑↓ a means the student says the acceleration is opposite with the given net force.
F ↑ 0 a means the student says the acceleration is zero even though there is a net force.

A car is on a hill, and the direction of the acceleration is uphill. What can you say about the motion of the car?

Test Type	N	a ↑↑ v	a (↑↑,↑↓, ↑ 0) v	a (↑↑, ↑↓) v	a (↑↑, ↑ 0) v	Other
Test 1	2	59%	37%*			4%
Test 2	40	28%	35%*	20%	8%	9%
Test 3	119	48%	23%*	17%	12%	0%

Force/ acceleration question

Test 1 says that students understand the force acceleration relationship, but when given extra choices students still do not seem to understand Newton's second law.

A possible explanation for this

The presence of extra answer choices helps remind students of other options for the acceleration/velocity relationship while it incorrectly makes them unsure of the force / acceleration relationship.

A soccer player pushes on a soccer ball with her foot. What can you say about the motion of the ball?

Test Type	N	F ↑↑ v	F (↑↑,↑↓, ↑ 0) v	F (↑↑, ↑↓) v	F (↑↑, ↑ 0) v	Other
est 1	191	58%	38%*		6	4%
est 2	2	5%	2%*	31%	%	16%
Test 3	19	61%**	11%*	12%	14%	2%

**A possible reason: Many students did not know what "net force" meant so we changed the wording to things like, "there are several forces but those to the west are bigger" for Test 3.

Examples of answer choices for different versions.

The prompt is "A car is on a hill and the direction of its acceleration is uphill. Which statement best describes the motion of the car?"

Test 1	Test 2 (Always, Sometimes, Never)	Test 3
a) it is moving uphill b) it is moving downhill c) it is not moving d) not enough information	(B) (S) (N): The car is moving uphill (D) (S) (N): The car is moving downhill (F) (S) (N): The car is not moving	a) It is moving uphill b) It is moving downhill c) It is not moving d) Both a and b are possible e) Both a and c are possible f) a, b, and c are possible

Reasons for the different test versions and interesting things we found from interviews

	Advantages	Drawbacks
Test 1	● Student's answers can be easily categorized into correct and the "common misconception" such as velocity in the direction of net force.	● Data is less meaningful because students are all grouped into the 4 available models. ● "Not enough information" is a unique answer choice. Students may choose it for none physics reasons.
Test 2	● All combinations of answers are available. This allows more accurate categorization of students into distinct conceptual models.	Students would often answer in a logically inconsistent manner. "It is always to the north, sometimes to the south, and never at rest." ● 9% of the questions were answered illogically ● Only 29 of 72 students made no logical mistakes

Results From Final Version (Test 3)

Standard error is about 4%. Some questions types have two questions that were given and thus two response percentages. The correct answer is denoted with a *. (N = 119)

Question Type	X (↑↑, ↑↓, ↑ 0) Y	X (↑↑) Y
v → F	11% *	73%
	13% *	4%
F → v	11% *	61%
	3% *	1%
a → v	36% *	32%
	23% *	48%
F → a	13%	56% *
a → F	5 %	84% *
F = 0 → v	14% *	84%
v = 0 → F	29% *	0%
Speeding up, v → F	1%	84% *

Conclusions

By comparing the three tests we see that the original simple multiple choice test , Test 1, does not show that students often have (↑↑,↑↓) or (↑↑,↑ 0) models. (Test 3 answer choice d or e above.)

Also, Test 1 overestimates the number of students understanding Newton's second law.

The results from our third and final test indicate that some students may understand some of the relationships between force, velocity, and acceleration better than other relationships. More students answered that:

- v ↑↑ F than F ↑↑ v
- a ↑↑ F than F ↑↑ a
- F ↑↑ v than a ↑↑ v

It appears as though there is a directionality to students' answering patterns. One explanation of this is that there is a hierarchy to student reasoning about these topics.

Certainly more varied and deeper assessments of student understanding are needed to investigate this finding further.