

Teaching and Learning of Physics in Grades 5-8

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Background and Context

My experience: 23 years of (mostly) college physics teaching, supplemented by:

- One year teaching 8th grade science in private middle school (10 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)

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

Requirements for Engaging Students

- If students do not become engaged or “hooked,” they (mostly) wouldn’t work
- The more the work resembles “play,” the more they are engaged
- Themes or goals may be helpful (build a motor, a flashlight, a Rube Goldberg device, etc.)

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

- 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).
- Create a graph devised from measurements of moving objects and their interactions, including:
 - position-time graphs
 - velocity-time graphs

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.

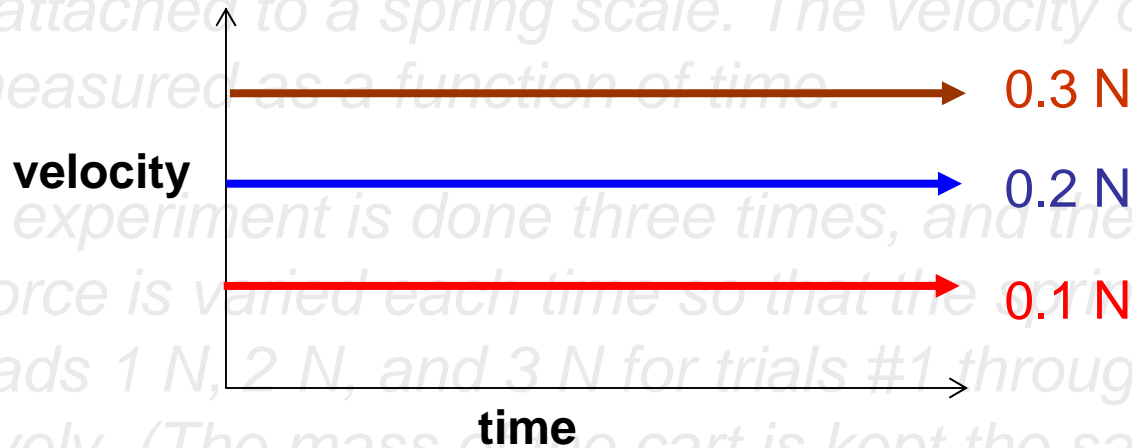
The experiment is done twice, and the pushing force is 0.1 N for the first trial and 0.2 N for the second. (The mass of the cart is kept the same for both trials.) During each trial the pushing force is constant, so the strength of the push doesn't change while the cart moves along the track.

*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.

Pretest response:
~50%

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.)

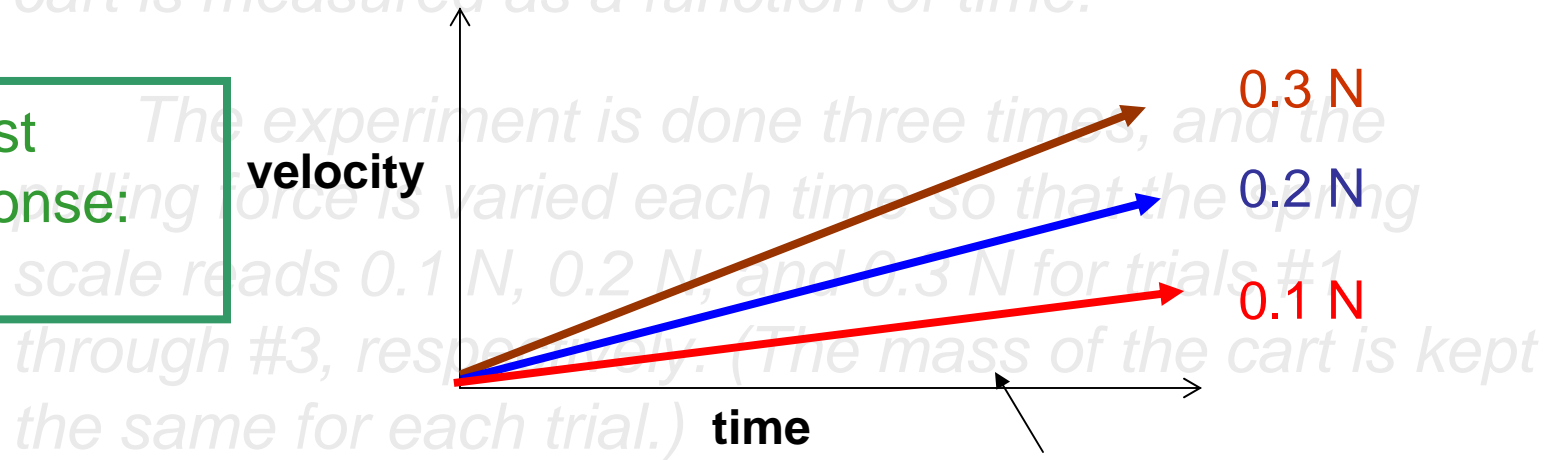


[or with order inverted]

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

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Pretest
Response:
~50%



[or with order inverted]

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

Quiz Taken from Arizona 8th 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.

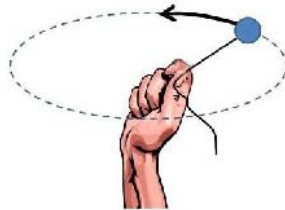


Figure 1 (view from side)

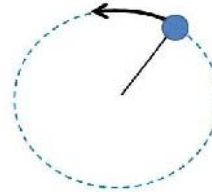
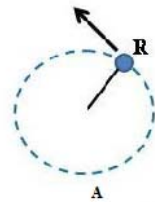
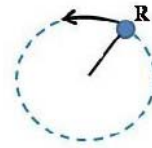


Figure 2 (view from above)

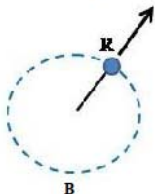
After several spins, the string was released when the ball was at point R. Which diagram shows the direction that the ball would fly the instant the string was released?



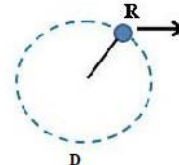
A



C



B



D

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**

Electromagnetism Unit

- Modeled in part on *Physics by Inquiry*
- Extended over three months (~ 10 class hours)
- Directed at goals of building, and understanding operation of, motor and generator.

Key Conceptual Goals

- Magnetic attraction and repulsion, relation to magnetic poles
- Field pattern of bar magnet
- Field pattern of current-carrying loops and coils
 - field-strength dependence on current magnitude
- Induction of electric current
 - by relative motion of magnet and coil
 - by sudden change in magnetic field strength

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 at a point on the page 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. Repeat this at about 20 different points.

Then, start again by placing the compass in contact with the magnet, drawing the arrow as before. Then place the compass so the tail of the needle is at the position of the *tip* of the first arrow; draw the second arrow. Continue this process until you run off the page or back into the magnet.

Field Mapping Homework

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

Now imagine that you put a real bar magnet on the paper and then imagine that you put about 20-30 small compasses all around the bar magnet.

Use your class notes to draw arrows representing the direction of all of those 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.

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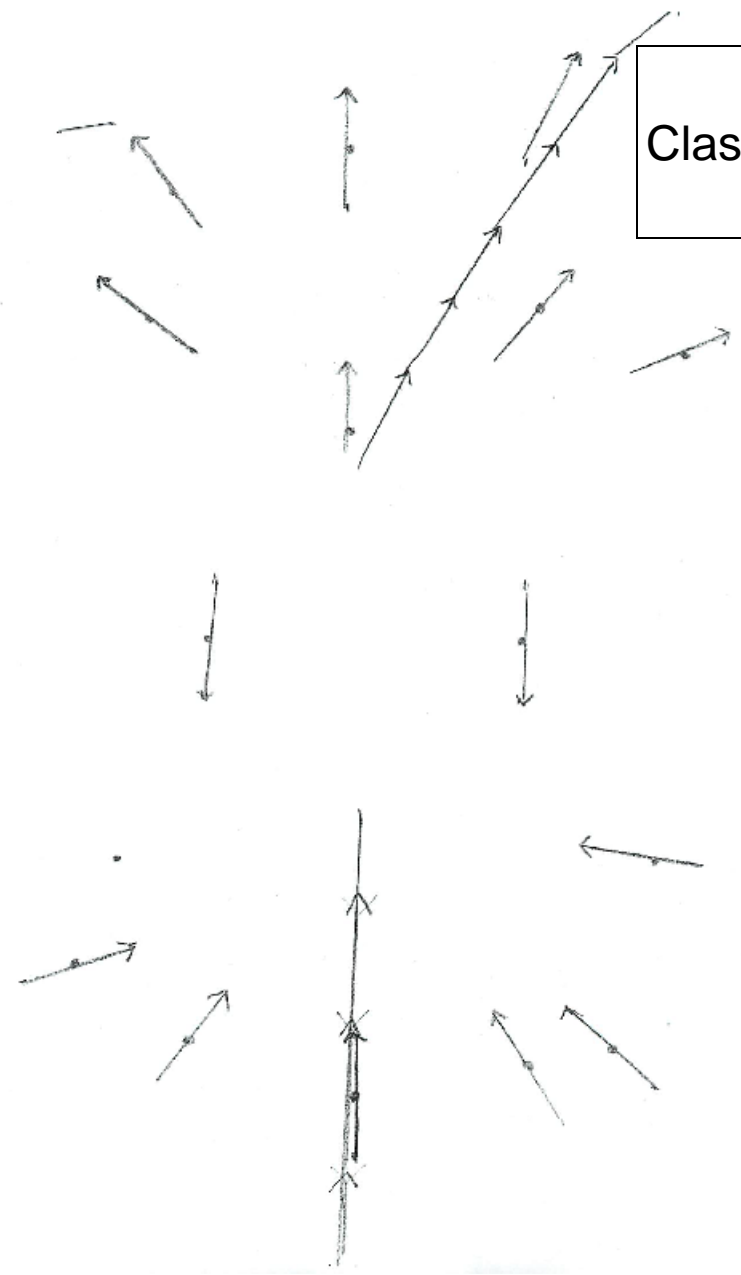
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Field Mapping Activity/Homework

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
- Grades 7/8 were *somewhat* more accurate

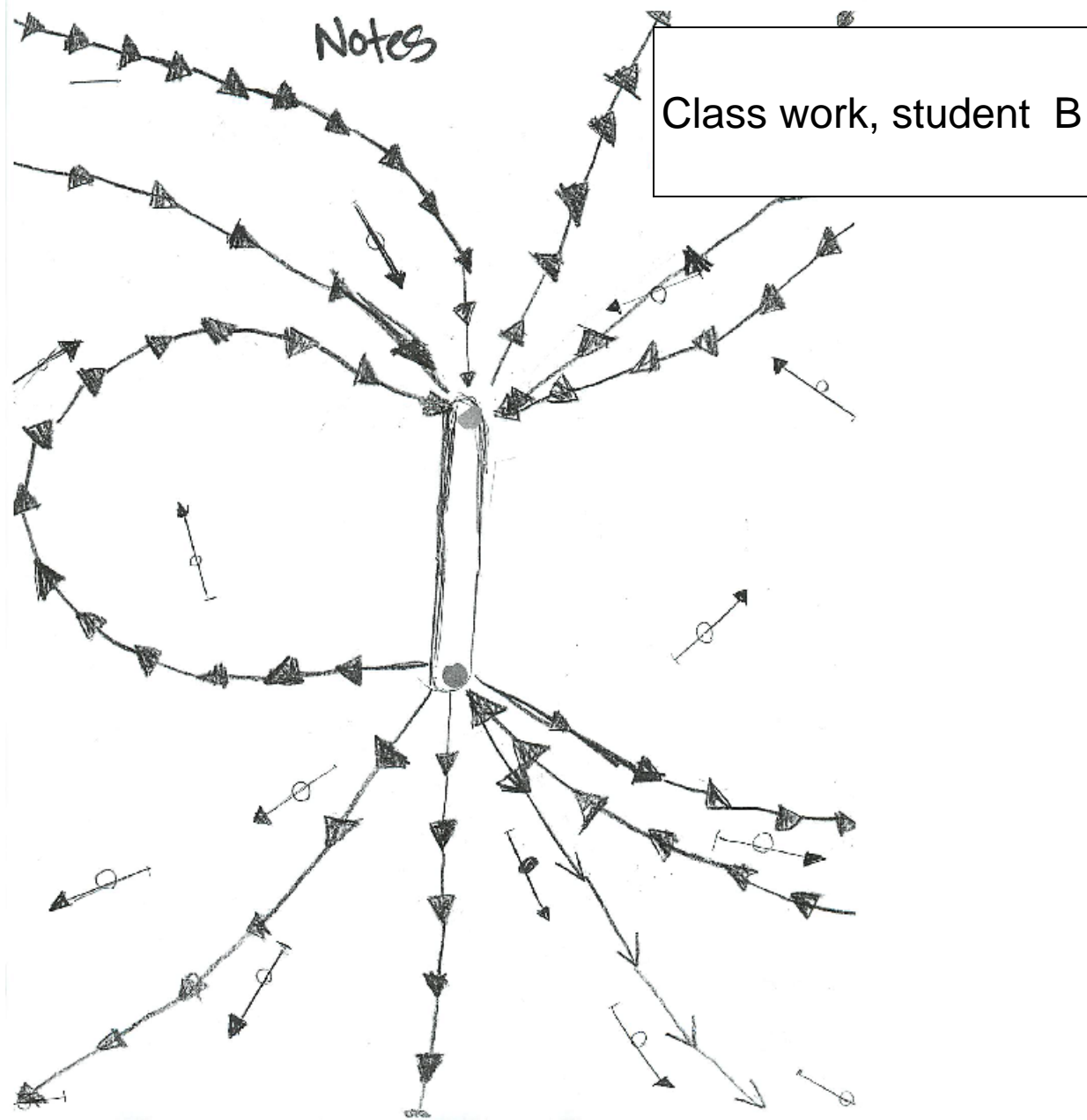


Class work, student A

Homework, student A

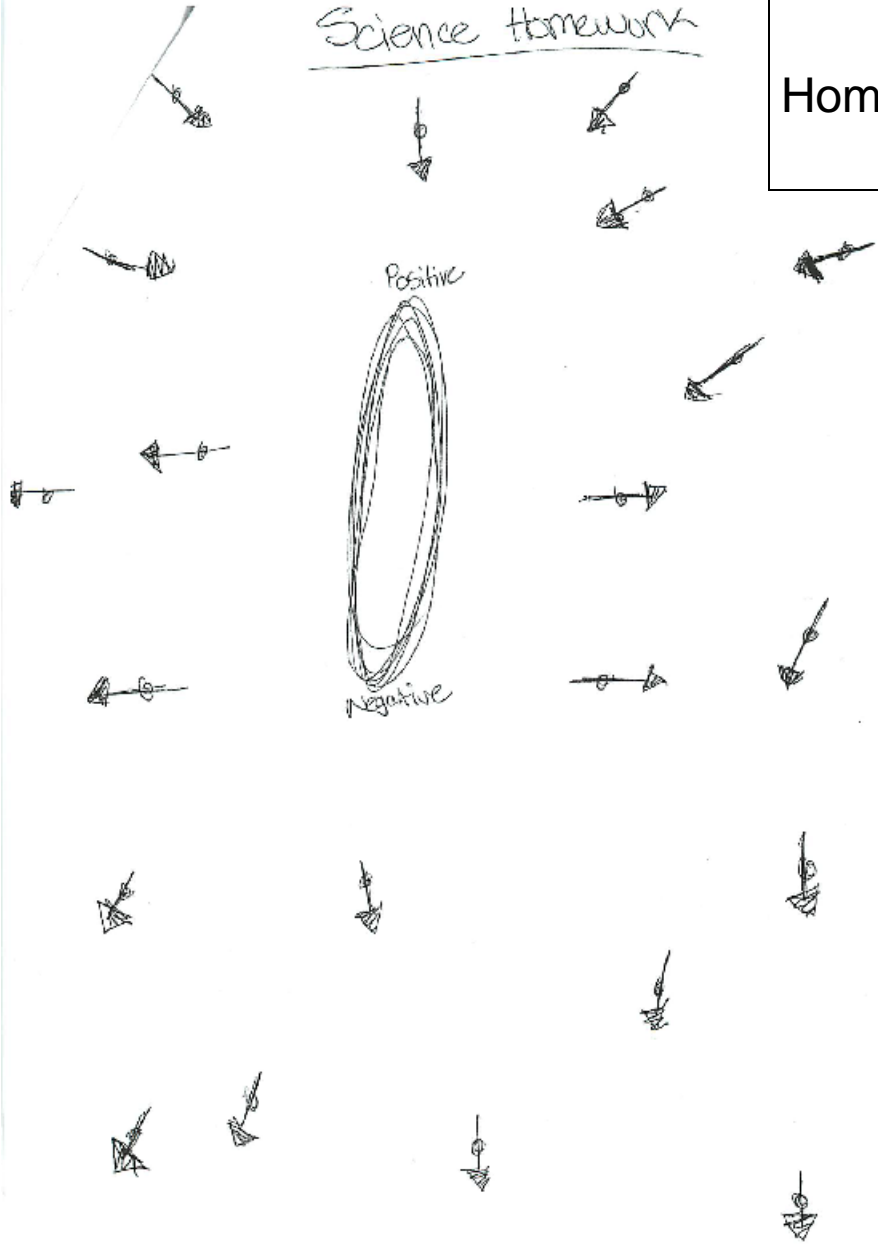
Melizer Assignment



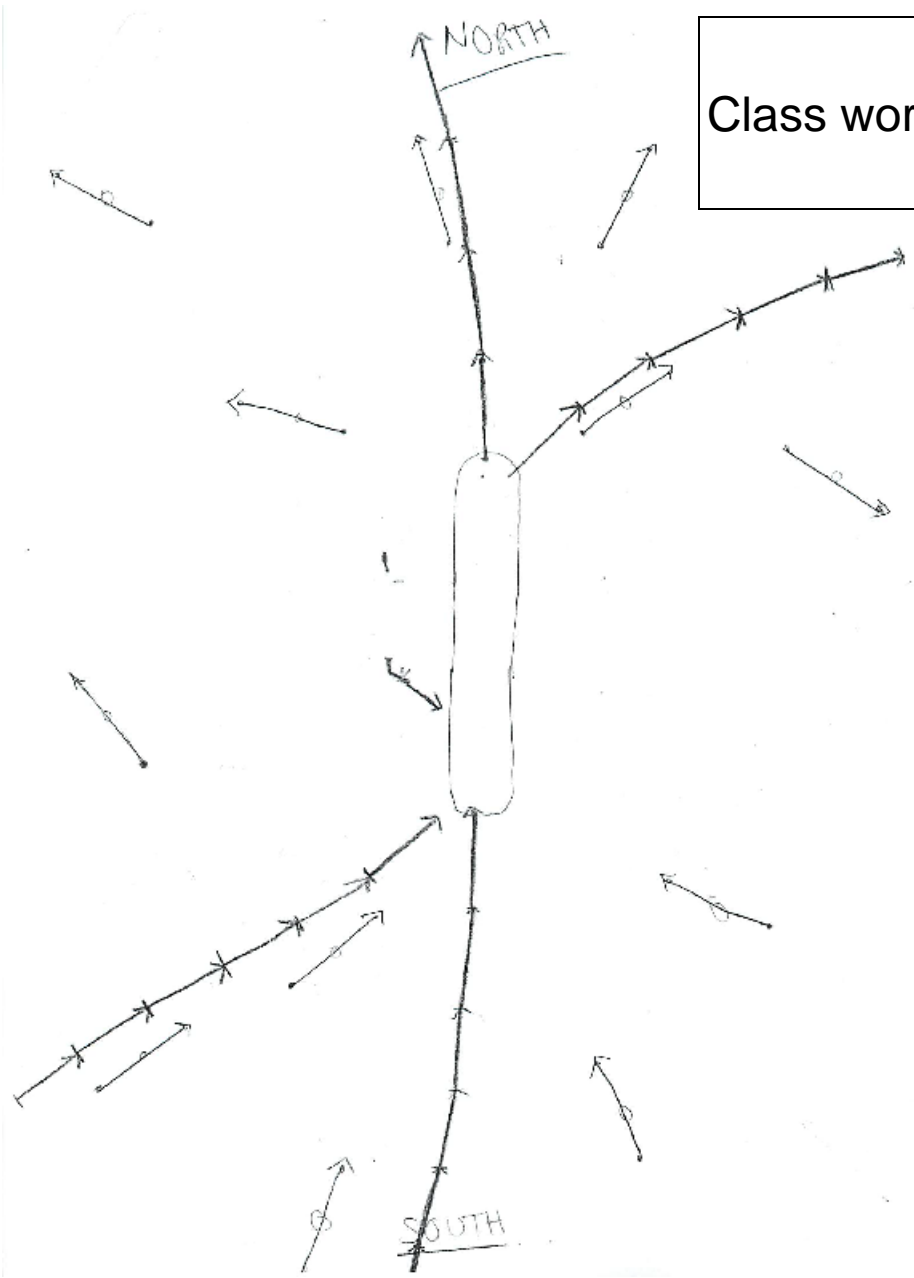


Science Homework

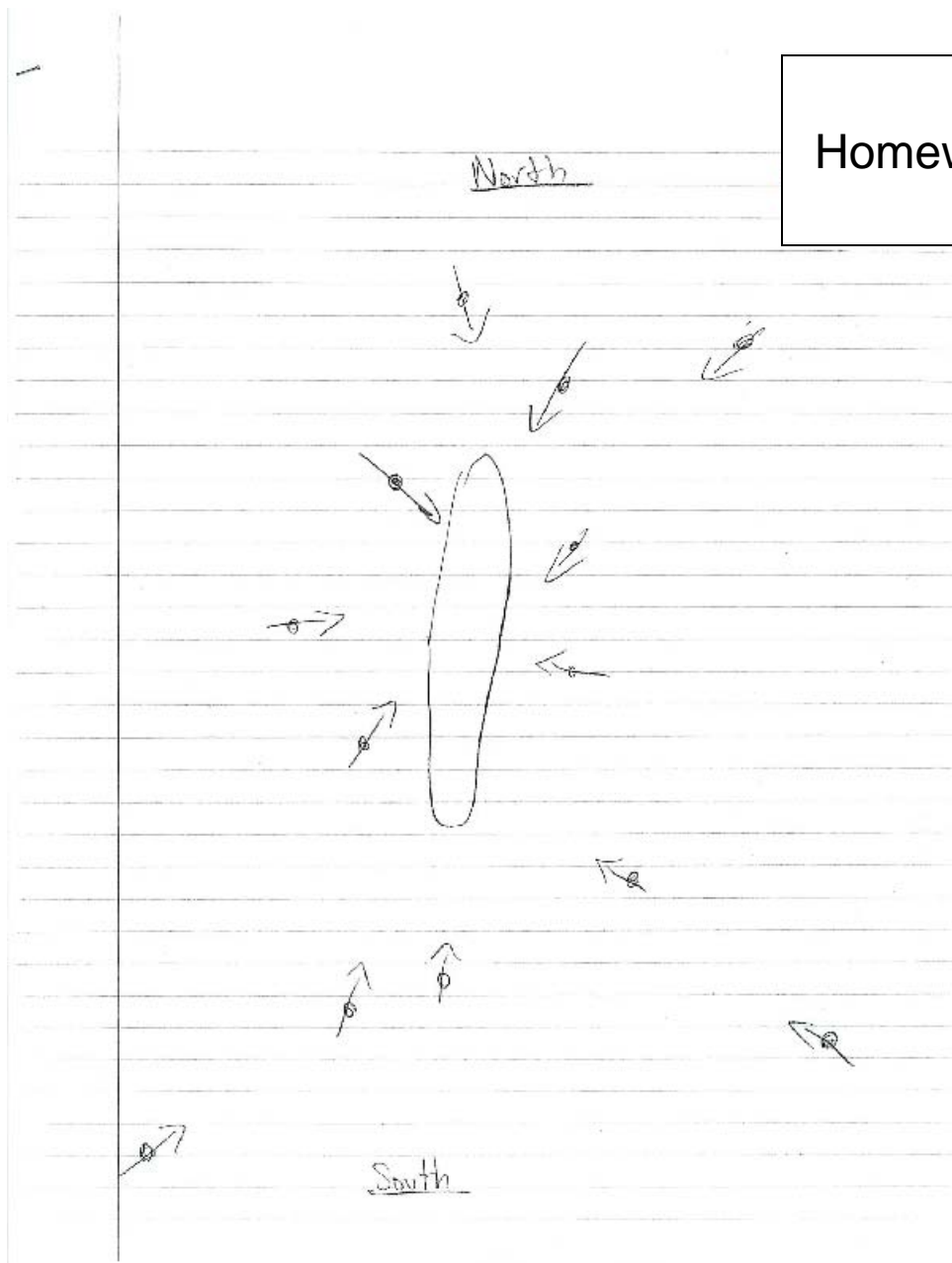
Homework, student B



Class work, student C



Homework, student C



Magnetic Field of Straight Wire

- Straight wire pulled through hole in cardboard sheet, connected to battery
- Place many small compasses on cardboard sheet, surrounding wire
- Sketch and describe pattern of arrows representing compass needles

Magnetic Field of Straight Wire, Homework

1. Describe what you saw when you put the compasses around the wire and connected the wire to the battery. Which way did the compasses point? Draw a diagram with many small arrows to show where all of the compass needles were pointing.

2. Describe what you saw when you switched the wire connections to the battery (when you took the wires connected to the "+" terminal and "-" terminal and switched them).

Magnetic Field of Straight Wire, Homework

Outcome:

- Students readily observed pattern change when current direction was reversed
- Only rarely was circular field-pattern drawn
- Most common patterns showed arrows all pointed in same direction, or inward/outward

1. The compasses pointed around the wire in a clockwise motion.

Student A



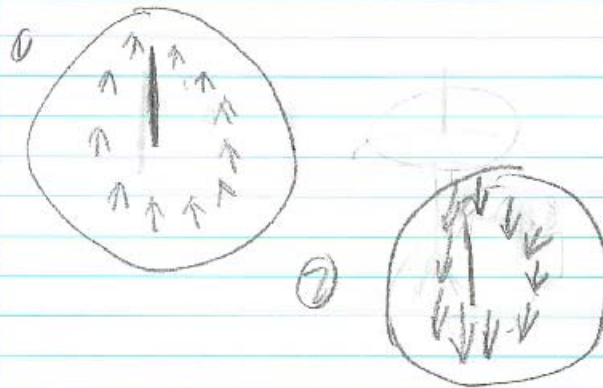
2. When the wire connections were swapped, the direction of the arrows reversed to counterclockwise.



Student B

① when we placed the compasses around the wire and then turned it on, the compasses pointed away from the wire.

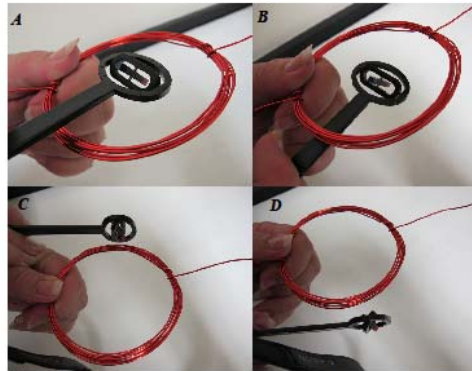
② when we switched the wires, all of the compasses then pointed toward the wire.



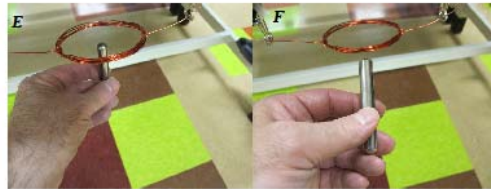
Intermediate Goal: Conducting-loop field pattern and magnetic interactions

- Explore magnetic fields of conducting loops and coils using compasses and Magnaprobos
- Investigate interactions between bar magnets and conducting loops
 - Observe attraction between unlike poles, and repulsion between like poles

Magnetic Field of the Flat Coil



Hold the Magnaprobe at different locations to check the direction of the magnetic field when the coil is connected to the battery (see photos above). Which way does the needle point when you hold it: (A) above the center of the coil; (B) below the center; (C) near one side; (D) near the other side? Where is the north pole of the coil? The south pole? How do your answers change when you reverse the connections to the battery terminals?



Try holding the magnet at different locations near the coil when the coil is connected to the battery: What happens to the coil when you hold the north pole of the magnet below the center of the coil as in photo E above? What happens when you hold it at the side of the coil (photo F)? How does this change when you flip the magnet around? How does it change when you reverse the connections to the battery terminals? See if you can make the coil spin around by holding the magnet in different positions while you repeatedly connect and disconnect the coil to the battery.

Homework, April 7

1. When you put the steel bolt through the center of the coil and connected the coil to the battery, what did you observe?

2.

a) When you connected the flat, hanging coil to the battery and brought the bar magnet near to it, what did you observe?

b) What happened when you turned the bar magnet around when it was near the hanging coil? Why do you think this happened?

Class Activity, May 11;18

Magnetism and Electric Current Activity

1. Connect the galvanometer to the flat coil. *Without* using the battery, but using the magnet, try to make the galvanometer needle deflect (move) either to the right or to the left. Do this *without* shaking or touching the galvanometer itself. Describe your method:
2. Once you have figured out how to make the galvanometer meter needle deflect, explain:
 - a) how to make a *large* deflection, and how to make a *small* deflection.
 - b) how to make a deflection to the left, and how to make a deflection to the right. Describe *two methods* for each.
 - i) Deflection to the left:
 - ii) Deflection to the right:
3. Construct an electromagnet using a steel bolt, wire, and battery. Connect the galvanometer to the flat coil or to the solenoid coil. Find a way to cause the galvanometer needle to deflect but *without* connecting the battery itself in the circuit containing the galvanometer.

Never connect the battery in a circuit containing the galvanometer! It could severely damage the galvanometer.

Describe your method:

Magnetism and Electric Current Activity

#19A

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Our method was to move the magnet over the coil and through the coil.

2. Once you have figured out how to make the galvanometer meter needle deflect, explain:

- a) how to make a *large* deflection, and how to make a *small* deflection.

Large = move magnet through coil quickly. Small = move magnet through coil slowly.

- b) how to make a deflection to the left, and how to make a deflection to the right. Describe *two methods* for each.

- i) Deflection to the left: move magnet in = one side of magnet
move magnet out = one side of magnet

- ii) Deflection to the right: move magnet out = one side of magnet
move magnet in = one side of magnet

3. Construct an electromagnet using a steel hull, wire, and battery. Connect the galvanometer to the flat coil or to the solenoid coil. Find a way to cause the galvanometer needle to deflect but *without* connecting the battery itself in the circuit containing the galvanometer.

Never connect the battery in a circuit containing the galvanometer! It could severely damage the galvanometer.

Describe your method:

First we connected alligator clips to the battery and also to the long coil. Then we put the steel bolt through the long coil. For the flat coil we connected the alligator clips to the galvanometer.

We pushed the steel bolt through the flat coil. ^{The galvanometer moved!}

Motor Assignment (After Building Motor)

The wire coil has two sides, a north pole, and a south pole. The same is with the cow magnet.



← If this side is North,



and this part is North,

when the magnet is near the coil, which is connected to the battery, they repel, causing it to revolve.

Impressions of Electromagnetism Outcomes

- Modest success in becoming familiar with magnetic fields of bar magnets and of current-carrying conductors, with induced currents, and with mechanisms of motors;
- Much repetition and revisiting of activities with slight variations required;
- 7/8th graders significantly quicker to learn than 5/6th graders, but not more enthusiastic.

Batteries and Bulbs, Conceptual Goals

Grade 5/6 [2013]

- Understand that:
 - energy is supplied by battery and battery gets “used up” in lighting bulbs, but:
 - “electric current” flows out from battery and may split or combine at nodes, but returns to battery undiminished
- Be able to predict bulb brightness in simple multi-bulb circuits, using current model
- Recognize that batteries will not last as long in circuits with bulbs that are more brightly lit

Activity Sequence

- Light bulb with battery and single wire
- Inspect bulb construction, recognize need for two terminals and complete conducting path
- Build one-bulb and two-bulb circuits, compare bulb brightness, discuss current flow amounts
- Draw circuit diagrams
- Attempt to construct two-bulb circuit in which “unscrewing one bulb does not make the other one go out” [usually successful]

Batteries and Bulbs, Initial Outcomes

- Students readily grasp need for complete closed path of conducting material, including battery, to get bulbs to light
- Impossible to avoid dealing with “energy”; students refer to it spontaneously and persistently in most explanations of observations

Persistent Challenges

- Very difficult to develop current concept distinct from energy, i.e., idea that battery current does *not* get “used up”
- Very strong and persistent idea that bulb brightness depends on distance from battery (either physical distance, or wire length)

Idea of Current Loss

- Extensive activity and discussion (on need for complete circuit) left students unconvinced that “current out” of battery would equal “current in”
- We presented a demonstration with student prediction: both one-bulb and two-bulb series circuits with “current meters” placed on either side of battery
- Instructor shows that one meter reads, e.g., “0.18” [current units]; students asked to predict what other meter will read.
- Demo placed on cart and wheeled around room for every student to see outcome for themselves

Quiz on Circuits

- Given week after current demonstration
- Asked students to compare amount of current flowing past points on either side of battery
- Most students correctly answered “same,” but many (~ 30%) did not
- Many students did not recall which 2-bulb circuit had the brightest bulbs

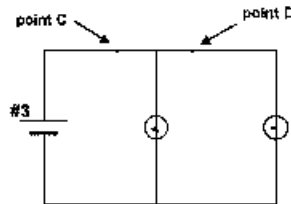
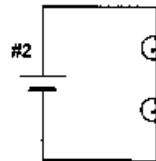
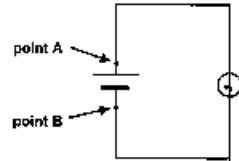
First Name



- We have learned that when current flows through the wires and bulbs, and then back into the battery. The more current that flows through a bulb, the brighter it lights.
- We have also learned that batteries store and supply electrical energy. They can give out a lot of energy quickly, but then they get used up fast and don't last very long. If they give out energy slowly, a little at a time, they can last a long time before running out.
- Remember: current is *not* the same thing as energy. However, if a battery is giving out energy quickly, more current will have to be flowing through the battery than if the battery is giving out energy slowly.

We tested the one-bulb circuit with the current meters to see how much current flowed out of the battery, and how much flowed back into the battery. (We called this circuit #1.)

1. In the one-bulb circuit diagram below, is the amount of current flowing past point B the same as the amount flowing past point A, or is it different? If it's different, is it larger or smaller? Answer: SAME



2. We have compared the two-bulb circuits #2 and #3. In which circuits are the bulbs brighter? Answer: 3

3. Both circuits #2 and #3 have just one battery, but the bulbs are brighter in one of the circuits. Which circuit has more current flowing through its bulbs? Answer: 3

4. We have to figure out how the bulbs can be brighter in one of the circuits even though *both* circuits have just one battery. Here is a possible hint: Let's compare the amount of current flowing past points C and D in circuit #3. Is the amount of current that flows past point D the same as the amount that flows past point C, or is the amount different? If it's different, is it larger or smaller? Explain your answer. Answer and explanation:

The amount is smaller because the current branches off as soon as it passes point C.

5. Do you think battery #3 will last as long as battery #2 before it runs out? Explain. No, because #3 has to have a bigger amount of current because it branches off.

General Observations

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)
- Clear need for more longitudinal assessment studies (see, e.g., Piaget [1964]: “Is this learning lasting? What remains two weeks or a month later?”)

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-appreciated
- 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