Making sense of how students make sense of science

Richard Steinberg
City College of New York

Results from cognitive science

- **Principle 1: Knowledge is built from the processing of information received.**
    - » yet our instructional model focuses on students receiving information rather than constructing it

Edward F. Redish, “Oersted lecture 2013: How should we think about how our students think?” *Am. J. Phys.* 82, 537-551 (2014).

National Research Council (1999). *How students learn: Science in the classroom*, Washington, DC: National Academic Press.

Results from cognitive science

- **Principle 2: Everything learned is learned via interpretation within a context.**
  - » yet we assume students are able to understand and apply complex ideas in a multitude of situations

Results from cognitive science

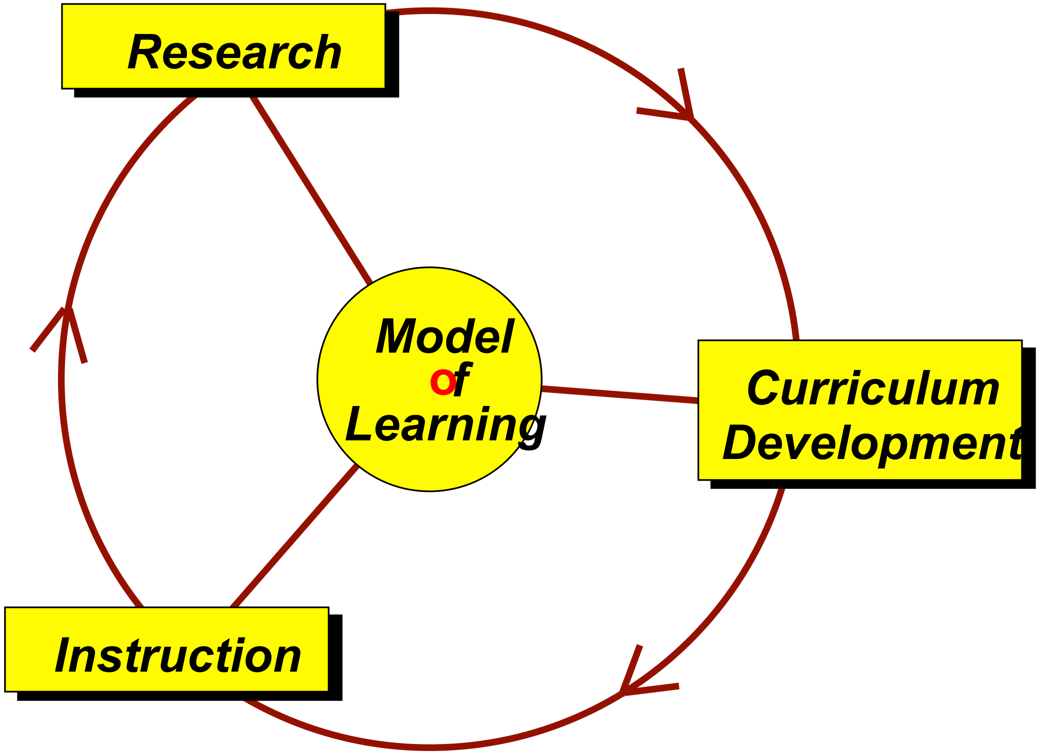
- **Principle 3: It is very difficult to change an established mental model substantially.**
  - » yet we expect students to abandon the beliefs they bring in favor of the beliefs we present

Results of traditional instruction

- **Many students leave science with an unsatisfactory change in their:**
    - reasoning ability
    - understanding of fundamental concepts
    - epistemological attitudes

- **Students' problem solving techniques are typically context dependent and not grounded in an understanding of the subject matter.**

Science Education Research



Research

Model of Learning

Curriculum Development

Instruction

J. Thompson and B. Ambrose, “A literary canon in physics education research,” in *Forum on Education Newsletter*, American Physical Society (Fall, 2005).

National Research Council (2012). *Discipline based education research: Understanding and improving learning in undergraduate science and engineering*, Washington, DC: National Academic Press.

Methods of science education research

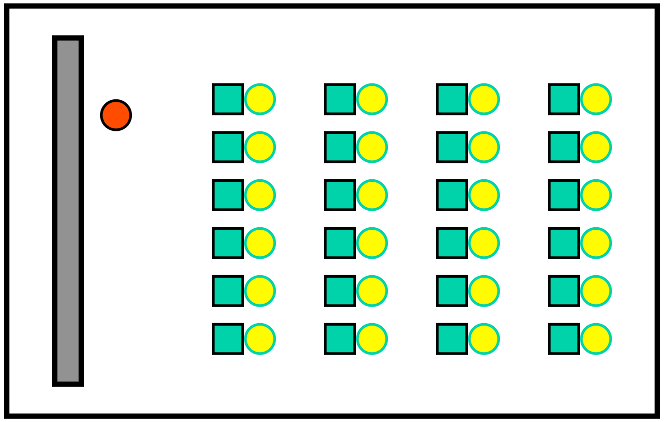
- **Classroom Observations**
- **Student Interviews**
  - demonstration interview
  - problem solving interview
- **Examination questions**
- **Free-response and multiple-choice diagnostics**

Instructional philosophy

- Students take an active role in their own learning.
- The emphasis is on the process of science rather than the presentation of facts.
- Students conduct investigations and use their observations as a basis for constructing physical concepts and developing scientific models.
- Teaching is not by telling but by guiding students to help them develop a functional understanding of the material.

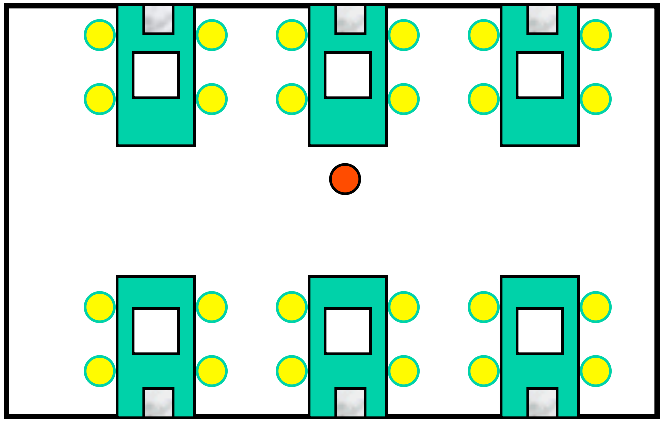
Instructional philosophy

traditional:



vs.

student-centered:

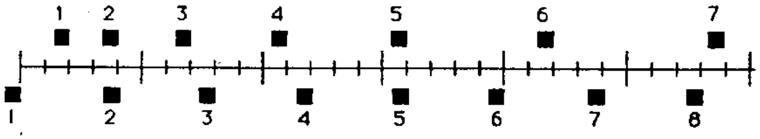


Tutorials at CCNY

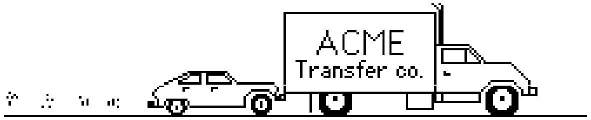
The City College of New York

Force Concept Inventory

- **29-item conceptual multiple-choice diagnostic in mechanics**
- **Distractors are based on the results of extensive research in physics education**



at what instants do the objects have the same speed

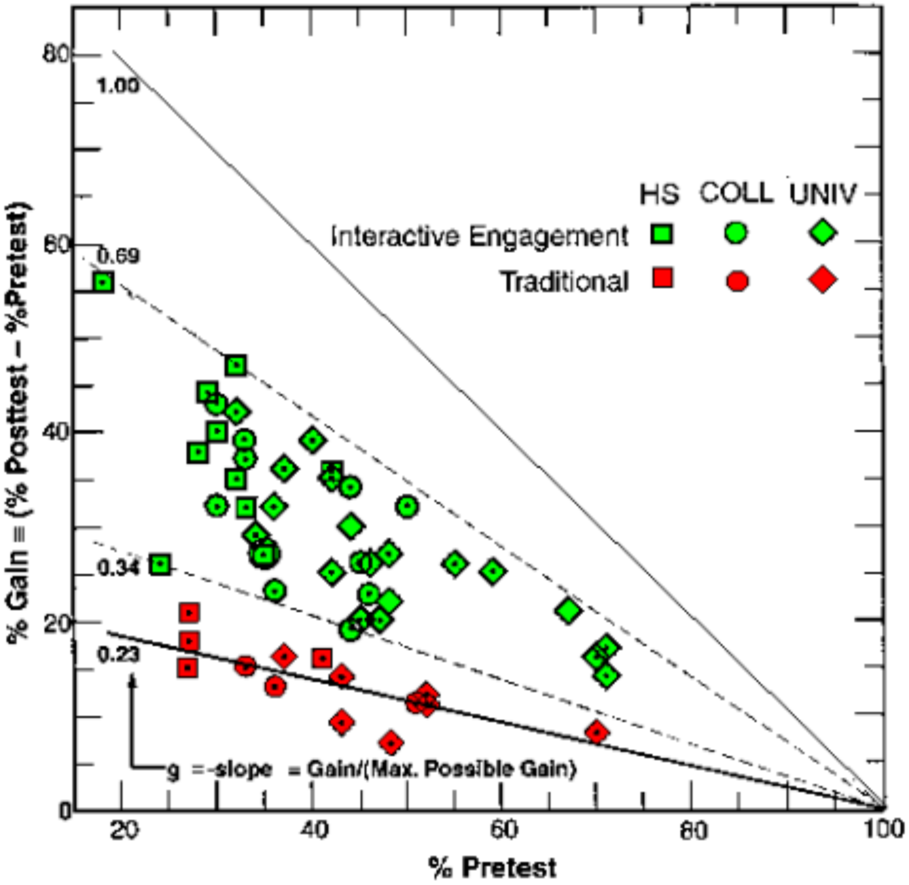


compare the forces of the car and truck on each other

D. Hestenes, M. Wells, and G. Swackhammer, "Force concept inventory," *Phys. Teach.* 30, 141-158 (1992).

Force Concept Inventory

FCI: Fraction of the possible gain



$$h = \frac{post\% - pre\%}{100 - pre\%}$$

R.R. Hake, “Interactive-engagement versus traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses,” *Am. J. Phys.* 66, 64-74 (1998).

Force Concept Inventory

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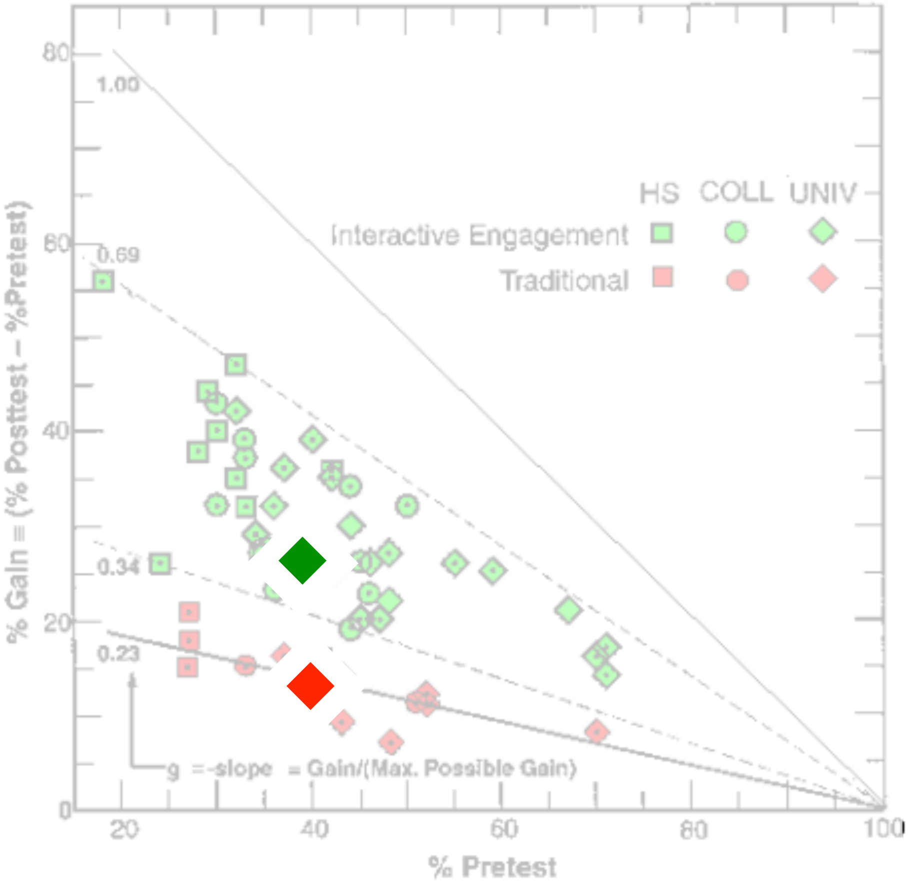

$$h = \frac{post\% - pre\%}{100 - pre\%}$$

◆ Tutorial $h = 0.43$

◆ Traditional $h = 0.23$

R.N. Steinberg and K. Donnelly, “Physics education research-based reform at a multicultural institution,” *Phys. Teach.* 40, 108-114 (2002).

Force Concept Inventory

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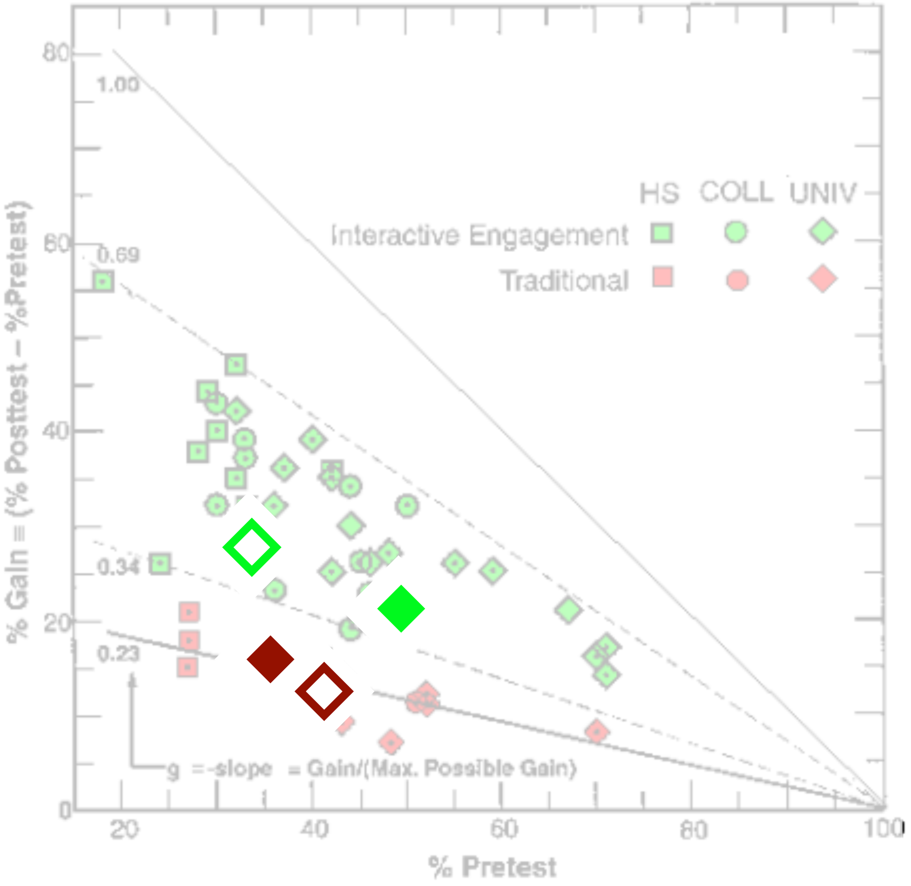


$$h = \frac{post\% - pre\%}{100 - pre\%}$$

◆ Tutorial $h = 0.46$
(native English)

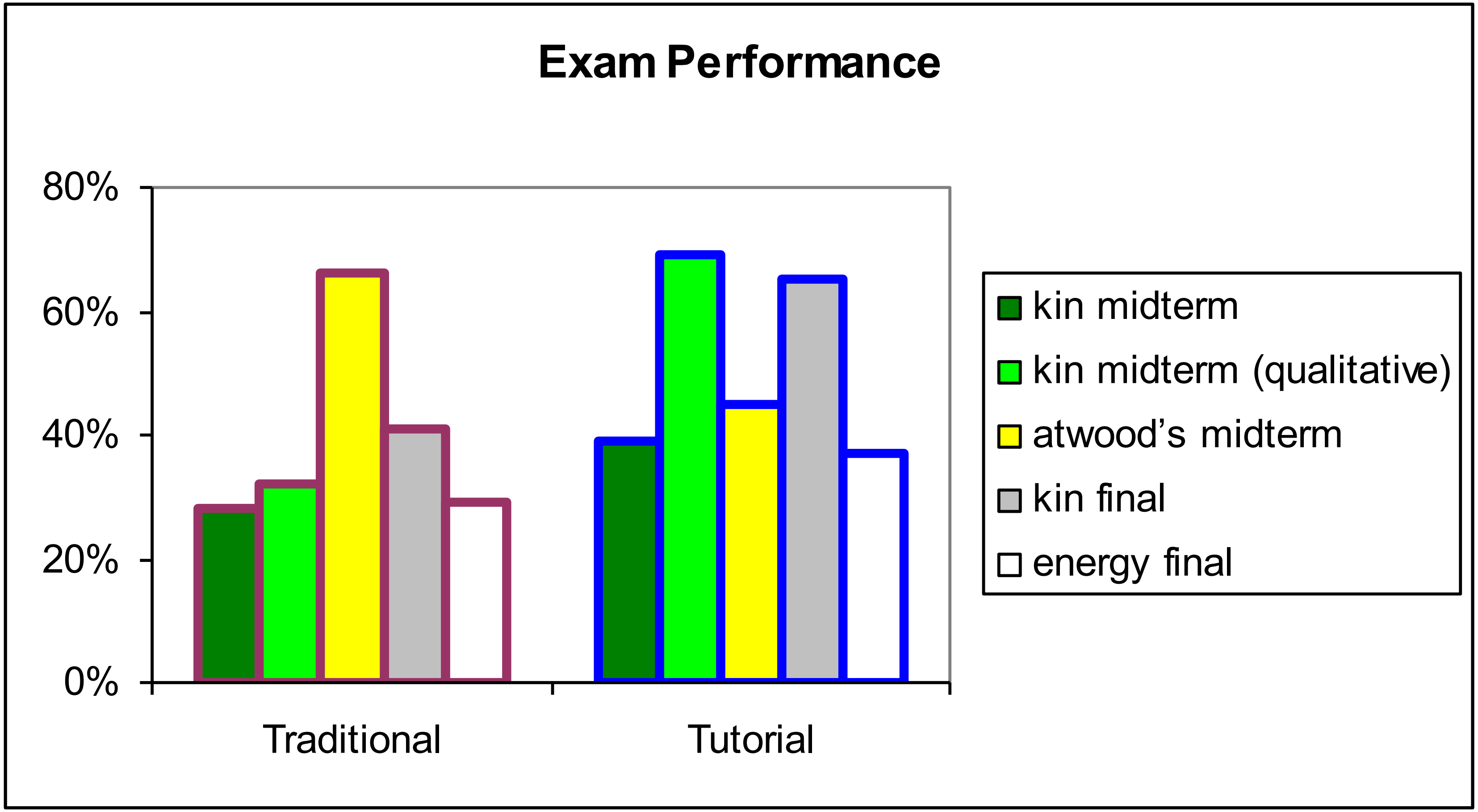
◇ Tutorial $h = 0.42$
(ESL)

◆ Traditional $h = 0.26$
(native English)

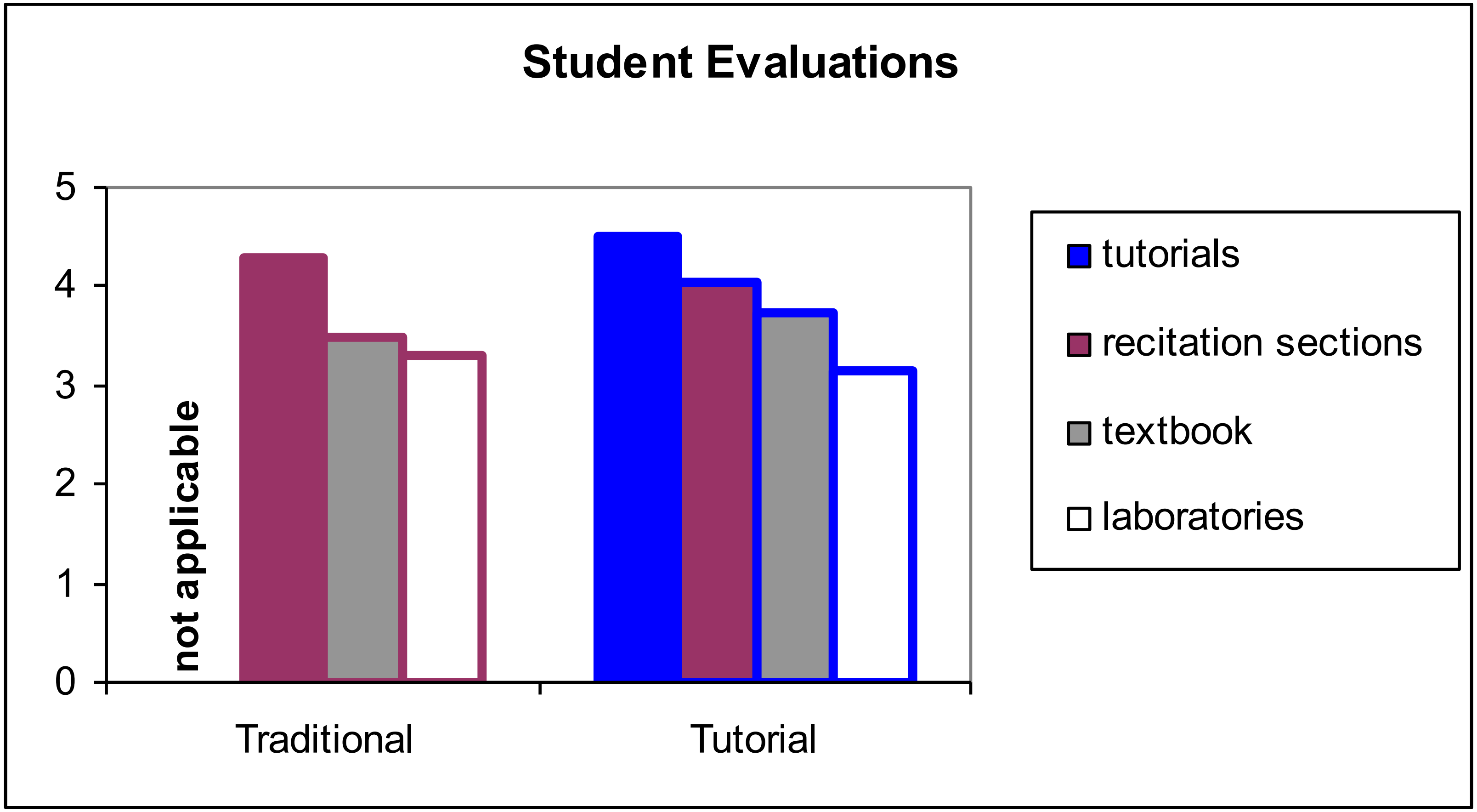
◇ Traditional $h = 0.21$
(ESL)

R.N. Steinberg and K. Donnelly, “Physics education research-based reform at a multicultural institution,” *Phys. Teach.* 40, 108-114 (2002).

Exam performance



Student Evaluations



Summer Scholars Program

- Selective academic program serving rising 10th – 12th graders throughout NYC
- Most students attend specialized high schools
- Flexible curriculum
- CCNY has offered observational astronomy to classes of about 25, nine hours per week for 6 weeks.

Pretest question

Which of the following do you think best approximates the relative motion of the earth and the sun?

A. The sun goes around the earth

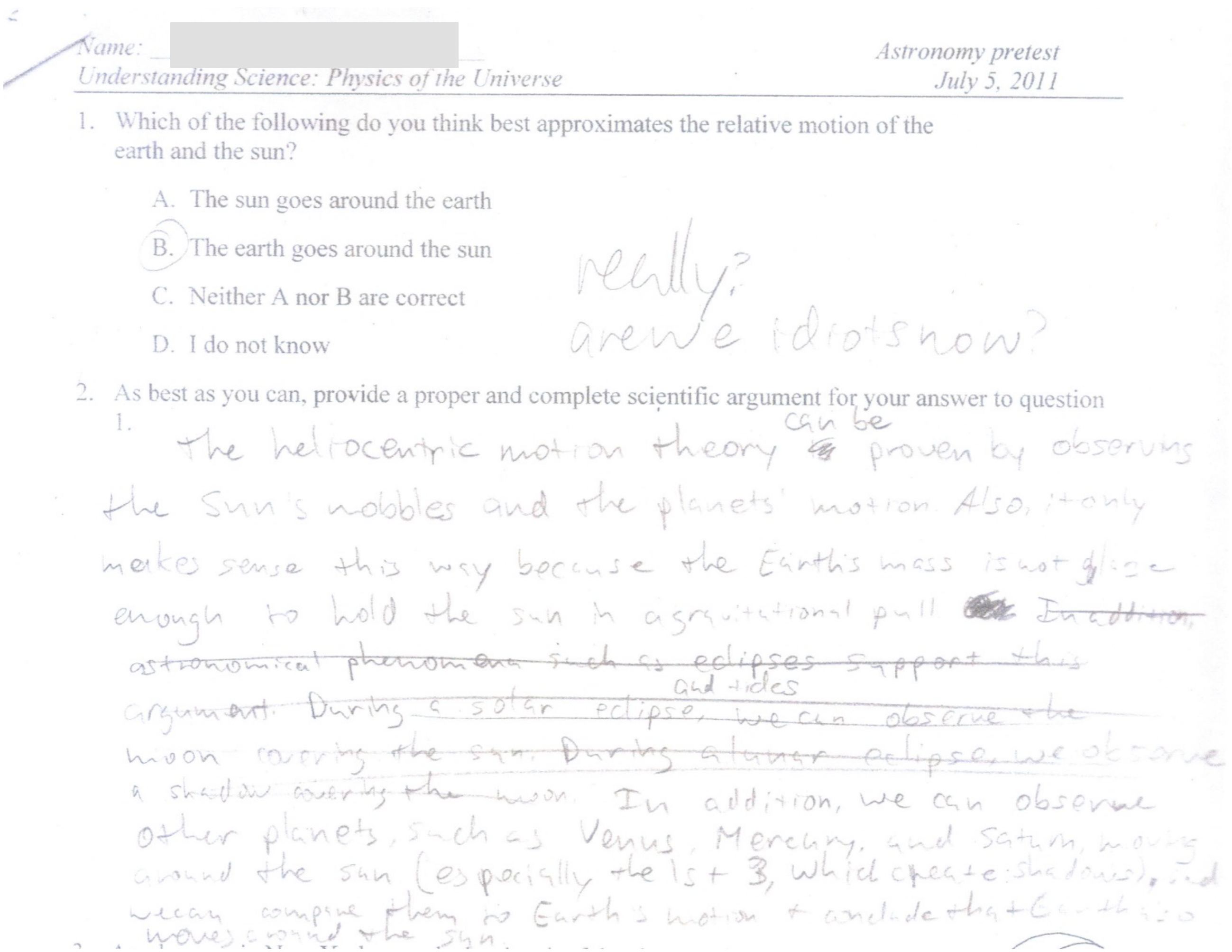
B. The earth goes around the sun

C. Neither A nor B are correct

D. I do not know

As best as you can, provide a proper and complete scientific argument for your answer.

Pretest responses



Name: [redacted]

Understanding Science: Physics of the Universe

Astronomy pretest

July 5, 2011

1. Which of the following do you think best approximates the relative motion of the earth and the sun?

   A. The sun goes around the earth

   [✓ B.] The earth goes around the sun

   C. Neither A nor B are correct

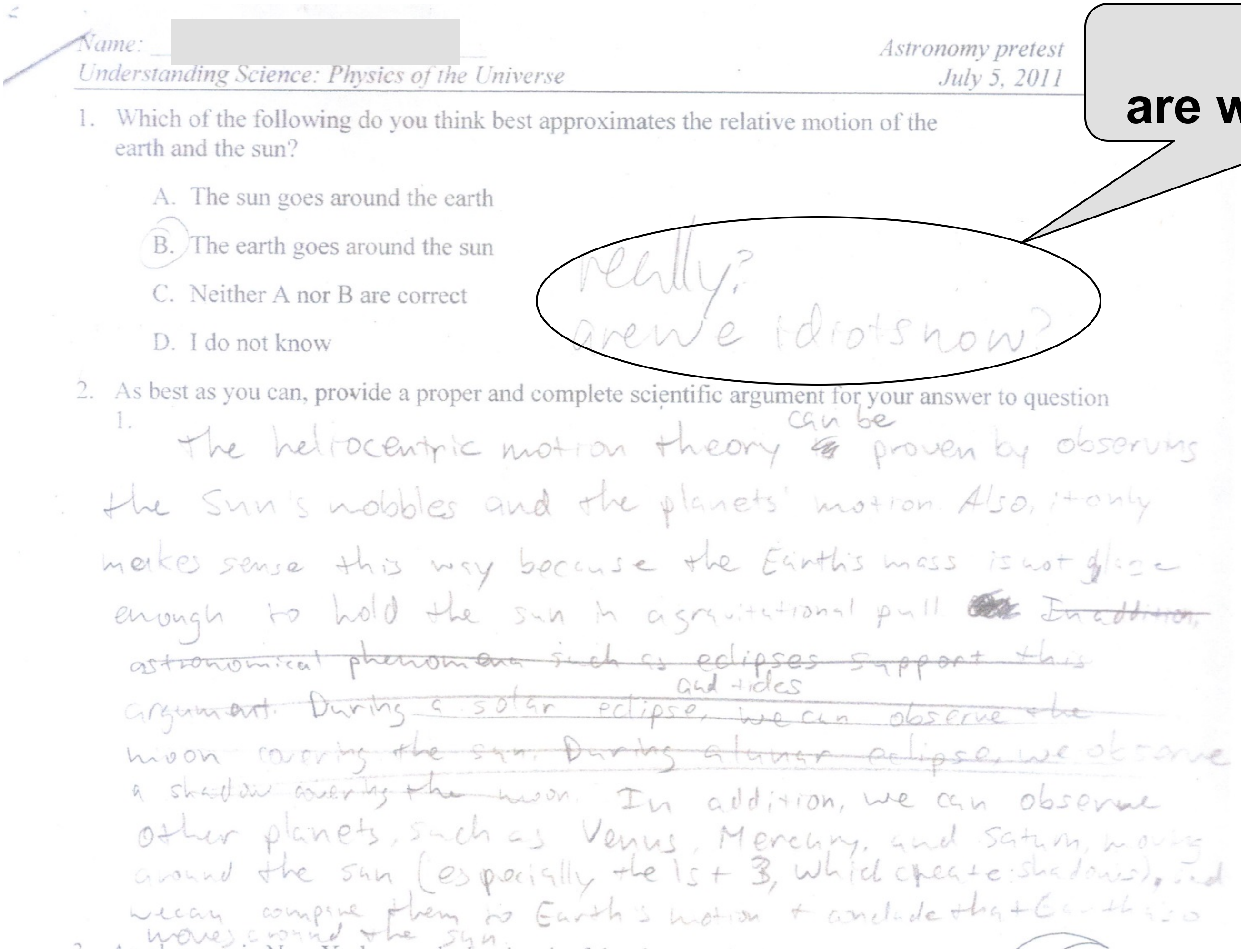
   D. I do not know

really?
are we idiots now?

2. As best as you can, provide a proper and complete scientific argument for your answer to question 1.

The heliocentric motion theory can be proven by observing the Sun's wobbles and the planets' motion. Also, it only makes sense this way because the Earth's mass is not large enough to hold the sun in a gravitational pull. ~~In addition, astronomical phenomena such as eclipses and tides support this argument. During a solar eclipse, we can observe the moon covering the sun. During a lunar eclipse, we observe a shadow covering the moon.~~ In addition, we can observe other planets, such as Venus, Mercury, and Saturn, moving around the sun (especially the 1st 3, which create shadows), and we can compare them to Earth's motion & conclude that Earth also moves around the sun.

Pretest responses



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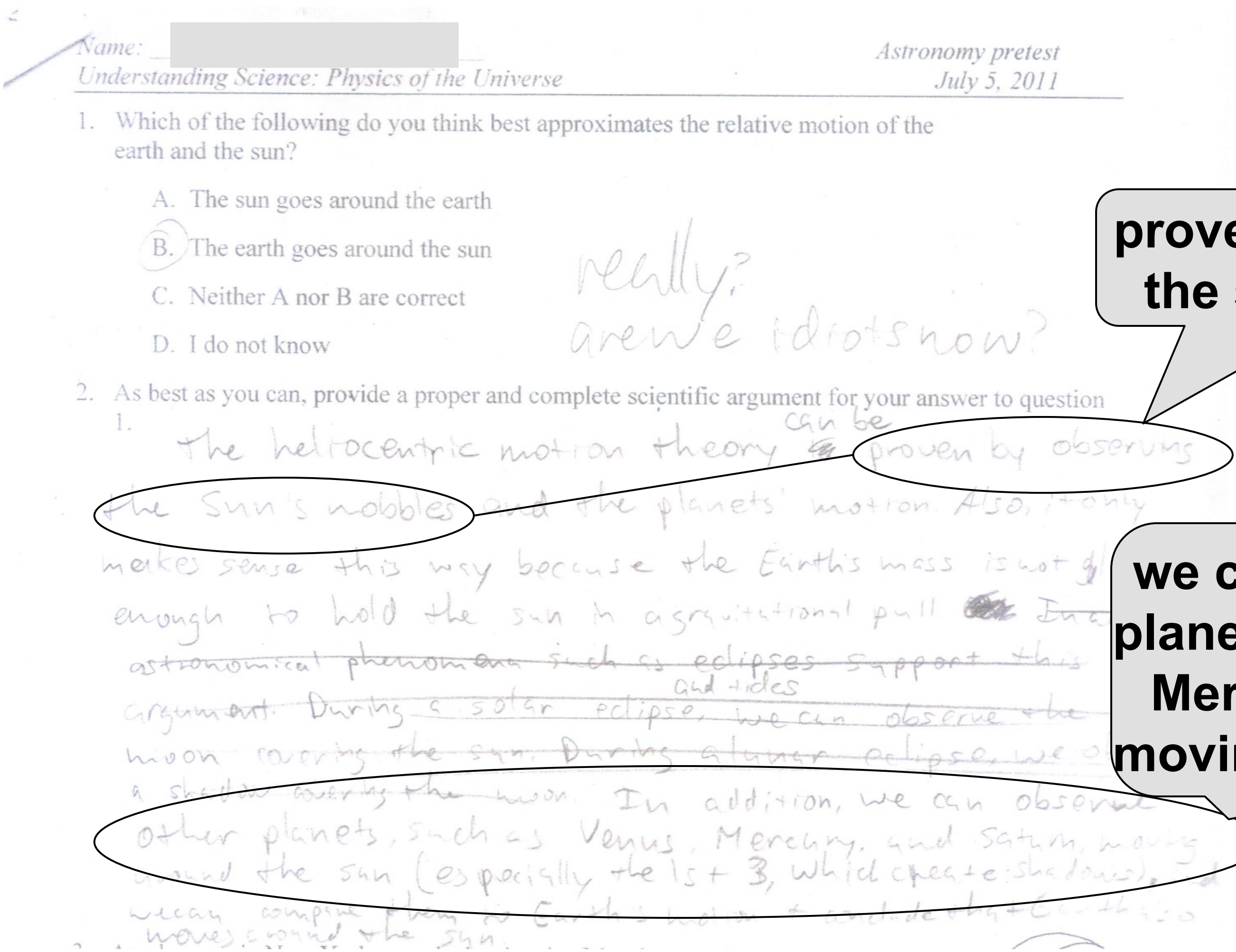

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proven by observing the sun's wobbles

we can observe other planets such as Venus, Mercury, and Saturn moving around the sun

Pretest responses

Student “reasoning”

- “The earth goes around the sun because that’s how we have different seasons. That is also how we have day and night as well as the different positions of the shadow.”
- “The model of the universe is a heliocentric theory. This means that the sun is the center of the universe and all of the planets revolve around it.”
- “During the scientific revolution, a theory was proved that …”

Pretest responses

Student “reasoning”

- “The earth is moving around the sun as the sun is a focus. It takes 24 hours to finish one round.”
- “The sun is a planet of great size which is stationary at all times. If observed for the entire day the sun will move across the sky. Therefore one of the planets is moving. Since the sun remains in one place, earth must revolve around it.”
- “I think the answer is B because we’ve been taught that since we were young. … the true answer is I do not know because I have not witnessed it myself.”

Physics by Inquiry

Exam question

Which of the following do you think best approximates the relative motion of the earth and the sun?

A. The sun goes around the earth

B. The earth goes around the sun

C. Neither A nor B are correct

D. I do not know

As best as you can, provide a proper and complete scientific argument for your answer.

Exam responses

Choice D

- “If I work with a model where the earth stays and the sun goes around the earth I can account for the motion of earth and sun. If I work with a model where the sun stays and the earth goes around the sun I can account for the motion of the earth and sun, too.”
- “I can account for the daily motions of the sun in 2 ways. …”
- “… Therefore I do not know which model is better. While the earth centered model can be more complicated than the sun centered model, if both are finely adjusted, both models can approximately show the relative motions of the earth and the sun. ”

Exam responses

Choice B

- “We observed that the sun moves across the sky. This can be explained by having the sun go around the earth or the sun still and the earth spinning. … The movements of the planets can be more easily explained by using the sun centered model and gravity so the earth going around the sun model is most likely correct.”
- “I think B best approximates the relative motion of the earth and sun. Although both A and B account for the movement of the earth, sun, moon, and stars, B is much easier to explain the movement of the planets. Since it is observed that the distance between the earth and certain planets change over time, it would be difficult to incorporate this in a geocentric model.”
- “I say B because the earth goes around the sun & that is true because how we get different season changes in the year.”

Quantifying results

Pre/Post test rubric, explanations

1- Student's use of jargon, authority, circular reasoning, or irrelevant observations/experiments represents a significant part of their answer.

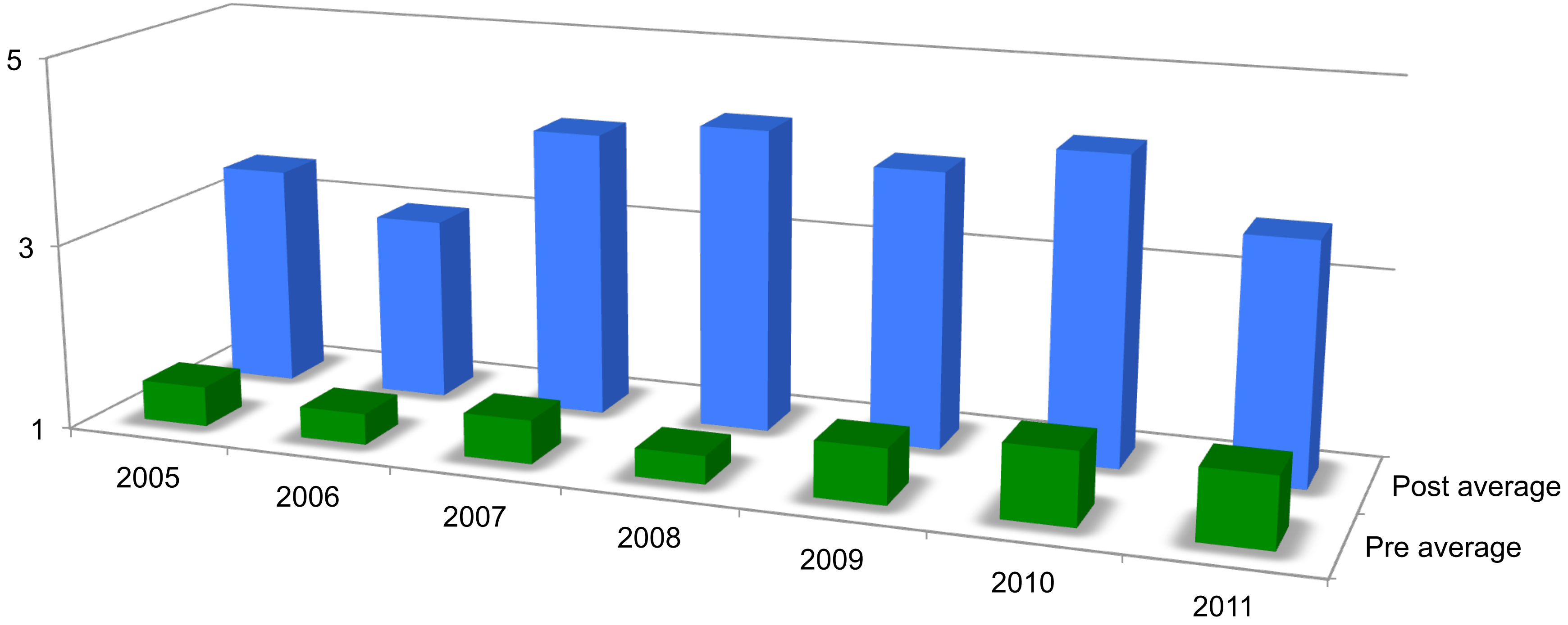
3- Student refers to relevant observation and experiments but part of explanation is erroneous or problematic.

5- Student cites observations/experiments distinguishing between 2 models and supports choice with proper explanation relevant to their answer.

“Probing student understanding of scientific thinking in the context of introductory astrophysics,” R.N. Steinberg, S. Cormier, and A. Fernandez *Phys. Rev. ST Phys. Educ. Res.* 5, 020104 (2009).

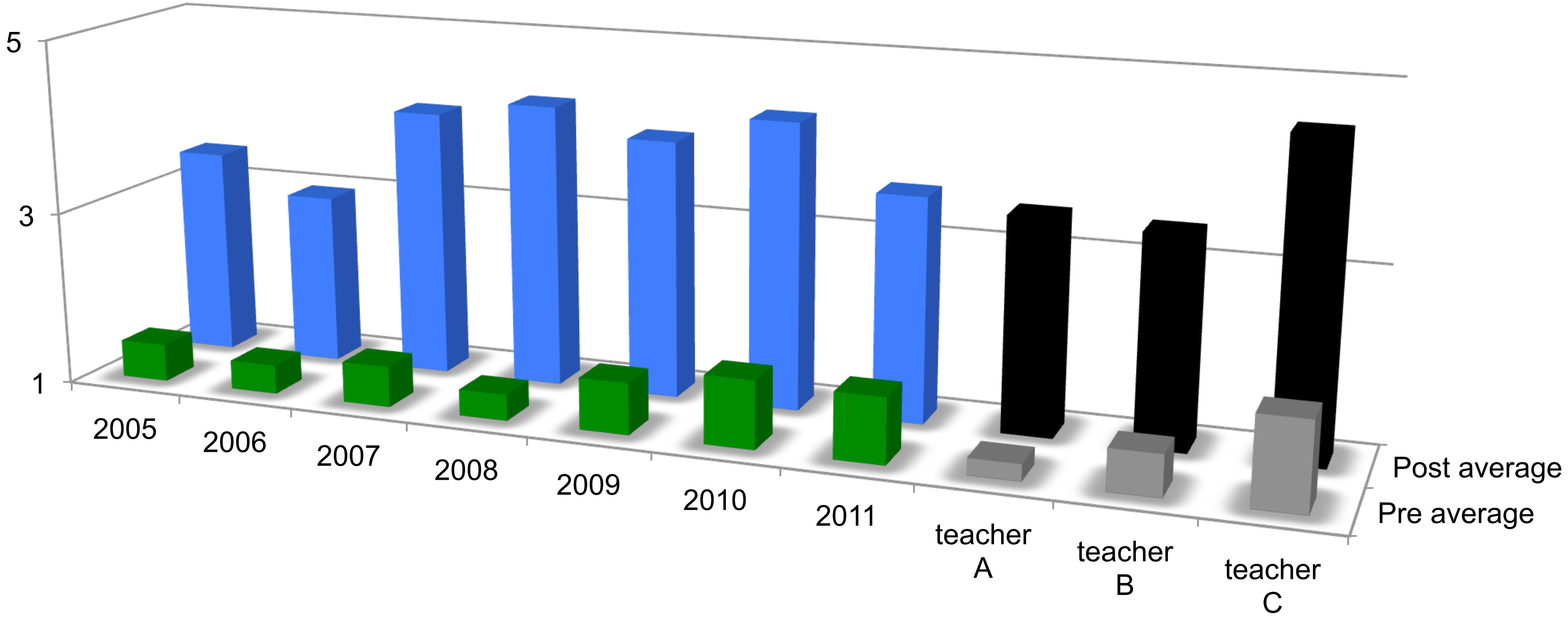
Quantifying results

- *N* = 139 (matched) over 7 year period
  - » Pretest: Average score = 1.50
  - » Post-test: Average score = 3.92



Quantifying results (teachers)

- *N* = 122 (matched) over 3 year period
  - » **Pretest: Average score = 1.50**
  - » **Post-test: Average score = 3.65**



"Understanding and affecting science teacher candidates' scientific reasoning in introductory astrophysics ," R.N. Steinberg and S. Cormier, *Phys. Rev. ST Phys. Educ. Res.* 9, 020111 (2013).

An inquiry into science education, where the rubber meets the road

Perspectives entering sabbatical as a full time high school science teacher

- **Introductory college physics instructor**
- **Science education program director**
- **Teacher education program participant**
- **New York City High School Teacher**

“An inquiry into science education, where the rubber meets the road,” R.N. Steinberg, Rotterdam, NL: Sense Publishing (2011).

Challenges of inquiry physics

- **Classroom management**

Challenges of inquiry physics

- **Classroom management**
- **Student approaches / epistemologies**
    - » The average of 36 and 38 is 57
    - » Q: Find T_f of 50g Zn block (T_i = 71°C) placed in 200g of water (T_i = 10°C).
      A: 3°C
    - » Solution to $5x = 80$ is $x = 75$

Challenges of inquiry physics

- **Classroom management**
- **Student approaches / epistemologies**
  - » "A car moves with a constant velocity of 9.5 m/s. What is the velocity of the car?"

Challenges of inquiry physics

- **Classroom management**
- **Student approaches / epistemologies**
  - » "A car moves with a constant velocity of 9.5 m/s. What is the velocity of the car?" … "I could not do this one because I did not know which formula to use."

Challenges of inquiry physics

- **Classroom management**
- **Student approaches / epistemologies**
- **Emphasis on standardized short-answer exams**
  - “Is that on the Regents?”

Challenges of inquiry physics

- **Classroom management**
- **Student approaches / epistemologies**
- **Emphasis on standardized short-answer exams**
  - » Regents question:
    - The tau neutrino, the muon neutrino, and the electron neutrino are all:”

      a. leptons b. baryons c. hadrons d. mesons
    - 82% answered correctly (*N = 38*)

Things that work / matter

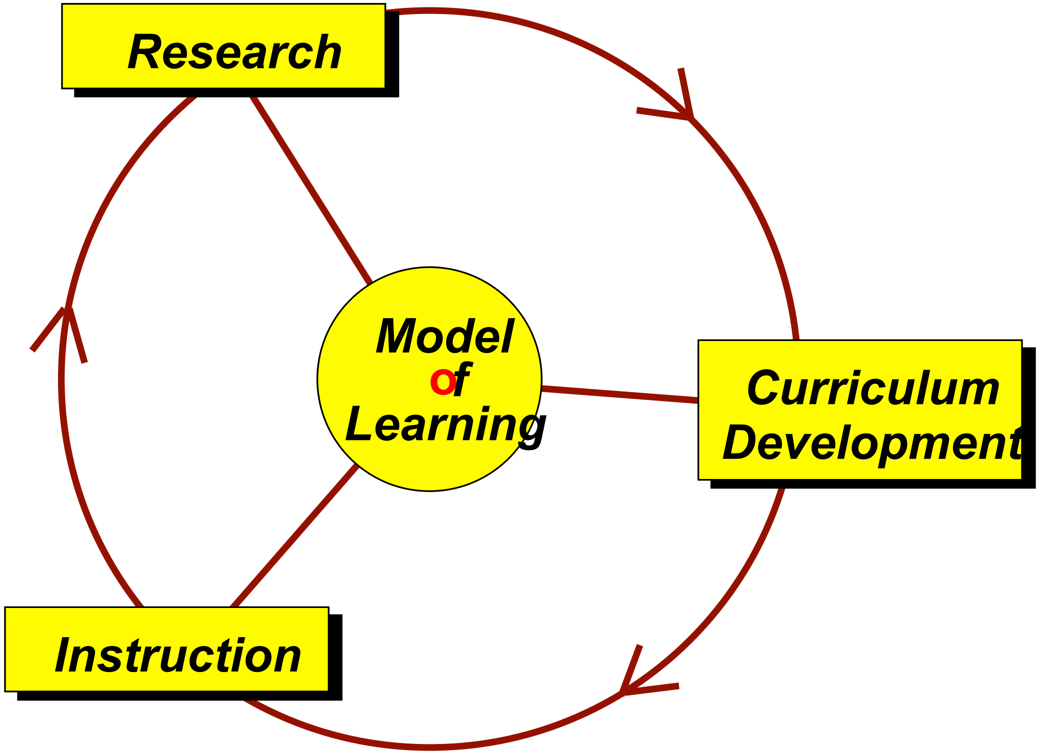
- **Mr. Diaz’s life science class**
- **Ms. O’Brien’s history class**
- **Scotch tape experiment**
- **Phet Simulations**
- **Miguel: “*Special aptitude in the field*”**
- **Carlos and Linda: Period 9**
- **Joan and Pedro: Parent teacher night**

Things that work / matter

***Physics by Inquiry*, Astronomy**

- ***Summer Scholars Program rubric scores***
  - » **N=139 (matched)**
  - » **Pretest: Average score = 1.50**
  - » **Post-test: Average score = 3.92**
- ***Public high school results***
  - » **N=35 students (19 took pretest, 9 took post-test)**
  - » **Pretest: Average score = 1.05**
  - » **Post-test: Average score = 3.44**

Conclusion



Research

Model of Learning

Curriculum Development

Instruction