Physical science instruction and assessment in the middle-school: Comparisons and contrasts with college-level instruction

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Background and Context

My experience: 29 years of (mostly) college physics teaching, supplemented by:

- One year teaching 8th grade science in private middle school (10 contact hours per week)
- Four years teaching weekly science classes to 5th-8th grade students at ASU-sponsored middle school
  - (80-150 students per week; each student one class hour per week; 3-5 contact hours per week)

⇨ About 1000 total contact hours teaching middle-school science

Overall Goals

I. Generate enthusiasm for engaging in science
   - For 5/6th graders: no problem, they love it
   - For 7/8th graders: more challenges

II. Develop abilities for engaging in science
   - Not formally assessed, but students become habituated to need for arguing from evidence based on experimental observation

III. Build understanding of science concepts: what are reasonable conceptual goals?
   - Highly challenging; the focus of this talk

General Issues

- Classroom management
- Student motivation
- Logistics

Classroom Management Issues

- If the students are not attempting to participate in class or engage with the activities, they will learn nothing
- Learning classroom management skills is done on the job or with previous equivalent experience; it is a highly nontrivial task

General Observations

- A **lot** of hands-on instructor assistance is needed to keep kids on task and on track;
- Logistics of handling supplies and maintaining equipment is a **major** concern;
- Written worksheets can be used if they are carefully edited and accompanied by **frequent** check-ins by the instructor.
- Students’ progress toward conceptual learning goals is extremely **slow** compared to college class

General Impressions of Student Reactions to Activities

- *College students (pre-service teachers):* burdensome tasks that had to be gotten through
- *College students (STEM majors):* generally enjoyable tasks, moderately enthusiastic
- *7th/8th graders:* Time to socialize with each other; moderate engagement and enjoyment
- *5th/6th graders:* Playtime: fun and high engagement

Additional Context, 2010-2011

- Generally one instructor, sometimes helped by graduate student aide
- Homework assigned and corrected most weeks; occasional quizzes (graded only for 7/8th grade)
- In the previous year I had taught many of the same students, including some of the same activities

Topics Covered, 2010-2011

- **Grades 7/8:** Major focus on motion and force (to prepare for Arizona 8th-grade science test); also did solar system astronomy, electromagnetism, some review of properties of matter, energy concepts, some chemistry

- **Grades 5/6:** solar system astronomy, optics, motion and force, energy concepts, electromagnetism, some biology

Small-to-moderate variations on this set of topics during other years, 2009-2013

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Motion and Force with 7/8th Graders

- Approximately 10-15 hours of activities, beginning with graph paper and stopwatches, moving on to dynamics carts and tracks, fan carts, motion sensors and GLX's (hand-held graphing computers).
- Many of the students had previous experience using GLX for position/time and velocity/time graphs.
- *Typical sequence:* explore with equipment; predict graphs for various motions; carry out series of experiments; describe and report results; explain and generalize.

Goals Tuned to Arizona 8th-Grade Science Standard

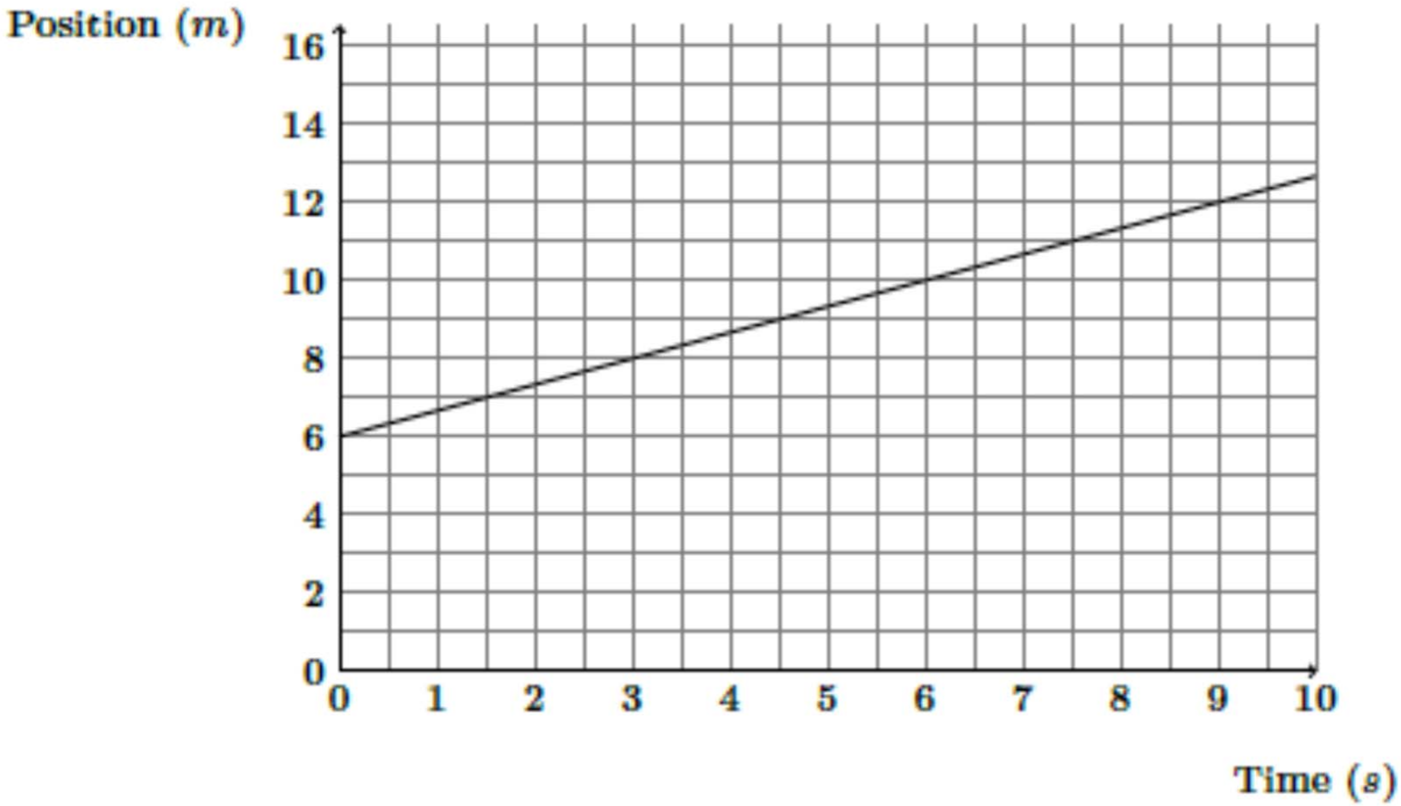
- Create a graph devised from measurements of moving objects and their interactions, including:
  - position-time graphs
  - velocity-time graphs
- Describe the various effects forces can have on an object (e.g., cause motion, halt motion, change direction of motion, cause deformation).
- Describe how the acceleration of a body is dependent on its mass and the net applied force (Newton's 2nd Law of Motion).

Cautionary Note: These ideas and skills are challenging for college students

- In our studies of college students, we have found that both the mathematical skills and the physical concepts can be challenging to learn and retain

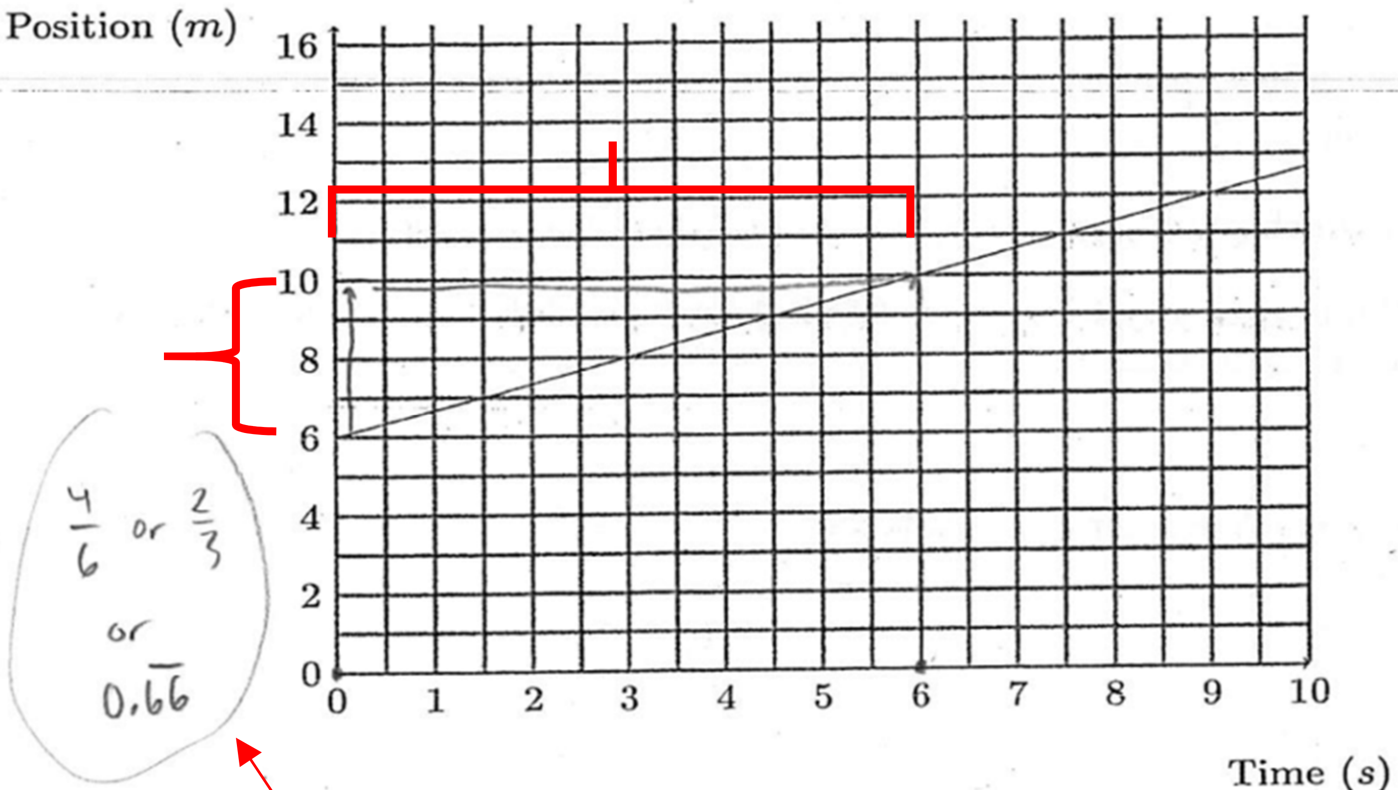
➢ An example from an ongoing study:

What is the slope of the graph below?



Desired answer: 2/3 m/s or 0.67 m/s

(Divide "rise" in meters by "run" in seconds)



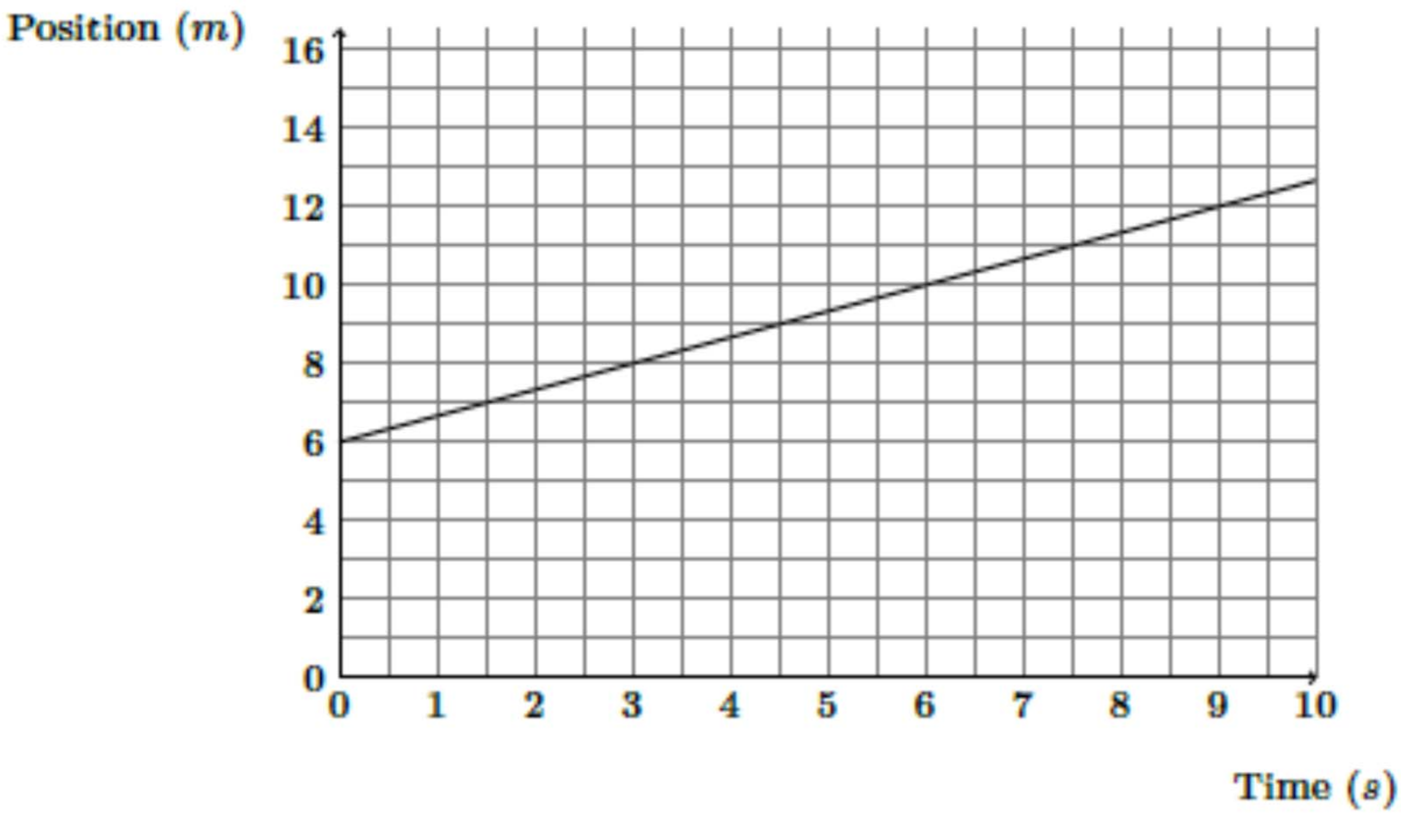
$\frac{10-6}{6-0} = \frac{4}{6}$ or $\frac{2}{3}$ or $0.\overline{66}$

Note: Units missing

Around half of all students ignore numbers on axes, and just count grid squares

What is the slope of the graph below?

Most common incorrect answer: 1/3



Correct Response Rate, Arizona State University; Fall 2018

Algebra-based physics course, first semester: 43% (N = 305)

Calculus-based physics course, first semester: 56% (N = 329)

Force and Motion Activities

- **Phase I:** Extensive work on kinematics, including position-time and velocity-time graphs using GLX graphing devices
- **Phase II:** Students introduced to measurement of “pushes” and “pulls,” use calibrated spring scales to pull on low-friction carts; measure pushing force of fan cart;
- **Phase III:** Administer and discuss pretest: Students use fan carts to determine shape of velocity vs. time graph of an object being acted upon by a force of unchanging magnitude.
- **Phase IV:** Circular motion activities; marble rolling on circular track with cut-out, analysis of hammer-throw video.

[Pretest]

A cart on a low-friction surface is being pushed by a fan mounted on the cart. The instantaneous velocity of the cart is measured throughout a time period, beginning when the cart has already started moving.

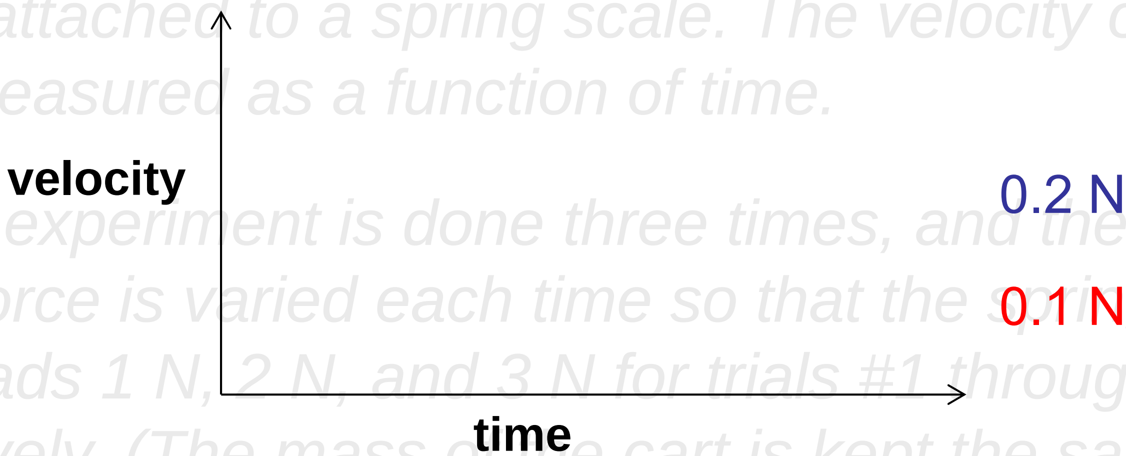
The experiment is done twice, and the pushing force is 0.1 N for the first trial and 0.2 N for the second. (The mass of the cart is kept the same for both trials.) During each trial the pushing force is constant, so the strength of the push doesn't change while the cart moves along the track.

On a **single** *set of v-t axes, sketch the appropriate lines for velocity versus time for the two trials, and label them 0.1 N and 0.2 N.*

A cart on a low-friction surface is being pulled by a string attached to a spring scale. The velocity of the cart is measured as a function of time.

The experiment is done three times, and the pulling force is varied each time so that the spring scale reads 1 N, 2 N, and 3 N for trials #1 through #3, respectively. (The mass of the cart is kept the same for each trial.)

On the graph below, sketch the appropriate lines for velocity versus time for the three trials, and label them #1, #2, and #3.



Pretest response: ~50%

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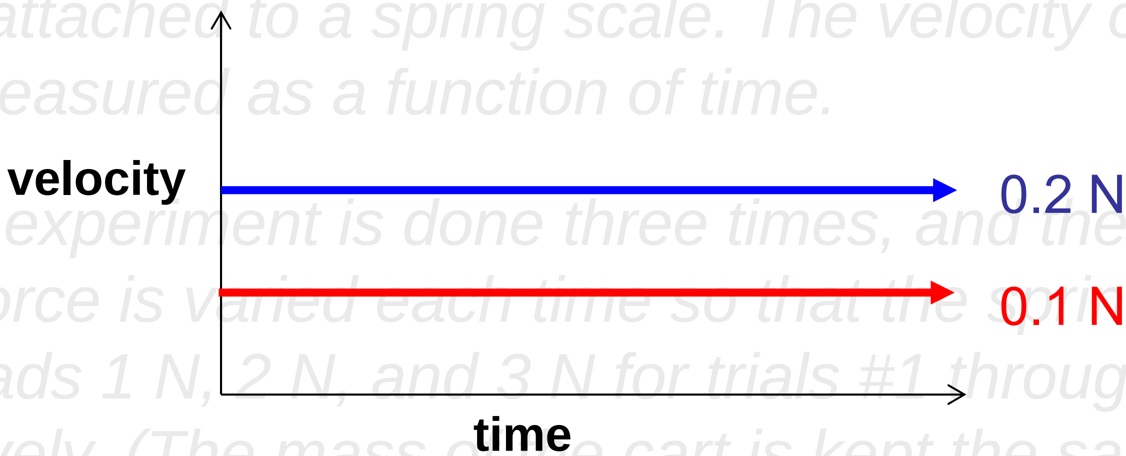

[or with order inverted]

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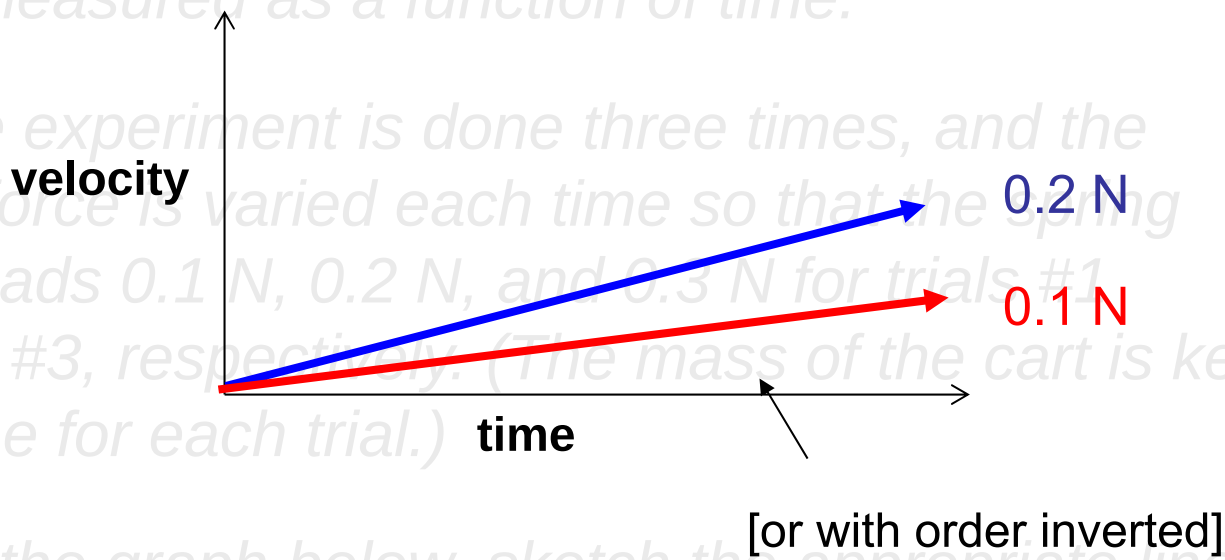

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Assessment Issues

- Different types of questions have advantages and disadvantages
- Need for practicality and efficiency of grading can conflict with desire for in-depth probes of student thinking
- Risky to draw conclusions about students' performance without at least some "explain your answer" types of questions

Question Types

- Multiple-choice questions can be efficient to administer and grade, but:
  - they require careful design and revision to avoid ambiguous or misleading statements
  - “correct” answers can obscure a great deal of actual confusion
- “Free-” or “Open-response” questions can reveal details of students’ thinking, but they:
  - require careful design to provide adequate guidance
  - are time-consuming to answer, grade, and analyze

Quiz Taken from Arizona 8^{th} Grade Sample Test

1 A ball was attached to the end of a string and spun in a circle as shown in Figure 1 below. The ball moved in a counter-clockwise direction when seen from above as shown in Figure 2.

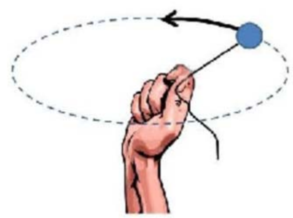


Figure 1 (view from side)

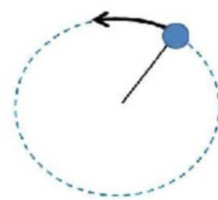
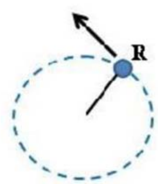
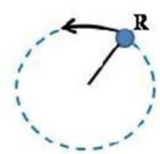


Figure 2 (view from above)

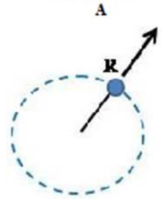
After several spins, the string was released when the ball was at point R. Which diagram shows the direction that the ball would fly the instant the string was released?



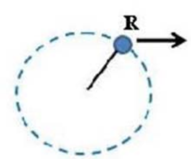
A



C



B



D

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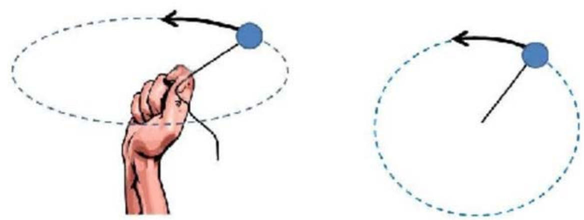

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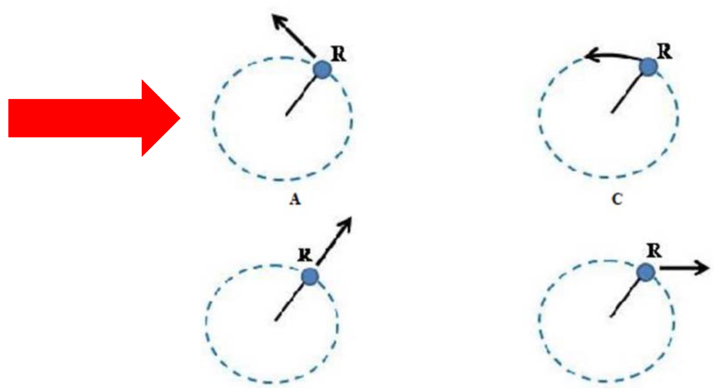
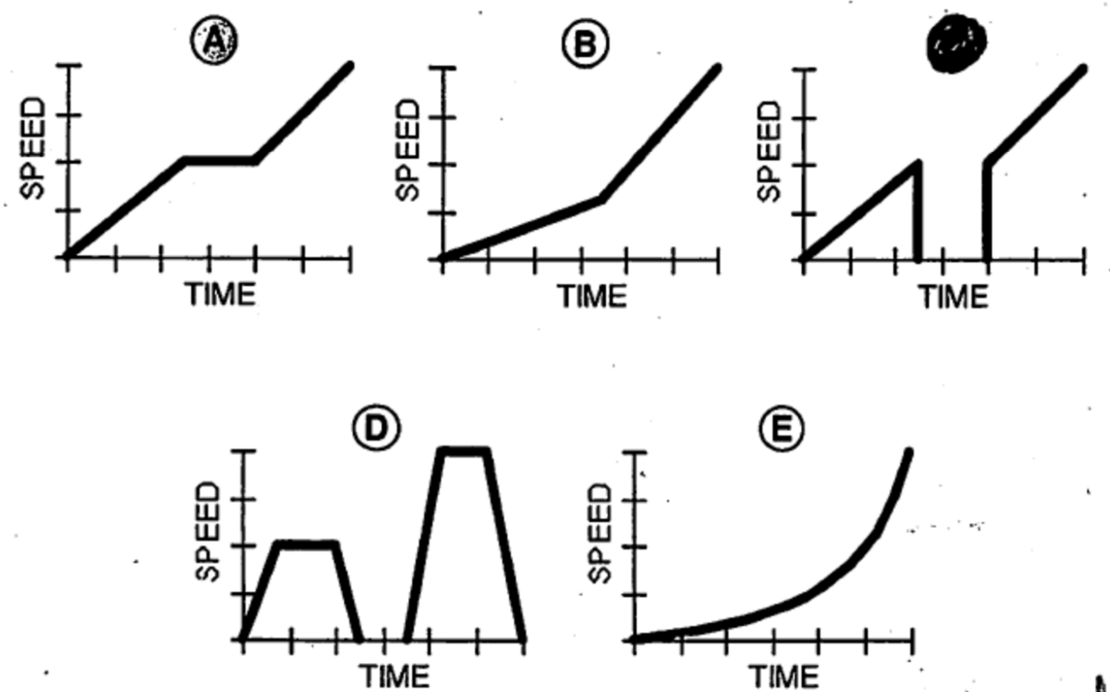


But why??

Item Taken from Widely Distributed Diagnostic Test

1. Carolyn walks a half mile to school. One morning, halfway to school, she stopped to watch a bird building a nest. When she realized she was late, she ran the rest of the way to school to avoid being marked late. Which graph below shows Carolyn's speed during her walk to school?



Explain your answer: She was increasing her speed then she stoped so her speed went down to zero then it increased and the slope became steeper than before

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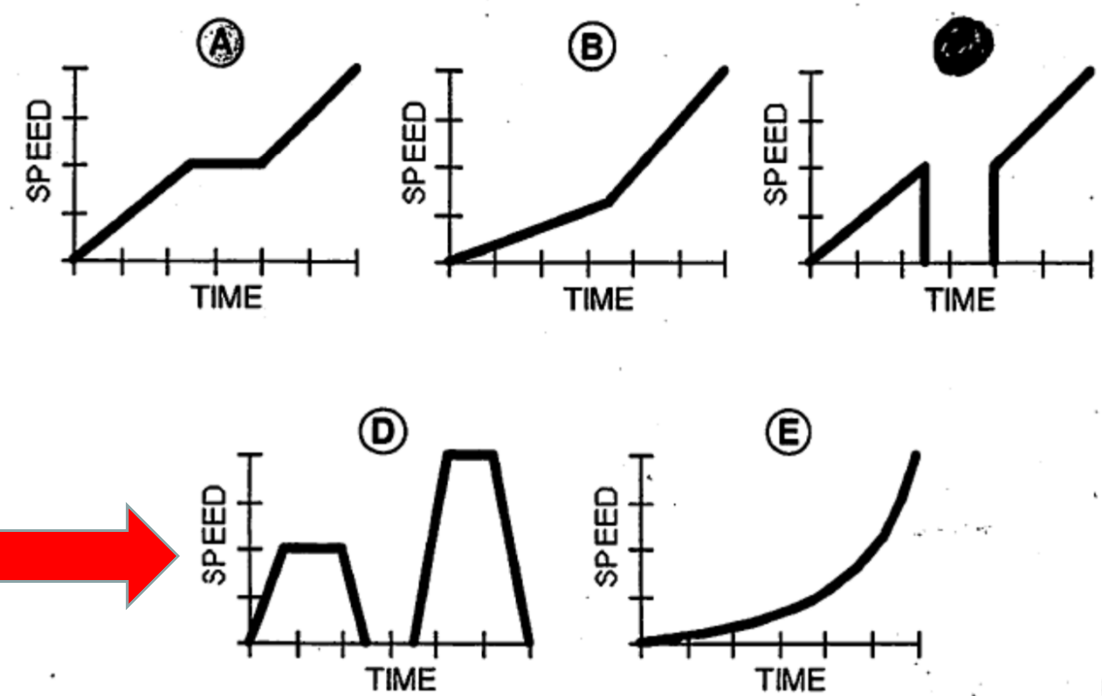
At constant speed??



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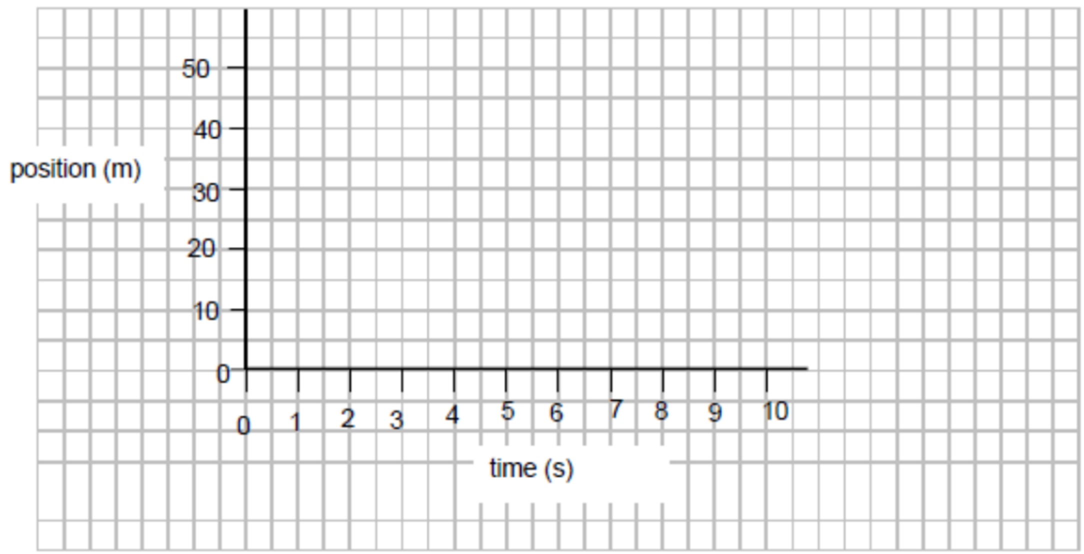
Grade 7/8 Results for Mechanics Instruction

- Good and consistent performance on position/time graphs

Grade 7/8 Science
Quiz #1
February 14, 2011

1. On the *position-time* graph below, draw a line to represent the motion of a bicycle traveling five meters everv second.



Position-time graph

Student response

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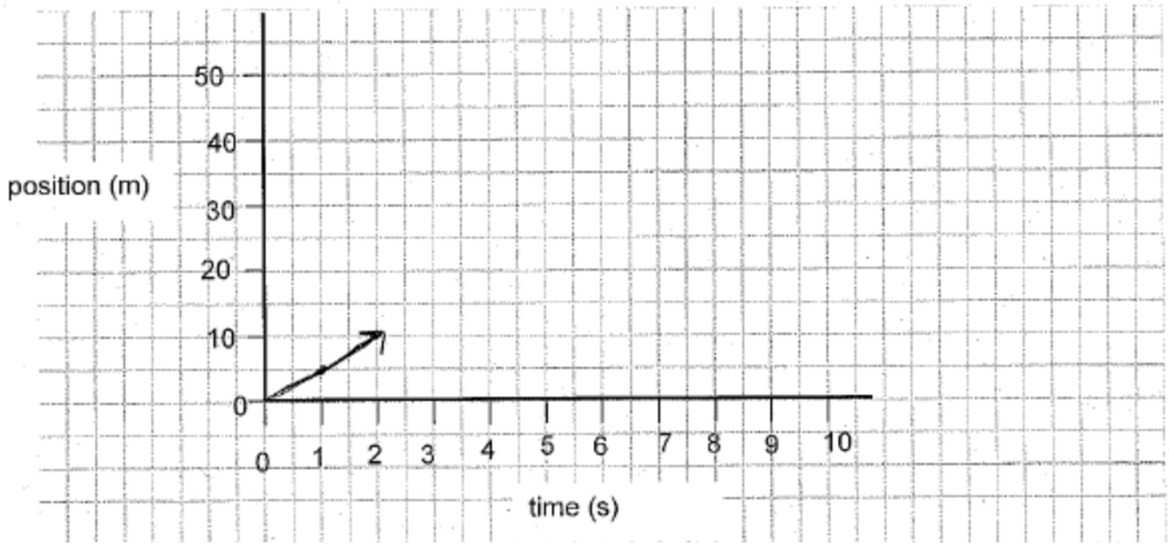

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- On velocity/time graphs, 40-50% qualitatively correct, 15-30% quantitatively correct

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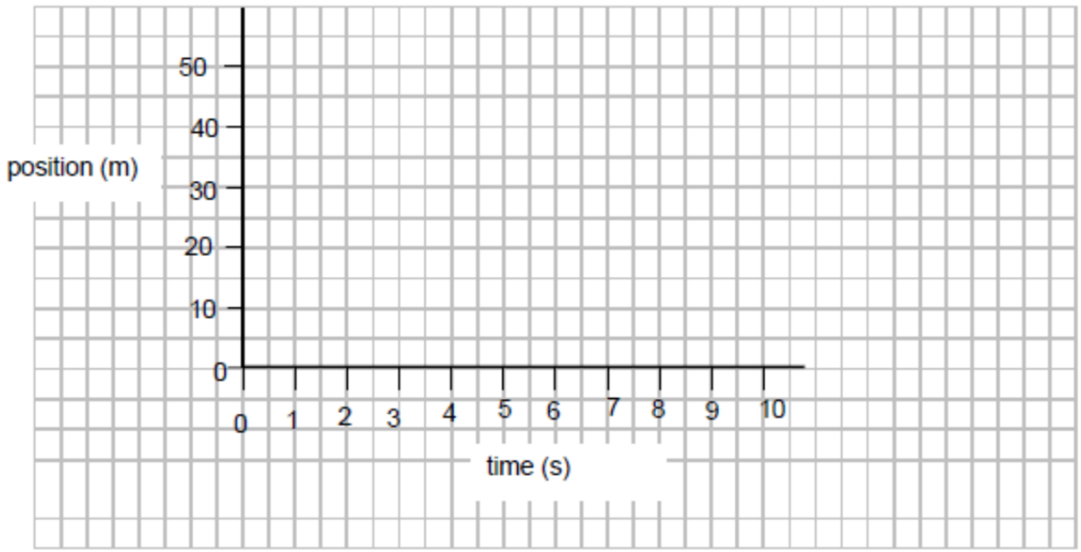

Position-time graph

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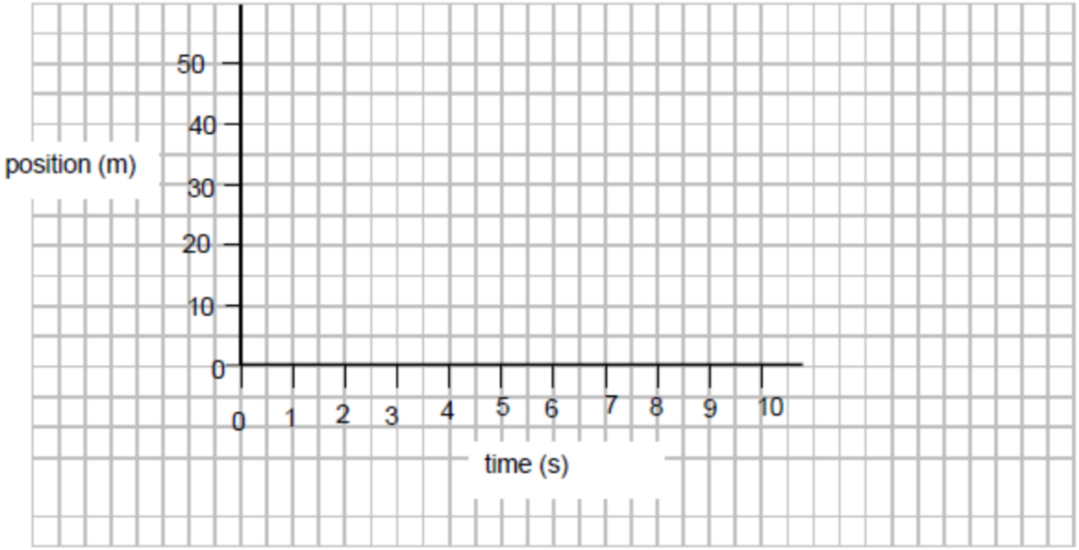

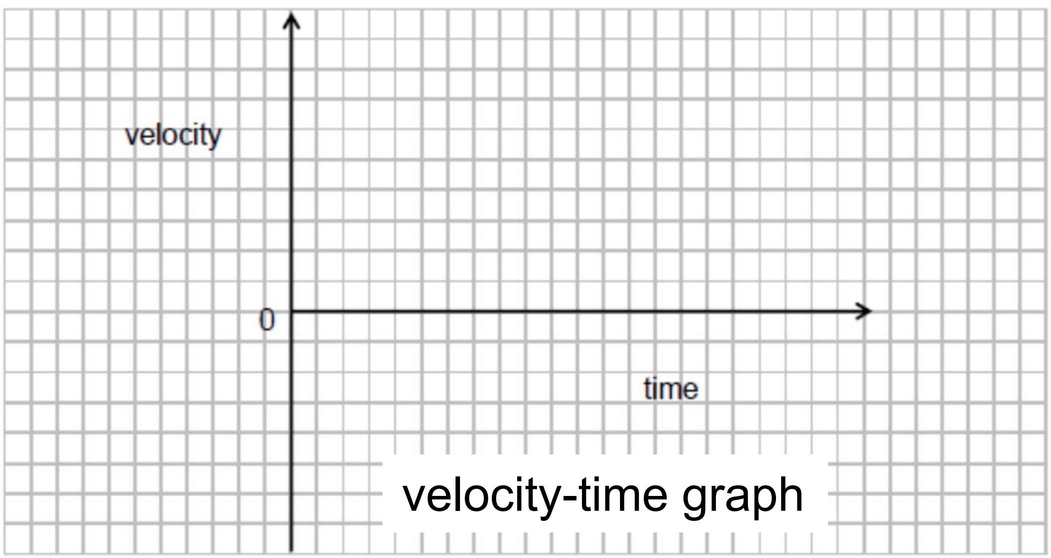

velocity-time graph

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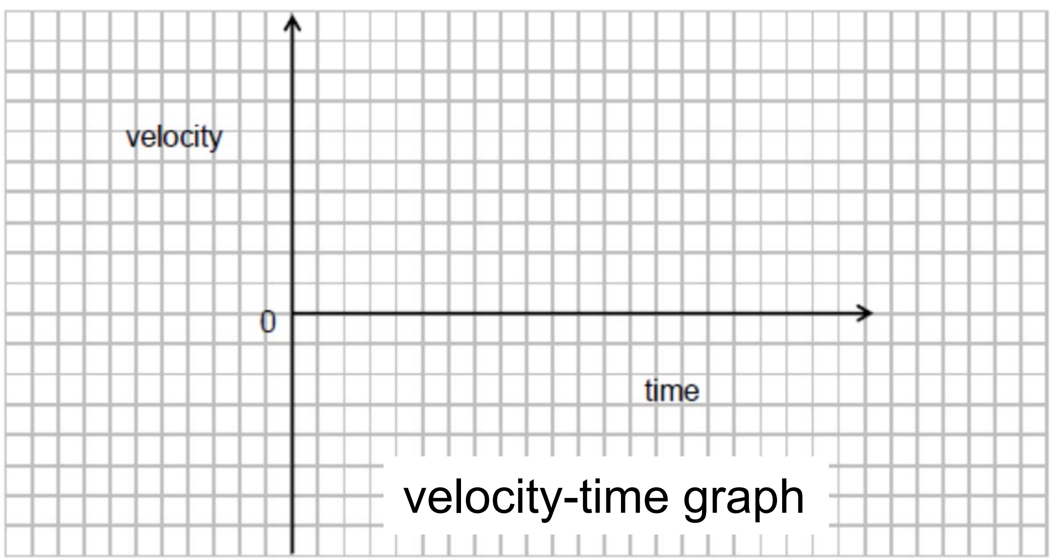

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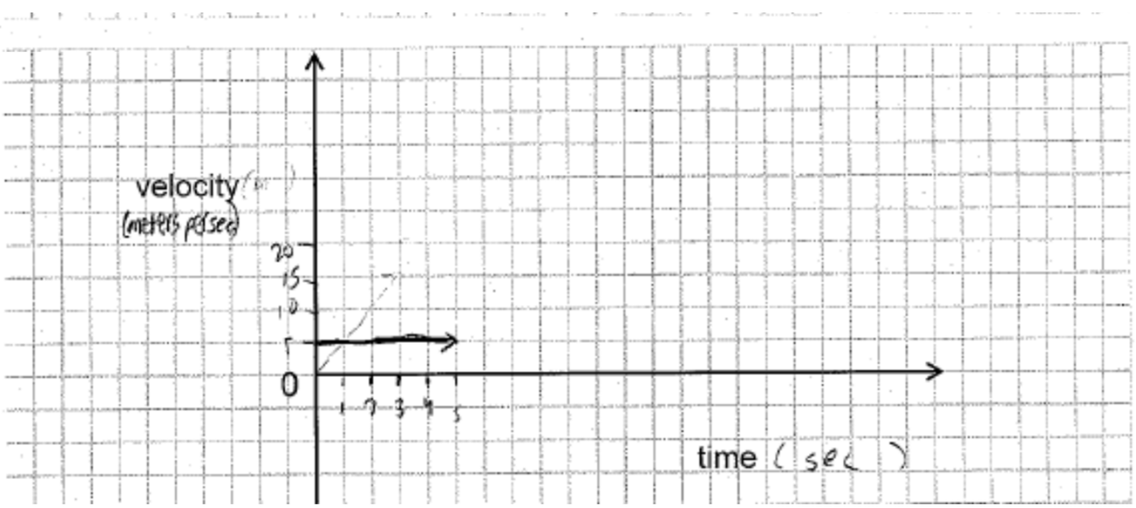

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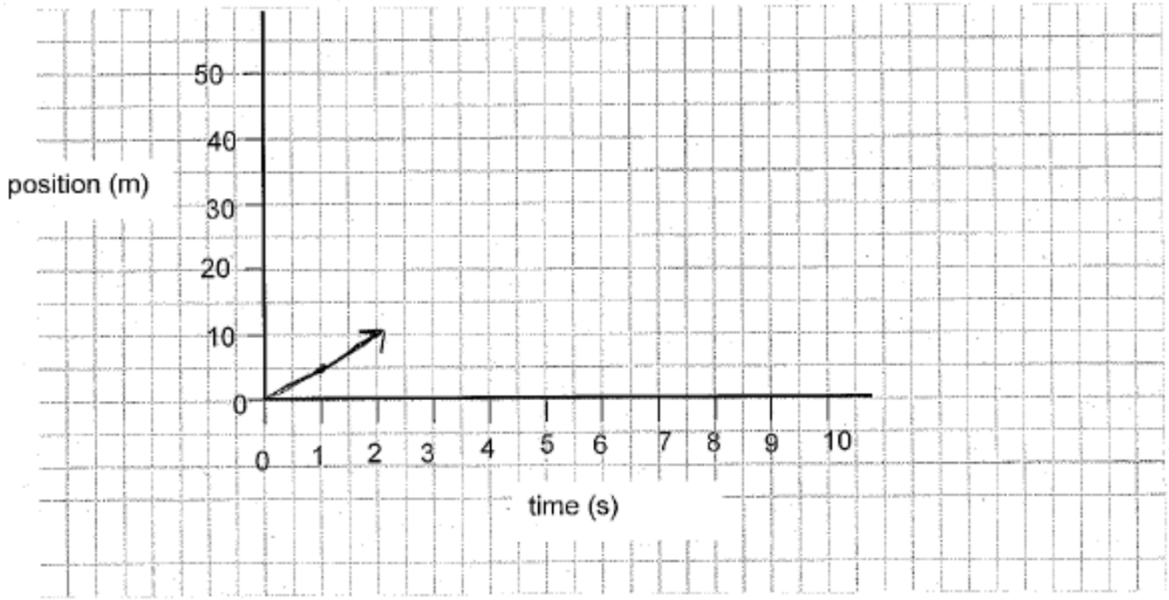

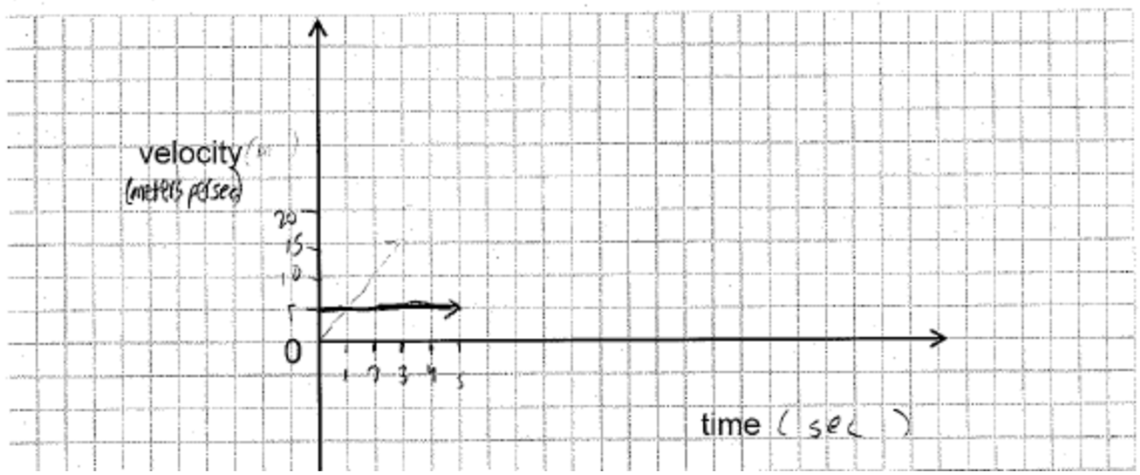

Grade 7/8 Results for Mechanics Instruction

- Good and consistent performance on position/time graphs

- On velocity/time graphs, 40-50% qualitatively correct, 15-30% quantitatively correct

- On acceleration graphs and force questions, 15-30% correct, 10-20% correct with correct explanations.

- **Overall impressions: State science standards are unrealistic, at least regarding mechanics**

[*A comment on NGSS…*]

NEXT GENERATION SCIENCE STANDARDS

For States, By States

PS2.A: Forces and Motion

• The motion of an object is determined by the sum of the forces acting on it; if the total force on the object is not zero, its motion will change. The greater the mass of the object, the greater the force needed to achieve the same change in motion. For any given object, a larger force causes a larger change in motion.

NEXT GENERATION SCIENCE STANDARDS

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Students who demonstrate understanding can:

Plan an investigation to provide evidence that the change in an object's motion depends on the sum of the forces on the object and the mass of the object.

What is that? How does one measure it?

Rubric Grading

- Even on quantitative questions, it’s often useful to insert qualitative items and award correct answers with partial credit.
- Example: Question on measuring power, for high school students in summer program carrying out lab activities

3. The fan carts used electrical power from batteries to spin the fans and get the carts moving along the tracks. If you had two different fan carts, how could you decide which fan was using the most power? What measurements would you make, and how would you use those measurements to figure out the answer?

Which cart uses the most power?

Relevant quantities:

mass (m); time (t); velocity (v)

kinetic energy (KE) = $\frac{1}{2} mv^2$

Power = change in energy, divided by time $= \Delta KE / \Delta t$

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(2 points) Measure mass (m) of cart

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Sample Student Response (High School)

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$$\text{Power} = \frac{\text{Energy}}{\text{Time}}$$

10/10

We measure mass and velocity (at the end) of both carts, and the time it takes to move a certain distance. Energy is $\frac{1}{2}mv^2$, but we use the average velocity over the timeframe as velocity is increasing (avg velocity = $\frac{V_{final}}{2}$).

$$\text{Power} = \frac{\frac{1}{2}m\left(\frac{V_{final}}{2}\right)^2}{\text{time}}$$

The cart with the higher value has the higher power.

29/30 = 97/100

3. The fan carts used electrical power from batteries to spin the fans and get the carts moving along the tracks. If you had two different fan carts, how could you decide which fan was using the most power? What measurements would you make, and how would you use those measurements to figure out the answer?

Could now add numerical question by giving actual values for masses, velocities, times, etc. (But that was not done in this case.)

Electromagnetism Unit

- Modeled in part on *Physics by Inquiry*, curriculum designed for pre-service teachers
  - *activity sequence followed, but original text not used*
- Extended over three months (~ 10 class hours)
- Directed at goals of building, and understanding operation of, motor and generator.

Motor and Generator

- Electric motor uses the principle that a coil of wire carrying an electric current behaves as a magnet itself (an “electromagnet”)

- Electrical generator uses the principle that an electric current is “induced” in a coil of wire, if a magnet is moved into and out of that coil.

➢ To understand these things, it’s helpful first to explore the magnetic field pattern of an ordinary magnet.

Field Mapping Activity

In the center of a blank sheet of paper, tape down a bar magnet and draw an outline of the magnet.

Place a small compass in contact with the magnet, and draw dots at the tip and tail of the compass needle. Remove the compass and draw an arrow to represent the direction of the needle.

Place the compass on the paper again, so the tail of the needle is at the position of the *tip* of the first arrow; draw a second arrow as you did the first. Continue this process until you run off the page or back into the magnet.

Repeat this process at different points on the magnet.

Assessment: Field Mapping Homework

On a blank sheet of paper, draw an outline of a bar magnet in the center of the paper.

Use your class notes to draw arrows representing the direction of all of the compass needles. You should have 20-30 small arrows drawn on your paper, along with the outline of the bar magnet.

Hand this in together with your class notes; make sure your name is on both sheets of paper.

Assessment: Field Mapping Homework

On a blank sheet of paper, draw an outline of a bar magnet in the center of the paper.

Use your class notes to draw arrows representing the direction of all of the compass needles. You should have 20-30 small arrows drawn on your paper, along with the outline of the bar magnet.

Hand this in together with your class notes; make sure your name is on both sheets of paper.

Field Mapping Activity/Homework

Outcome

• In-class field maps were reasonably accurate and detailed

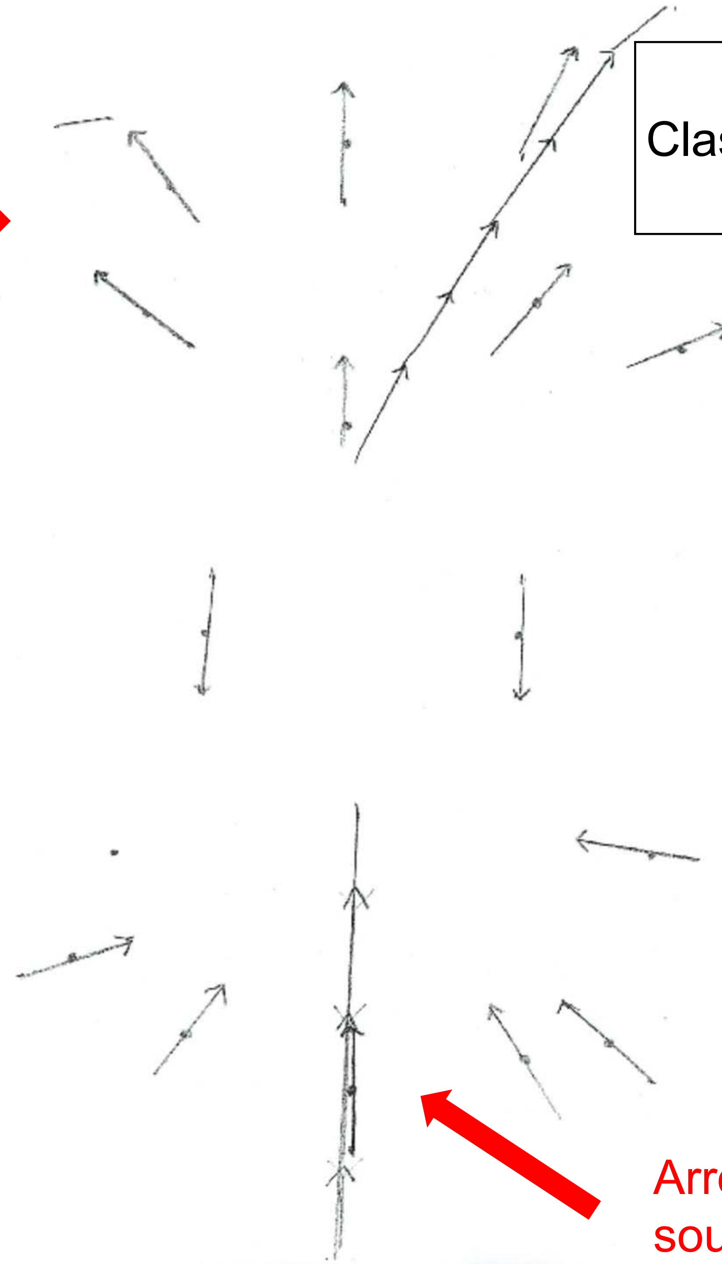
• On homework, by contrast, there were many errors regarding relative direction of arrows at North and South magnet poles

• On homework, only rarely were map details away from poles accurate

Class work, student A

[Accurate map]

Arrows point *away* from north pole of magnet

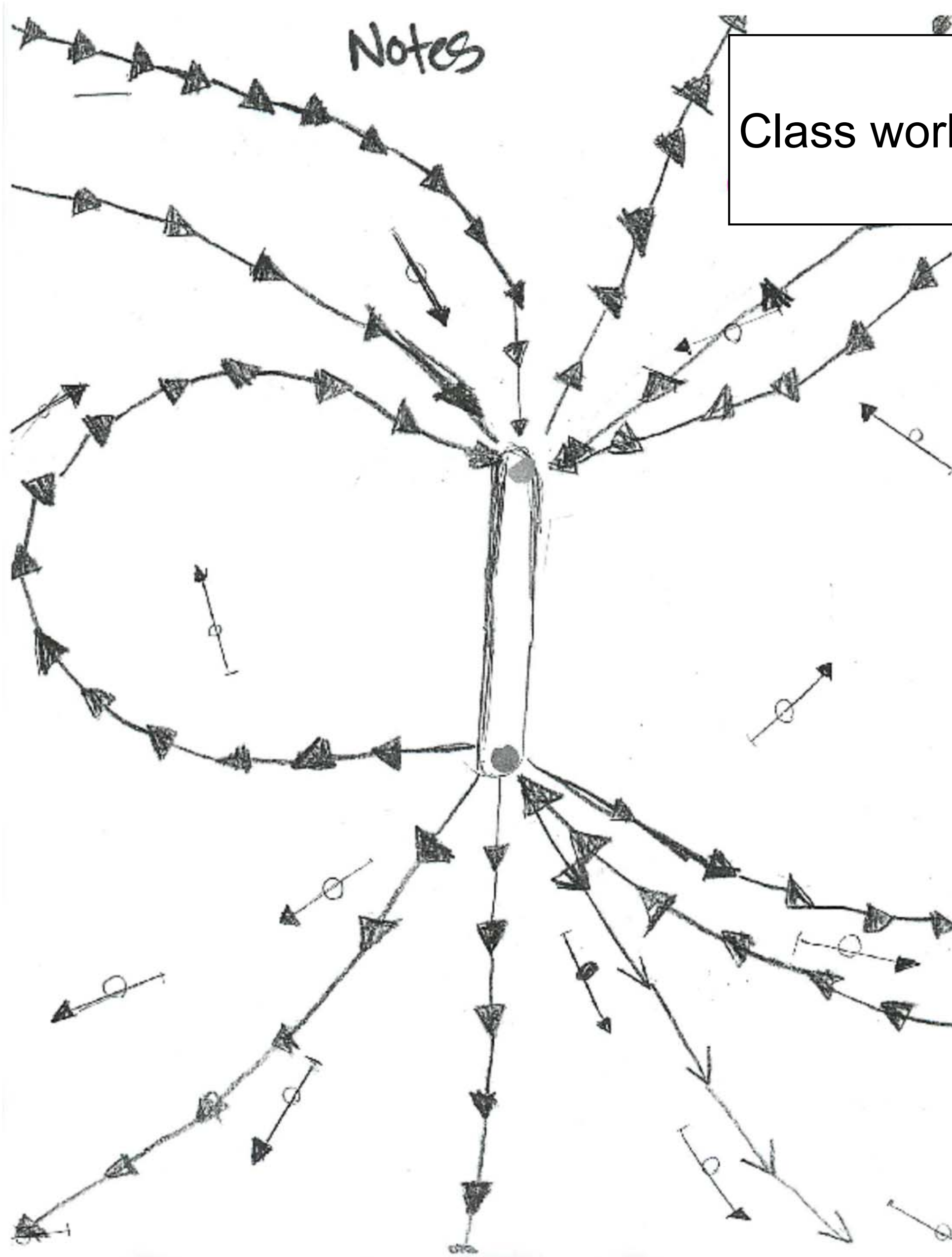


Arrows point *toward* south pole of magnet

Homework, student A

Meltzer Assignment

(Fairly accurate map)

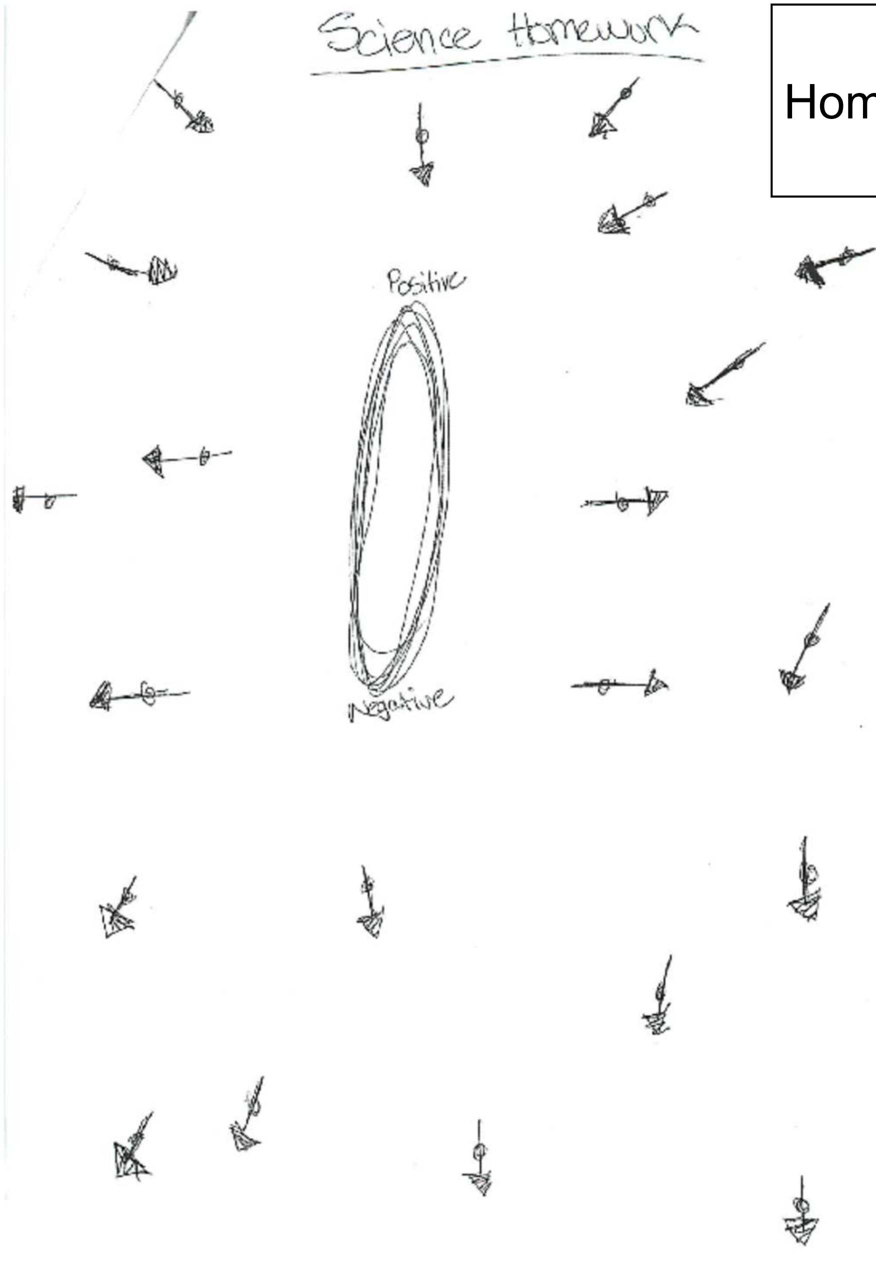


Class work, student B

[Accurate map]

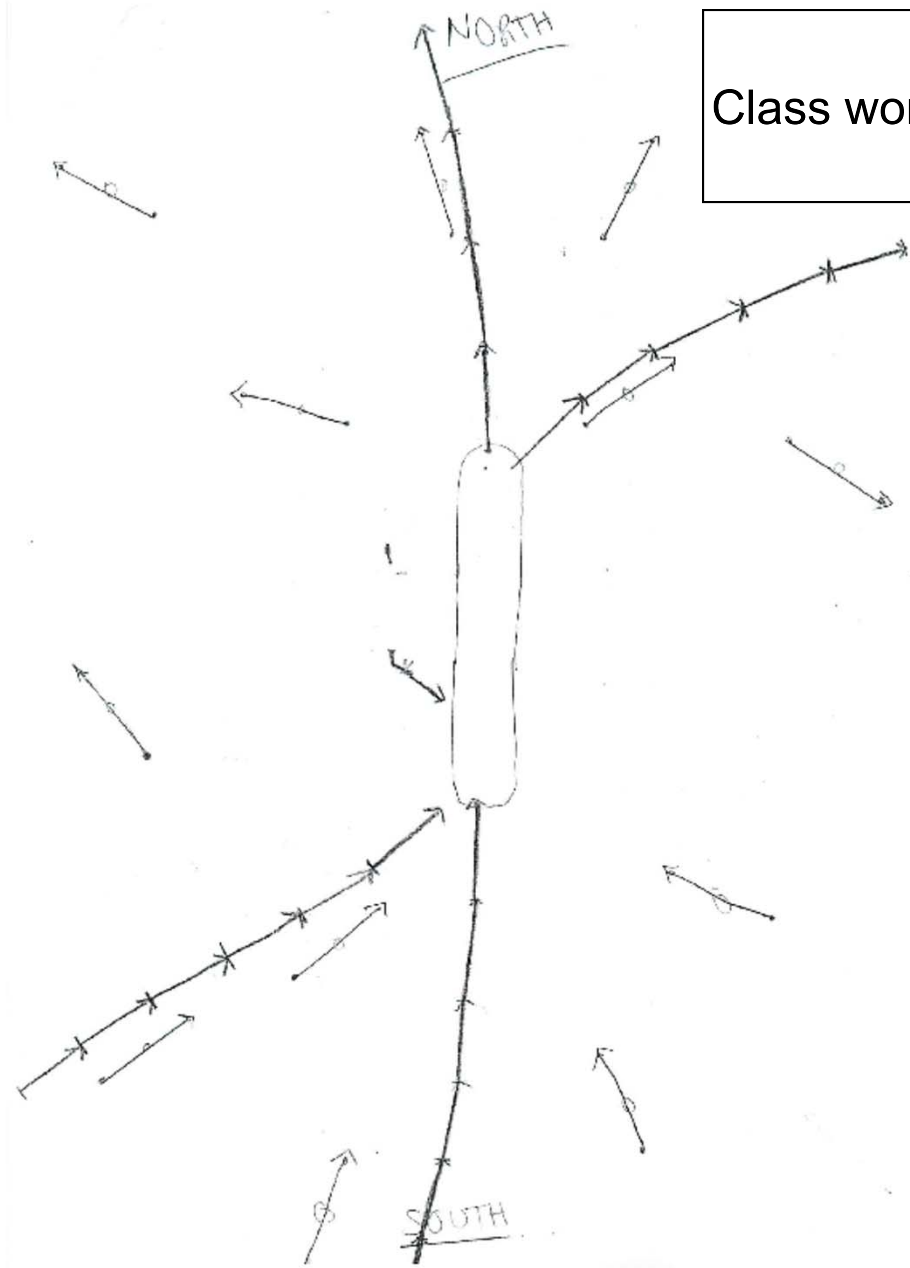
Homework, student B

[Less accurate map]



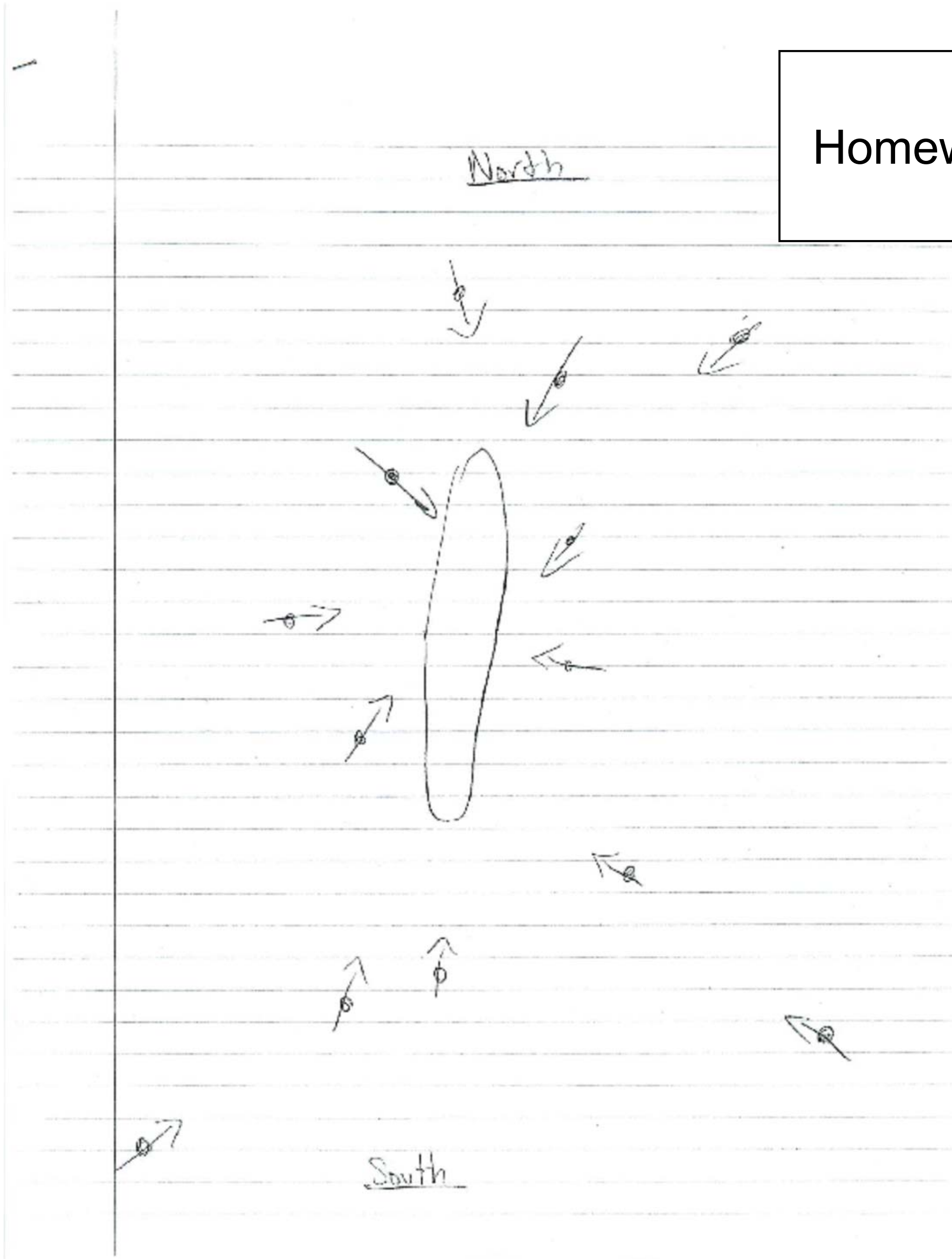
Class work, student C

[Fairly accurate map]



Homework, student C

[Incorrect map]



Short-lived Learning

- Careful and accurate classroom observations reflected imperfectly on follow-up homework assignment

Caution:
Learning Gains May Be Temporary

I taught most of these students at least two consecutive years, some three or four

- Most did same or similar activities at least twice
- Short-lived nature of many apparent learning gains was surprising and disturbing (to me)

- In several cases, students who had shown clear indications of learning of certain concepts in one year, when observed a year or two later, no longer retained their original understanding

Relevant Questions from Jean Piaget

- "…some investigators have succeeded in teaching [certain things]. But, when I am faced with these facts, I always have three questions which I want to have answered before I am convinced….

“…The first question is: ‘Is this learning lasting? What remains two weeks or a month later?’

“The second question is: ‘How much generalization is possible?’ [*that is, can the student apply the learning to other situations?*]

“…the third question [is]: ‘…what was the…level of the subject before the experience and what…has this learning succeeded in achieving?’ [*that is, can the student now learn other concepts of similar complexity?*]”

Jean Piaget, *J. Res. Sci. Teach.* **2**, 176 (1964)

Summary

- There is great potential for significant physics learning at the middle-school level
- The time required to achieve such outcomes is enormous and perhaps under-appeciated
- There are grounds for skepticism regarding appropriateness of many common grade-level standards
- Assessment of middle-school learning must take into account potentially large decay rates