

Representations of Force and Motion Concepts at the Middle Level[‡]

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Abstract

Project 2061 is creating assessment items targeting the learning goals recommended by AAAS's *Benchmarks for Science Literacy* (1993) and the NRC's *National Science Education Standards* (1996). One of our topics is Force and Motion at the middle grades level. To reduce the dependence of student performance on verbal ability, we employ graphical representations of concepts and situations. We will describe representations of (1) position versus time (Oil Drop), (2) force, speed, and change of speed (block and line arrows), (3) speed versus time (speed table). We will present sample assessment items and preliminary results from pilot testing and student interviews on comprehensibility, grade-level suitability, and effectiveness relative to purely verbal representations.

Oil Drop (Motion Map, Strobe Diagram)

Goal: Pictorial representation of changing speed

(from Motion key idea) "Given two objects in motion, the one that travels farther in a given time interval is the one with the greater speed."

(from Change of Speed key idea) "Constant speed occurs when an object travels equal distances in successive equal time intervals. Increasing speed occurs when the distance traveled by an object in successive equal time intervals increases, and decreasing speed occurs when the distance traveled by an object in successive equal time intervals decreases."

Typical Item

A car is leaking oil. One drop falls on the road every second.

The oil drops make a pattern on the road.

The car is at a traffic light. When the light turns green, the car speeds up until it reaches a speed of 50 mi/hr. Then it maintains that speed. Which pattern of drops could have been caused by this motion?

A. (Correct answer—acceleration then constant speed)

B. (Incorrect—continuous acceleration)

C. (Incorrect—slow constant speed then fast constant speed)

D. (Incorrect—constant speed)

Results from Pilot Testing

- The item above was administered to 6th, 8th, and 9th grade students.
 - Students' prior experience with this representation unknown.
 - Performance was poor: 0% correct (31 students).
- 12 of 31 students, including 10 of 14 9th grade students, provided written evidence of understanding the motion depicted by at least one answer choice.
- No student provided written evidence of noticing the constant-speed portion of the correct choice (A).
- No student provided evidence of using fence posts to judge distance.

Results from Interviews

- The item was administered to two gifted/talented (G/T) students with classroom instruction in force and motion and possible prior exposure to this representation. The item was administered to two students with no instruction in force and motion and no prior exposure to this representation.
- The G/T students understood the motion depicted by every answer choice, and selected the correct answer.
- The other students seemed to understand motions B, C, and D but did not understand A. These two students remarked on the plausibility of the motion (puddles at stoplight, acceleration value).

Conclusions from Interviews and Pilot Testing

- Student performance was artificially low because correct answer (choice A) was the most complicated.
- This representation needs improvement.
 - More effective position marker than fence posts.
 - Dot spacing that will be recognized as accelerated motion. For example, try non-constant acceleration.
- With improvement, this representation will be suitable for middle grades.

Force and Motion Arrows

Motivation

We believe that representations of force and motion should be used in assessment.

(from Forces key idea) "A force diagram uses arrows to represent the forces acting on an object at a particular moment. The length of the arrow represents the relative magnitude of the force. The direction of the arrow represents the direction of the force acting on the object."

Goal: Representations of force and motion that are intrinsically valid and easy to draw

Our representation must be able to show...

- the direction of a force *relative to object's motion*.
- the relative magnitude of two forces that are acting on the same object at the same time.

Implementation: Line and Block Arrows

- A force is represented by a line arrow. Length of arrow represents strength of force.
- (Direction of) Motion is represented by a block arrow.
- Arrows are positioned to suit the scenario.

Typical Item

In the drawing below, the arrows labeled "WIND" and "WATER" represent forces acting on the sailboat. The lengths of the arrows represent the strengths of the forces, and the directions of the arrows show the directions of the forces. The arrow labeled "Motion" shows the direction of the sailboat's motion. The force of the wind on the sailboat is stronger than the force of the water on the sailboat the entire time.

Which statement describes the sailboat's motion while these forces are acting?

A. The sailboat will speed up the entire time.
 B. The sailboat will move at a constant speed the entire time.
 C. The sailboat will speed up for a short time and then slow down.
 D. The sailboat will speed up for a short time and then move at a constant speed.

Results from Pilot Testing: Students Prefer Representation to Text

- The item above (the representation version), and an all-text version, were administered to comparable groups of 6th grade and 8th grade students.
- Students' prior experience with arrow representations unknown.
- Performance on the representation version was same or better than on all-text version.

Grade	Item Version	n	Correct	No choice	Confusing
6 th	Representation	59	44%	5%	7%
	Text	39	23%	18%	33%
8 th	Representation	45	51%	16%	18%
	Text	39	21%	28%	36%

Results from Pilot Testing: Force Arrow Style Preference

"Which arrow looks more like a force: or ?"

Grade	n	block arrow : line arrow
6 th	25	3:2
8 th	14	3:4
8 th G/T	21	3:8

6th grade students think block arrow looks more like a force because it is larger.

8th grade students think line arrow looks more like a force because it is darker.

For 8th graders there is evidence of a small effect of prior instruction using line arrows.

Additional Use of Representation: Changing Speed

Changing Speed is represented by block arrows. The arrows also show the direction of motion.



Speed Table

Motivation: Time is important

- Failure to consider the time during which forces act, and during which speed changes, may be at the root of common student misconceptions.

Unclear ideas about time are linked to the (incorrect) association of force with motion in Jung, W., "Some methods of inquiry into knowledge structures in mechanics," Jung, Pfundt, and Rhoneck (eds.), *Proceedings of the International Workshop on problems concerning students' representation of physics and chemistry knowledge*, 14-16 September, Pedagogische Hochschule, Ludwigsburg, pp. 254-267 (1981).

- Continuously changing speed ($a \neq 0$) is difficult to distinguish from change of speed ($v_2 \neq v_1$) in the context of middle-school assessment.
- Leaving the duration of item contexts unbounded invites distracting "eventually" issues:

A student may say, "It's not true that the speed increases while the force acts, because eventually the object will hit terminal velocity."

A student may say, "It's not true that the speed decreases while the force acts, because eventually the object will speed up in the other direction."

These issues are a distraction from assessment of the targeted content.

- Graphs (speed-time and position-time) are great, and we use them, but there are many student difficulties associated with graphs.

Goal: A way to represent and assess time-related aspects of force and motion

(from Forces key idea) "Some forces, like gravity, are acting all the time. Other forces, like the force of a person pulling a wagon, begin acting at some time and then finish acting at some later time. Sometimes forces act for a very short time interval."

(from Newton's Second Law key idea) "If an unbalanced force acts on an object in the direction of its motion, then the object's speed will increase, and will continue to increase for as long as the force acts."

Implementation: Speed Table

- Each answer choice is a row of the table.
- The columns are times (clock readings).

Typical Item

At 9 o'clock in the morning (9:00 AM), an object is moving at a speed of 10 meters per second (10 m/s). At 9:03 am, an unbalanced force begins to act on the object. The direction of the force is opposite to the direction that the object is moving and the force continues to act for a long time. Which row of the table shows what the object's speed could be each minute? Assume that any change in speed can be detected.

Time	9:00 AM	9:01 AM	9:02 AM	9:03 AM	9:04 AM	9:05 AM	9:06 AM
Row A	10 m/s	9 m/s	8 m/s	7 m/s	6 m/s	5 m/s	4 m/s
Row B	10 m/s	9 m/s	8 m/s	7 m/s	7 m/s	7 m/s	7 m/s
Row C	10 m/s	10 m/s	10 m/s	10 m/s	9 m/s	8 m/s	7 m/s
Row D	10 m/s	10 m/s	10 m/s	10 m/s	7 m/s	7 m/s	7 m/s

A. Row A
 B. Row B
 C. Row C
 D. Row D

Results from Pilot Testing

- Students include time considerations in their comments on the answer choices. Comments on choice C (the correct answer):
 - (6th grade, correct) "It acted on the right time"
 - (6th grade, correct) "After the unbalanced force acts upon it, it slows down at the '4 sec' mark"
 - (8th grade, correct) "Yes it is constant till 3rd sec then starts to slow as the force acts upon it."
 - A disadvantage of tables is that the data is not continuous. We must be alert for associated problems. Comments on choice C (the correct answer):
 - (6th grade, correct) "After the unbalanced force acts upon it, it slows down at the '4 sec' mark"
 - (8th grade, correct) "Yes seconds are short. When the force acts on the 3rd sec, it won't matter until the next sec. Then the force decreased, so this seems right."
- Do these students believe that the speed changes occur *after* a force acts?