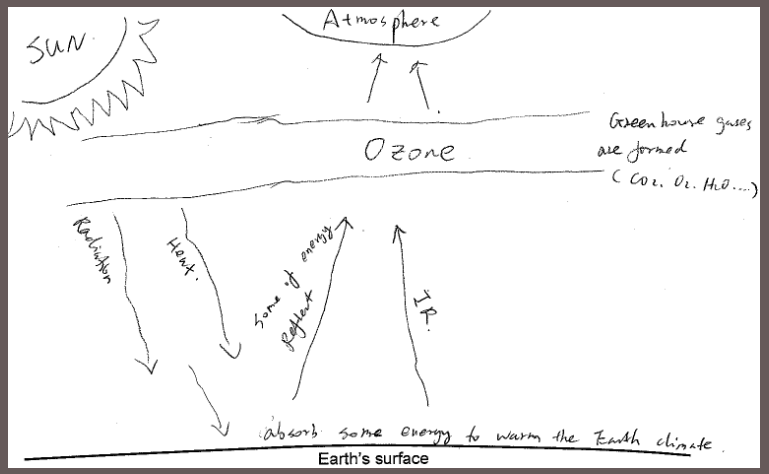
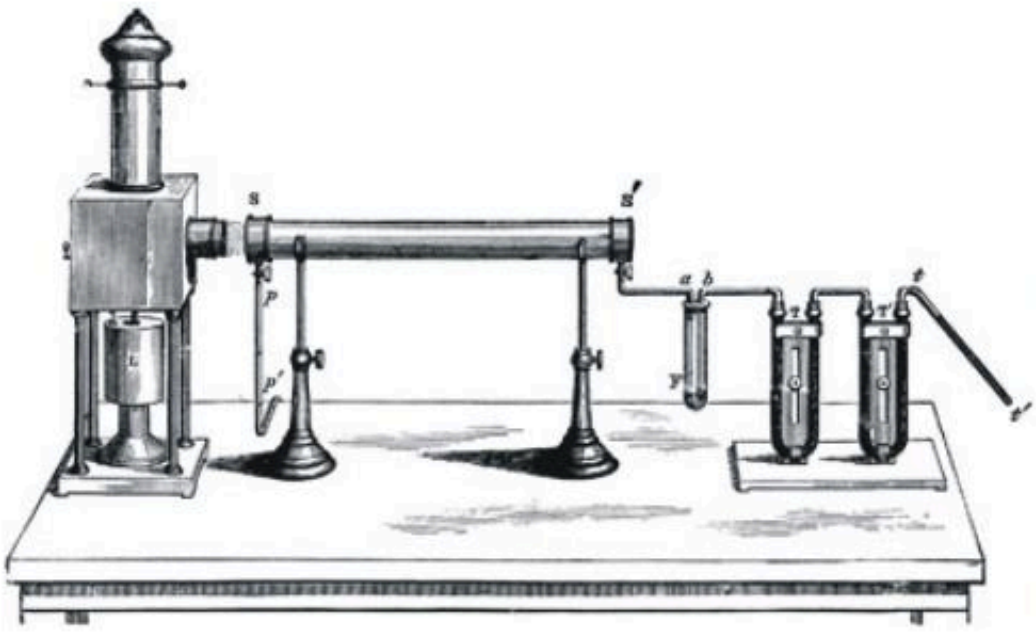
MEASURING UNIVERSITY STUDENTS' UNDERSTANDING OF THE GREENHOUSE EFFECT



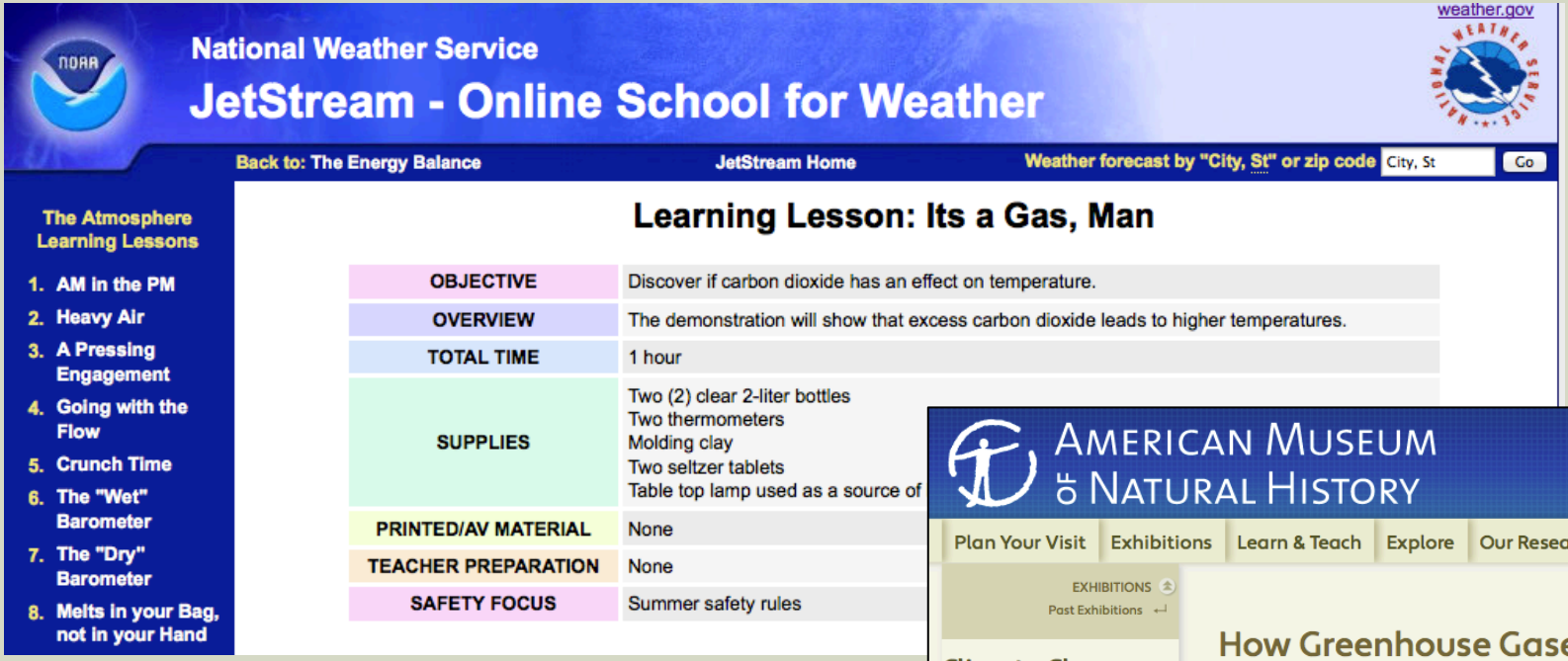
Anne U. Gold,
CIRES, University of Colorado
&
Sara Harris,
University of British Columbia

a place of mind
THE UNIVERSITY OF BRITISH COLUMBIA

CIRES
Cooperative Institute for Research in Environmental Sciences



Experimental setup for one of John Tyndall's experiments, by which he investigated the infrared absorptive powers of different gases (left). John Tyndall lecturing at the Royal Society (right).


National Weather Service
JetStream - Online School for Weather
weather.gov
Back to: The Energy Balance
JetStream Home
Weather forecast by "City, St" or zip code
City, St
Go
The Atmosphere Learning Lessons
1. AM in the PM
2. Heavy Air
3. A Pressing Engagement
4. Going with the Flow
5. Crunch Time
6. The "Wet" Barometer
7. The "Dry" Barometer
8. Melts in your Bag, not in your Hand
Learning Lesson: Its a Gas, Man
OBJECTIVE
Discover if carbon dioxide has an effect on temperature.
OVERVIEW
The demonstration will show that excess carbon dioxide leads to higher temperatures.
TOTAL TIME
1 hour
SUPPLIES
Two (2) clear 2-liter bottles
Two thermometers
Molding clay
Two seltzer tablets
Table top lamp used as a source of
PRINTED/AV MATERIAL
None
TEACHER PREPARATION
None
SAFETY FOCUS
Summer safety rules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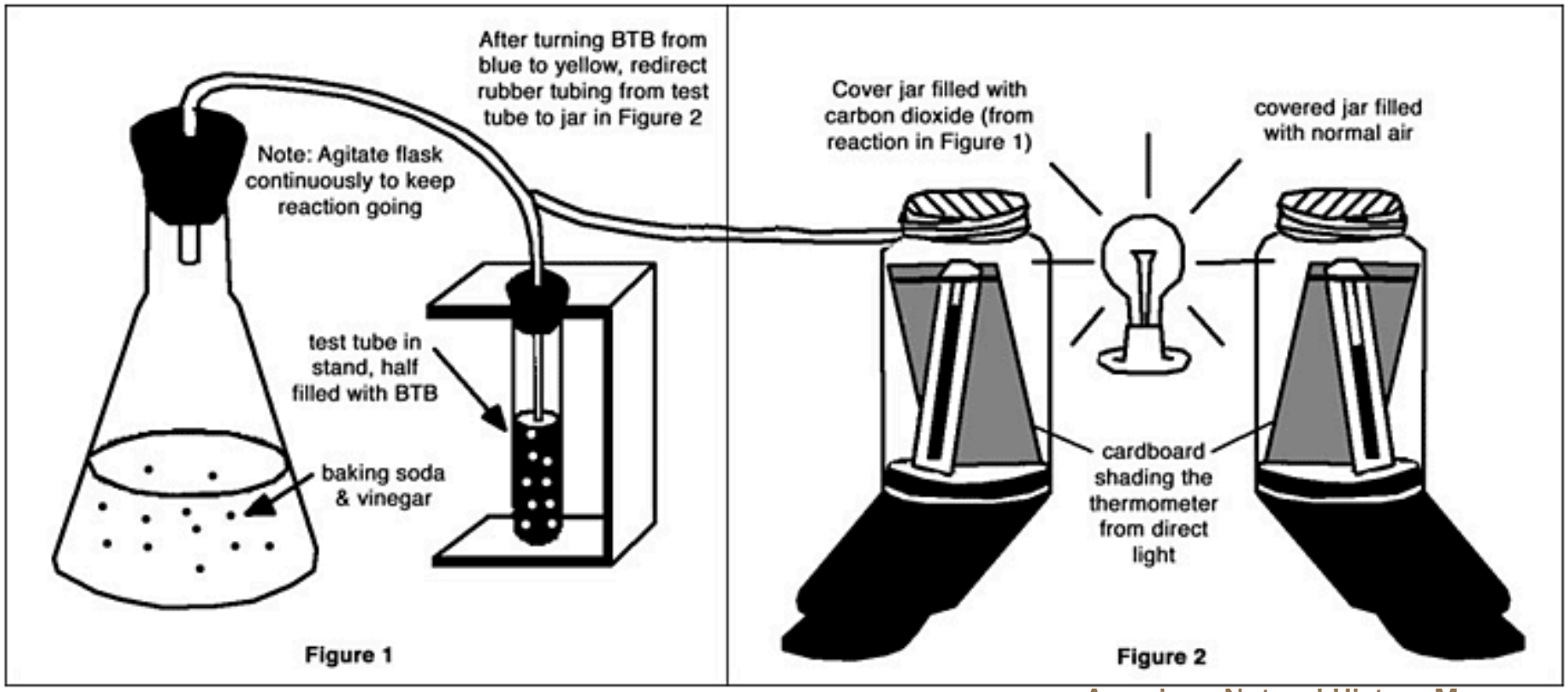
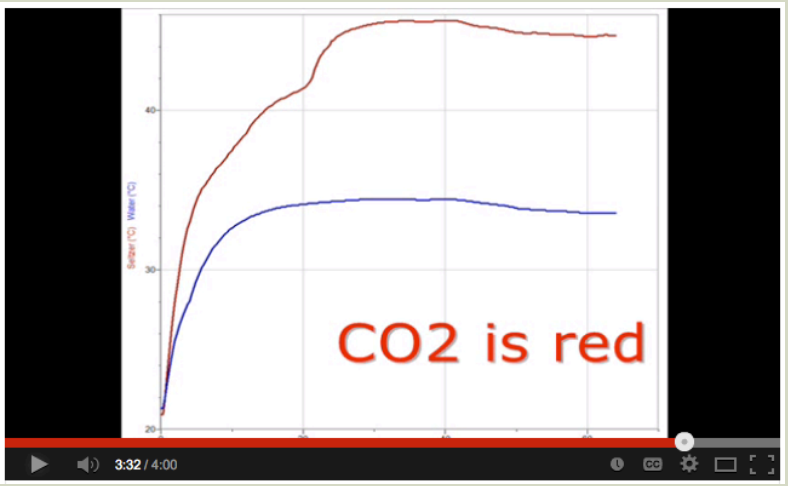
Changing Ice
Changing Ocean
Changing Land
Adaptations
Making a Difference
A New Energy Future
Meet the Curators
How Greenhouse Gases Absorb Heat
Earth's atmosphere is composed of a mixture of gases: 78% nitrogen, 21% oxygen, >1%
amounts of other gases, including carbon dioxide. some gases absorb and re-radiate infra
sense as heat. these heat-absorbing gases are often referred to as greenhouse gases. hu
been adding carbon dioxide and other greenhouse gases to the atmosphere. how will ear
respond to this increase in the amount of greenhouse gases? Scientists create physical m
experiments to compare how systems respond to changed conditions.
In this experiment students will observe two model atmospheres: one with normal atmosp
and another with an elevated concentration of carbon dioxide. These two contained atmos
exposed to light energy in a sunny window or from a lamp.
Objective
Students will:
• understand that greenhouse gases in the atmosphere absorb and hold heat
Materials Per Group
• Student Worksheet
• 15 ml of Bromothymol Blue (BTB), an acid and carbon dioxide indicator
• 1 small beaker or jar

USGS
science for a changing world
Greenhouse Gases
Description of the Activity
Students observe and contrast thermal properties of three major greenhouse gases. Using simple, readily available materials, students collect temperature change over time for dry air, water saturated air, carbon dioxide, and methane.



American Natural History Museum



http://www.youtube.com/watch?v=kwtt51gvaJQ, Erik Christiansen, SFU

ISSUES WITH EXPERIMENT

- Right trend but reason wrong
  - Experimental set up (i.e. distance to heat source, wavelength spectrum of commercial lamps)
  - Specific heat capacity of CO2 vs. air
  - Pressure difference in bottle
  - Heat generated in reaction
  - Effect by magnitudes too large
  - …
  - *(issues w/variation of experiment described in Wagoner, 2010)*
- Not reproducible data, classroom setting

GOALS OF THIS STUDY

- Develop alternative lessons around greenhouse effect
- Study the effectiveness of different lessons
- Study students' mental models and changes in the mental models around the greenhouse effect
  - Compare multiple-choice questions with concept sketch assessment
- *Identify key concepts around learning the greenhouse effect*
- *Develop and classroom-test hands-on activity based on our findings*

SETTING & PARTICIPANTS

- Large research university (University of British Columbia)
- Intro course: “Atmospheres and Oceans”
- Open to all: wide diversity of backgrounds
- Enrollment = 248
- 164 students wrote all the assessments (4)

LEARNING GOALS
(aligned with lessons, aligned with assessments)

1. Identify greenhouse gases; identify non-greenhouse-gas air molecules
2. Differentiate between short wave radiation from the Sun and long wave radiation from the Earth
3. Contrast the molecular structure of greenhouse gases versus non-greenhouse gases (common air molecules)
4. Explain how the greenhouse effect warms Earth in terms of the physical processes that happen.
5. Describe how greenhouse gases themselves absorb and emit radiation, including what kinds of radiation (shortwave or longwave).
6. Describe how greenhouse gases influence flows of energy within the atmosphere, to and from Earth's surface, and to and from space.

Knowledge

↓

Comprehension

↓

Application

↓

Analysis

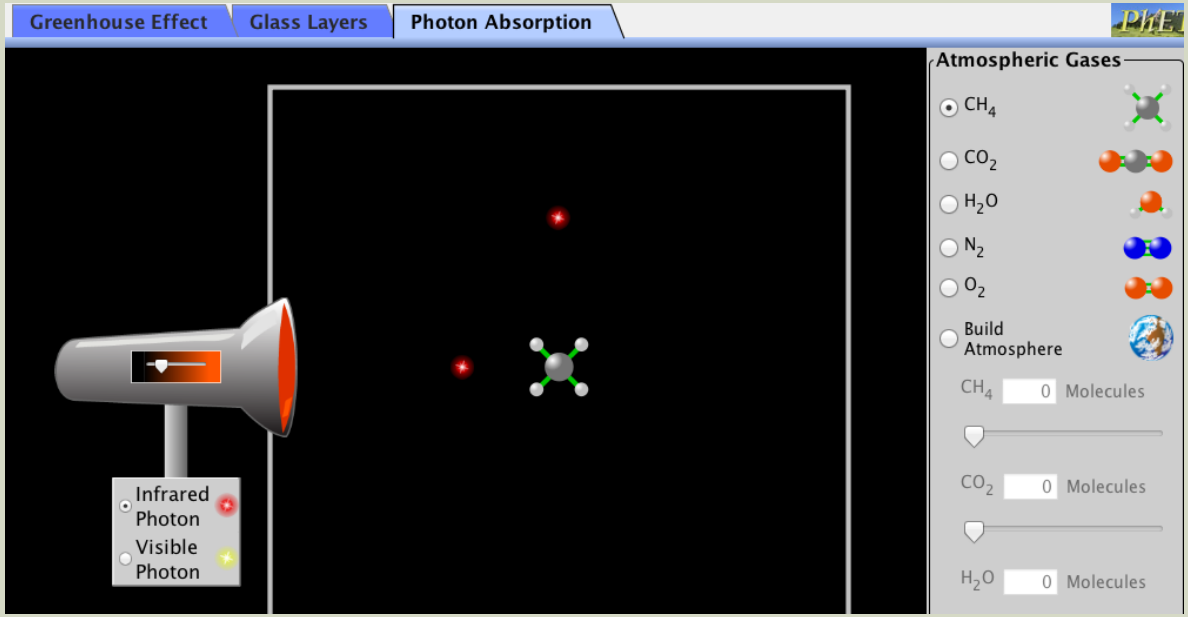
↓

Synthesis

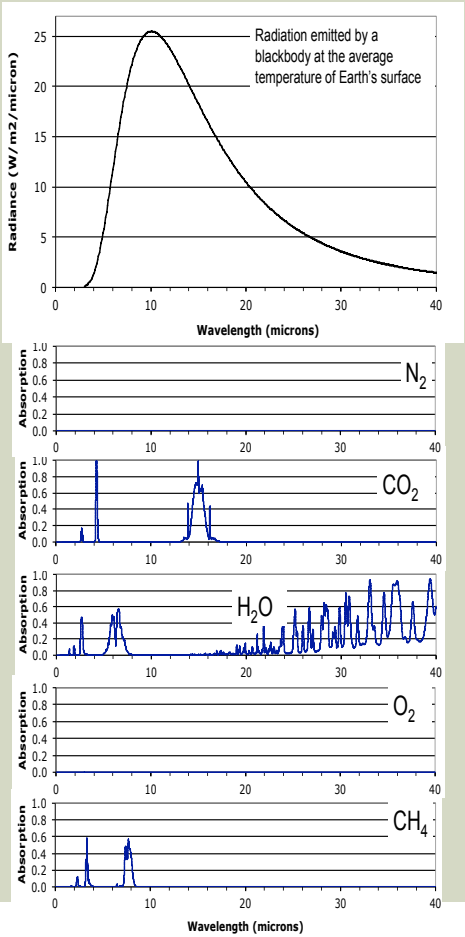
[Evaluation]

TWO CONTRASTING LESSONS

1. PhET Interactive Simulation (Greenhouse effect)

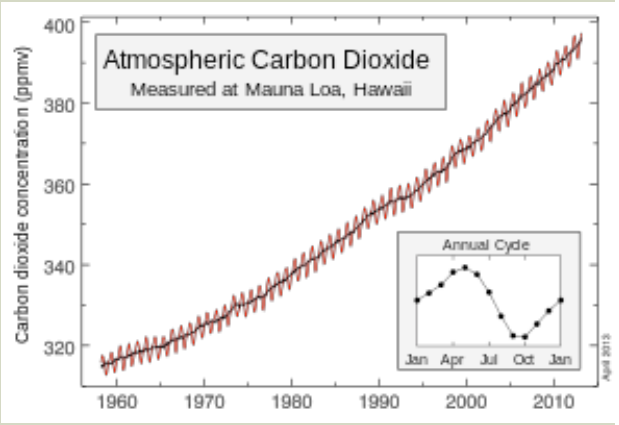


2. "Data" lesson (Absorption Spectra)



COMMON LESSON

- Hook: Keeling curve
- Composition of atmosphere (group work)
- Earth's energy balance (clicker question)
- Mini lesson on physical properties of the atmosphere
- Absorption and reemission of IR by greenhouse gases



ASSESSMENTS

PART 1: Concept Sketch* (4 times (5 including retention))

"Sketch, label, and describe how the greenhouse effect works. Identify the key features you decide to include. Explain the processes that happen. Indicate how the features and processes are related. Use clear, complete sentences and leaders."

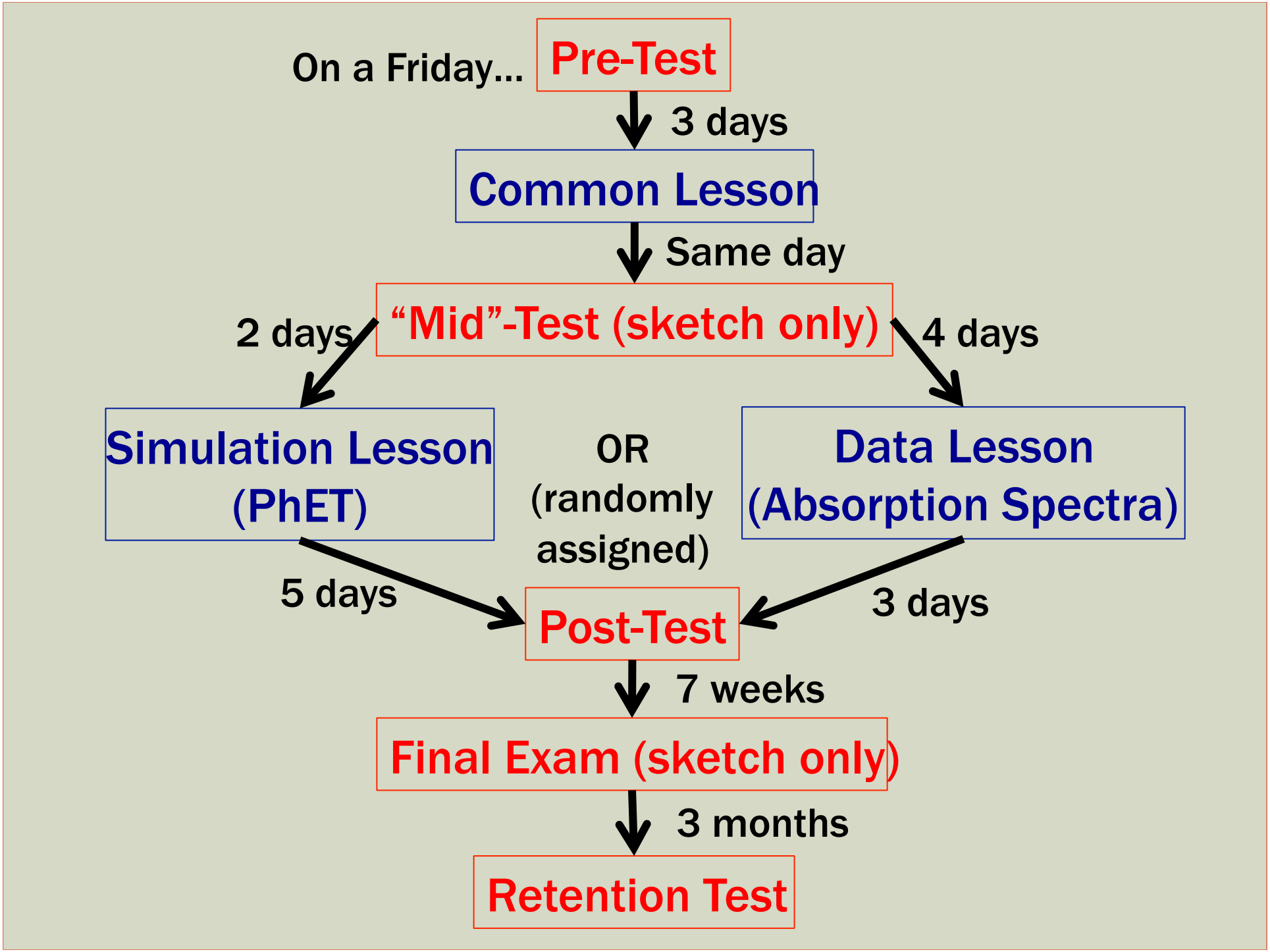
PART 2: Short Answer and Multiple Choice (2 times (3 including retention))

3 Short Answer questions

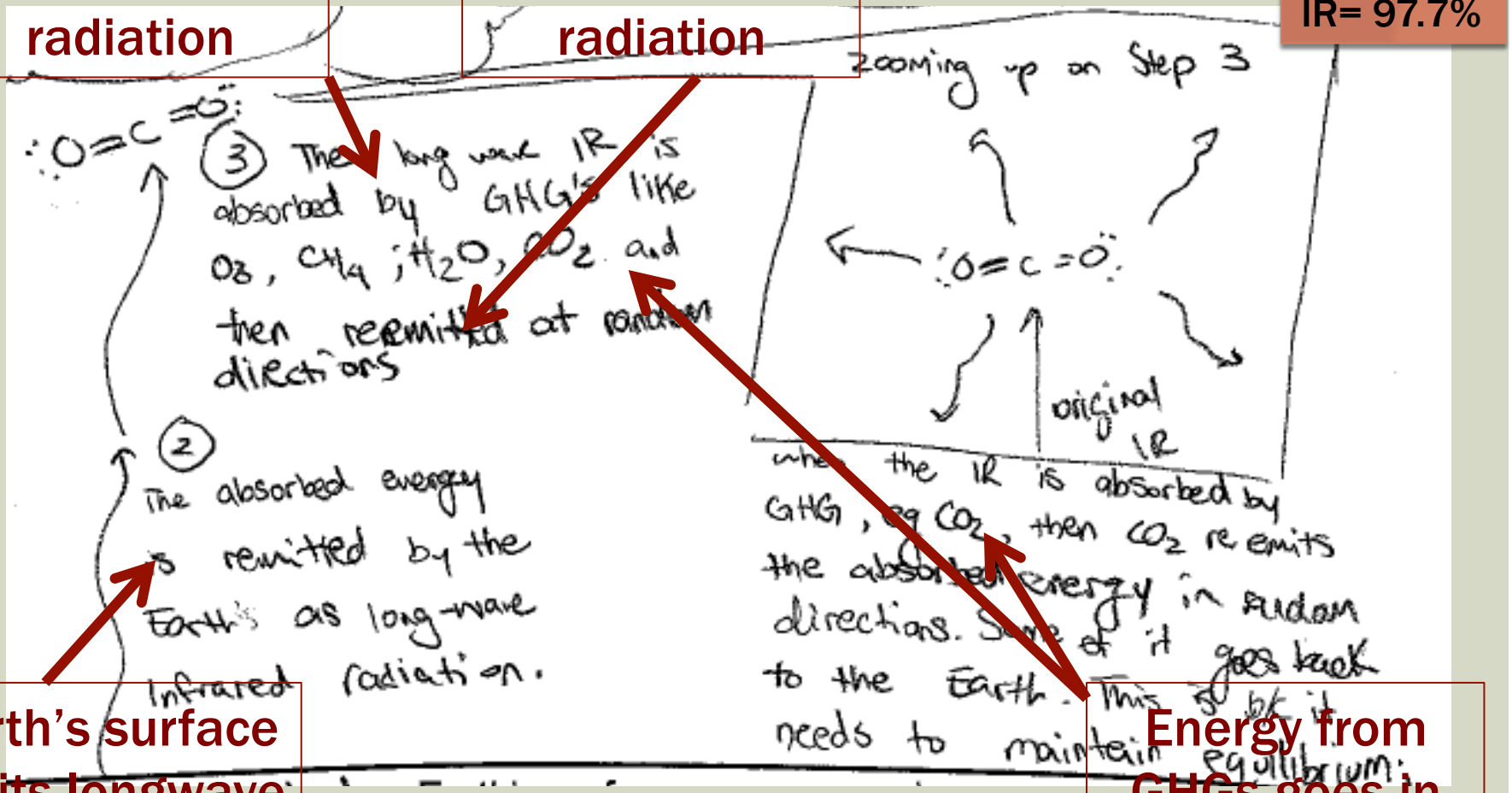
9 Multiple Choice questions (level of confidence (3) and distractors (6))

Questions developed and modified from existing questions. Qualitative validation w/ student interviews, expert review.

*(*Johnson and Reynolds, 2005)*


On a Friday...
Pre-Test
3 days
Common Lesson
Same day
"Mid"-Test (sketch only)
2 days
4 days
Simulation Lesson (PhET)
OR (randomly assigned)
Data Lesson (Absorption Spectra)
5 days
3 days
Post-Test
7 weeks
Final Exam (sketch only)
3 months
Retention Test

Coding Concept Sketches (39 statements)



Coding 3 Short Answers (36 statements)

because of any descriptive elements of the picture (e.g. double bond, multiple atoms, atoms of different sizes)

IR= 97.3%

Written answer 4.

Here is the chemical structure of an atmospheric gas. Do you think this is likely to be a greenhouse gas or not? Explain your reasoning.

Yes; the bond structure appears as though it is able to vibrate. Absorption of radiation requires that the bonds are able to vibrate to store kinetic energy. CO_2, a greenhouse gas, has a similar structure.

because it is (or looks like) chemical formula of a GHG (any example).

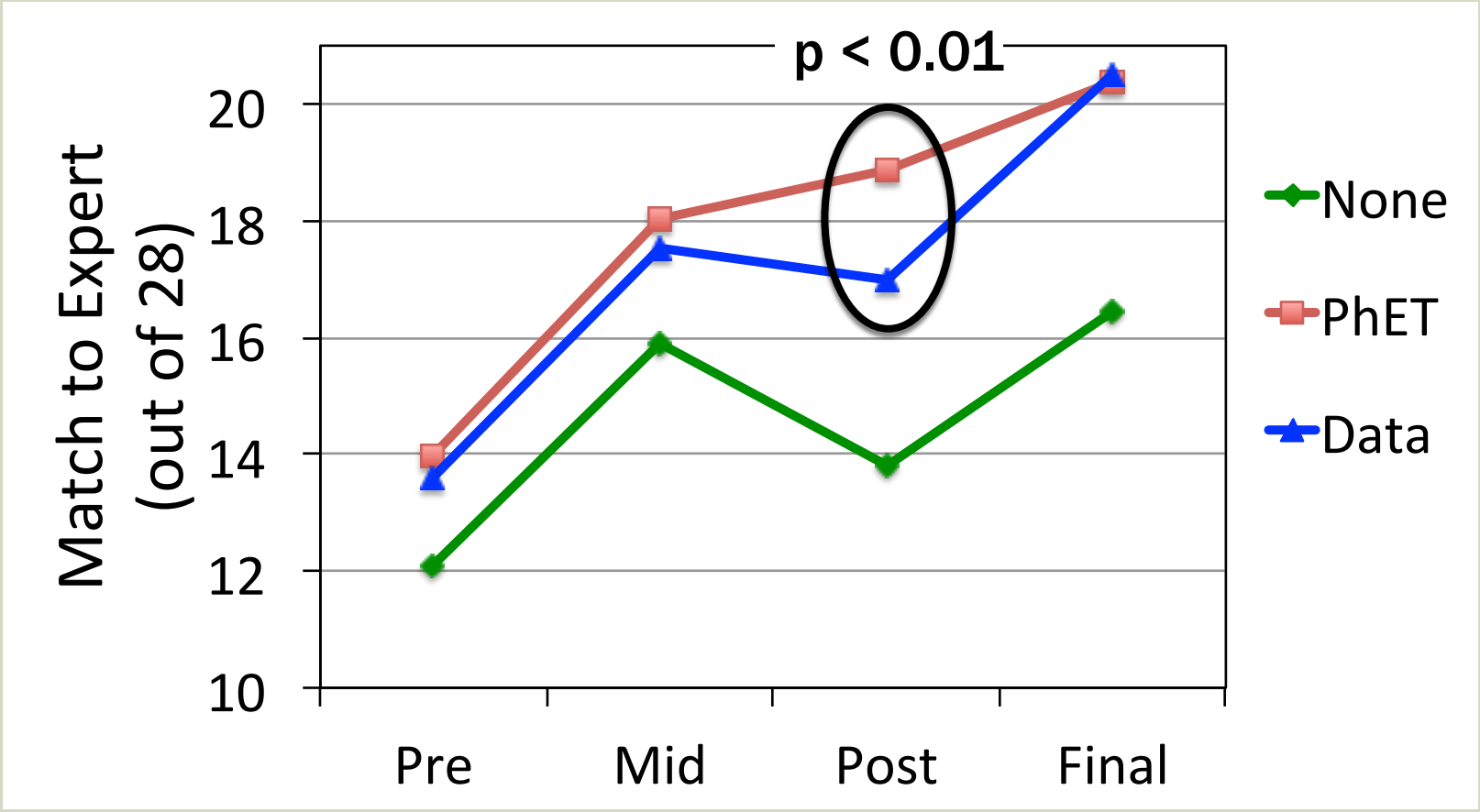
EFFECTIVENESS OF LESSONS

- PHET – Lesson
  - visual exploration
  - “playing around” in groups of 3 students
  - clicker questions for check in
  - very visual about the absorption – reemission

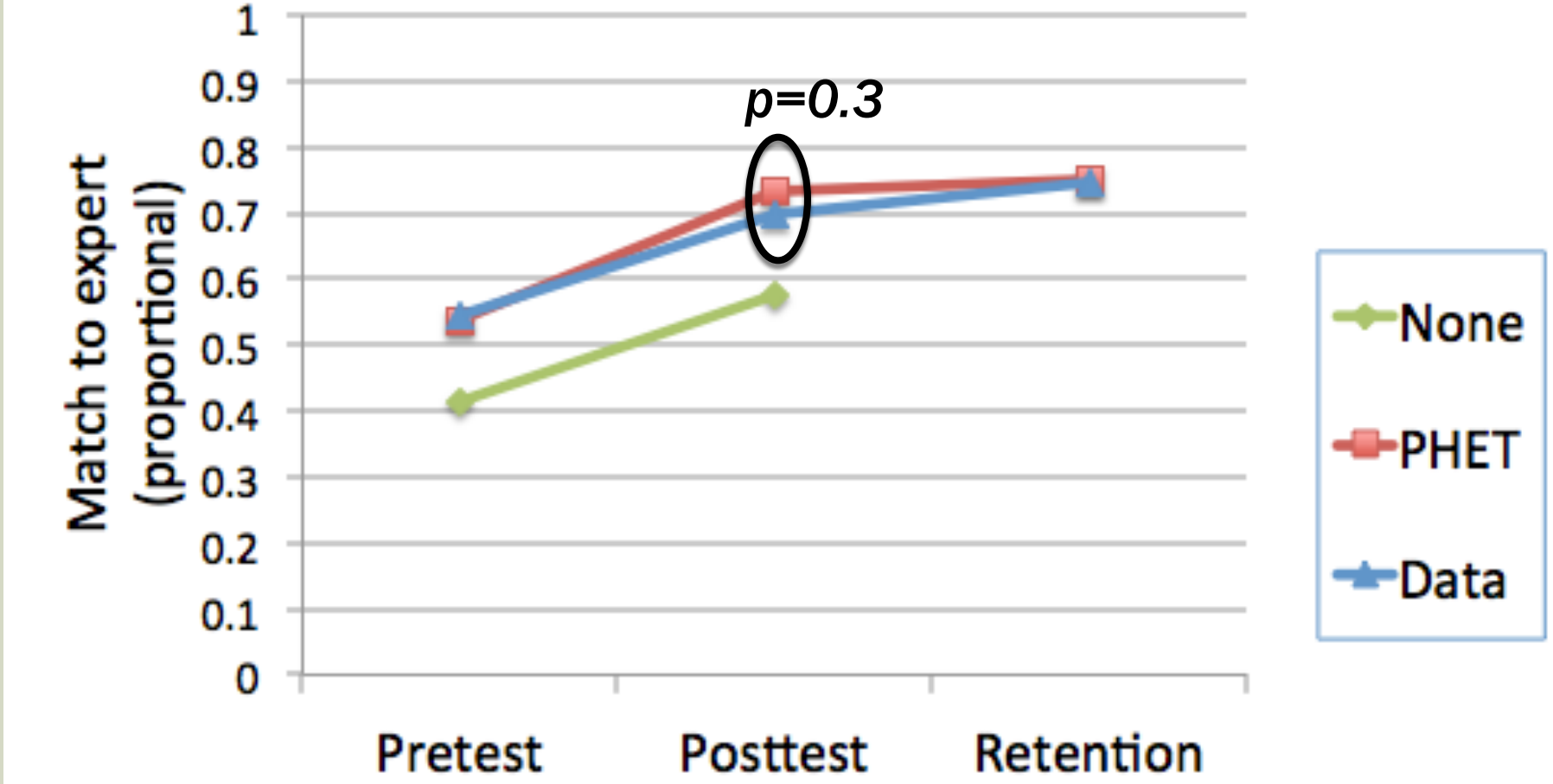
- Data – Lesson
  - graphing exercise and graph interpretation
  - group work on worksheet
  - clicker questions for check in
  - very explicit about differences in absorption spectra of different gases

Concept Sketch Scores Over Time

(average scores)



MULTIPLE CHOICE QUESTION SCORE OVER TIME

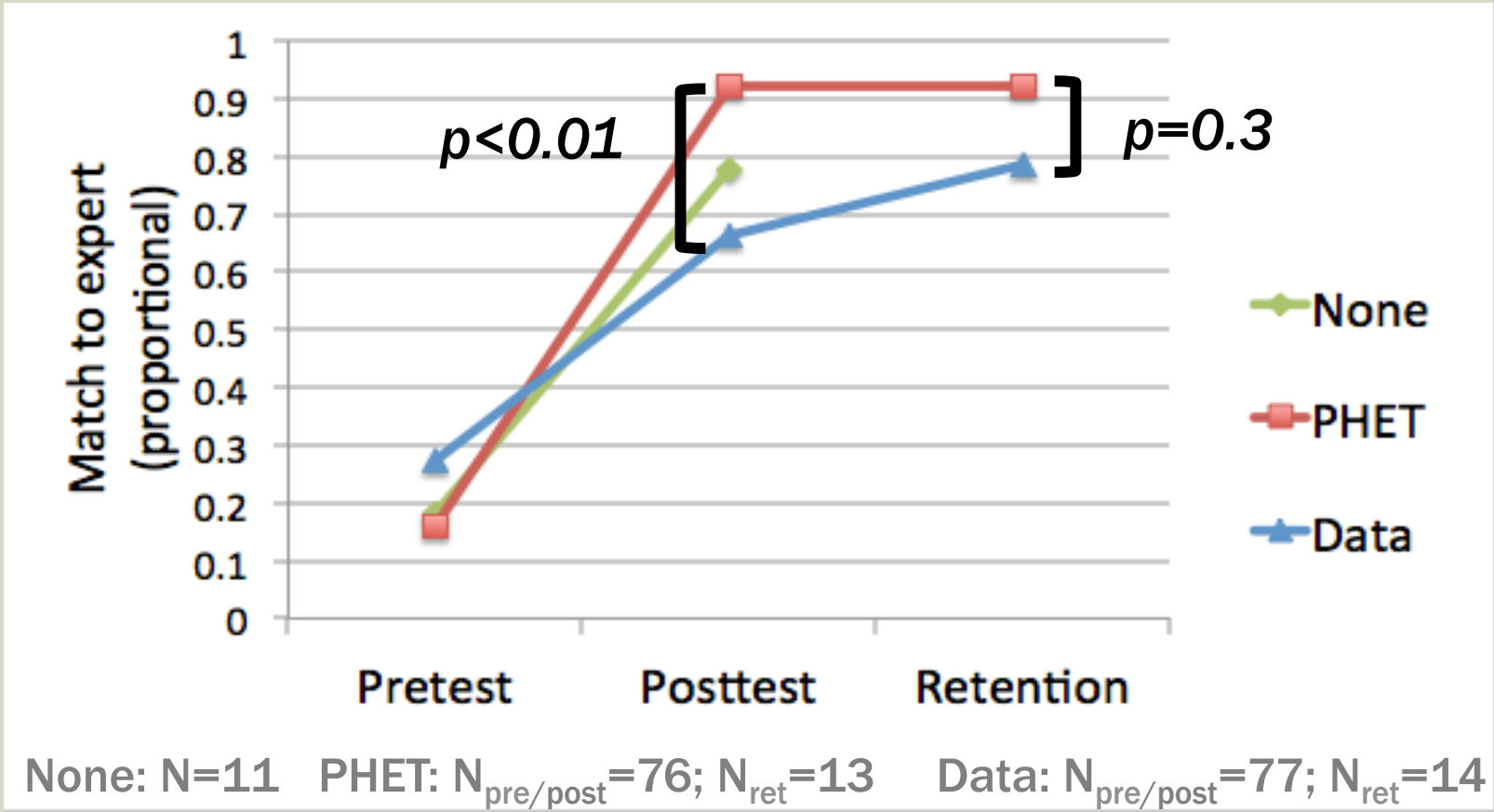


None: N=11 PHET: $N_{pre/post}$=76; N_{ret}=13 Data: $N_{pre/post}$=77; N_{ret}=14

IF A GREENHOUSE GAS MOLECULE ABSORBS, THEN EMITS, A PHOTON, WHERE WILL THE PHOTON MOST LIKELY GO?

It'll most likely _____.

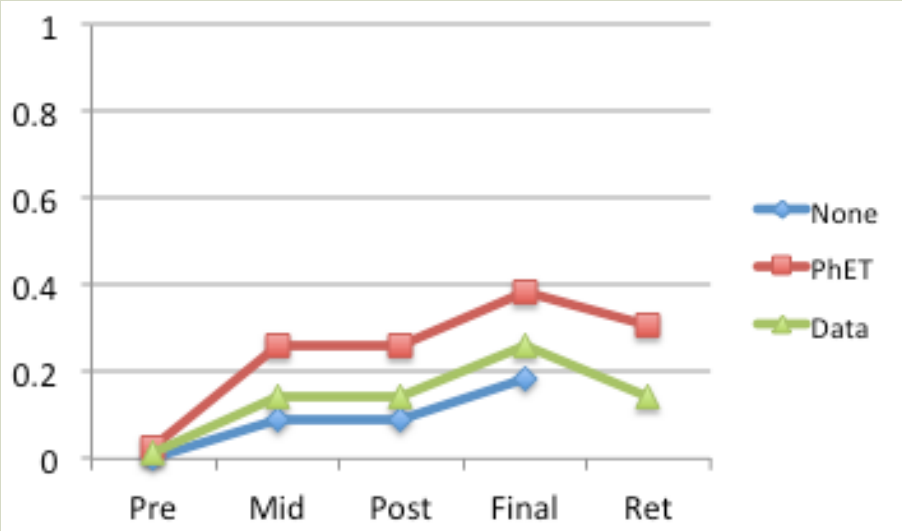
A. get emitted upward away from Earth's surface
B. get emitted back towards Earth's surface at the same angle that it hit the molecule.
C. get emitted at an unknown angle, but back toward Earth's surface
D. get emitted at an angle parallel to Earth's surface
E. get emitted in an angle that is impossible to predict



None: N=11 PHET: $N_{pre/post}$=76; N_{ret}=13 Data: $N_{pre/post}$=77; N_{ret}=14

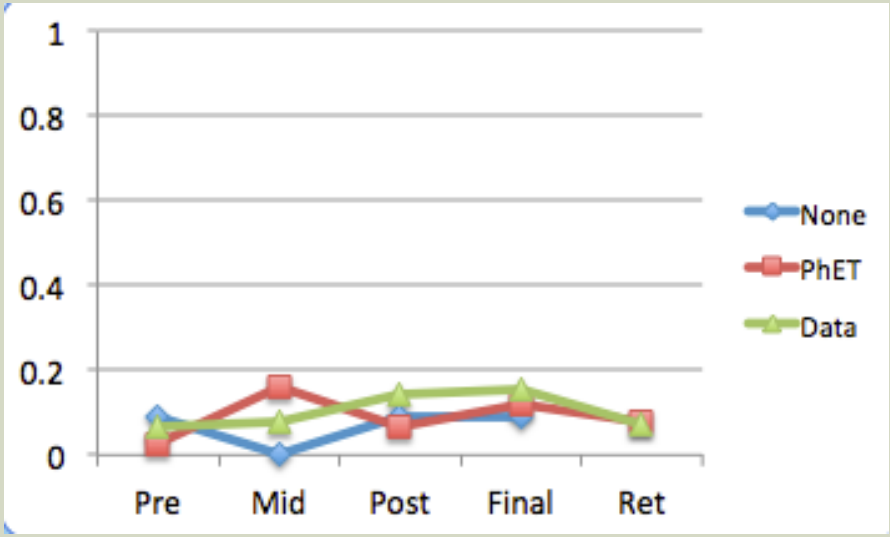
DISCRIMINATING ITEMS ON CONCEPT SKETCH???

GHG wiggle and/or vibrate when interacting with radiation.



PHET lesson should have made a difference….

Specific atmospheric gases interact with specific wavelengths of radiation

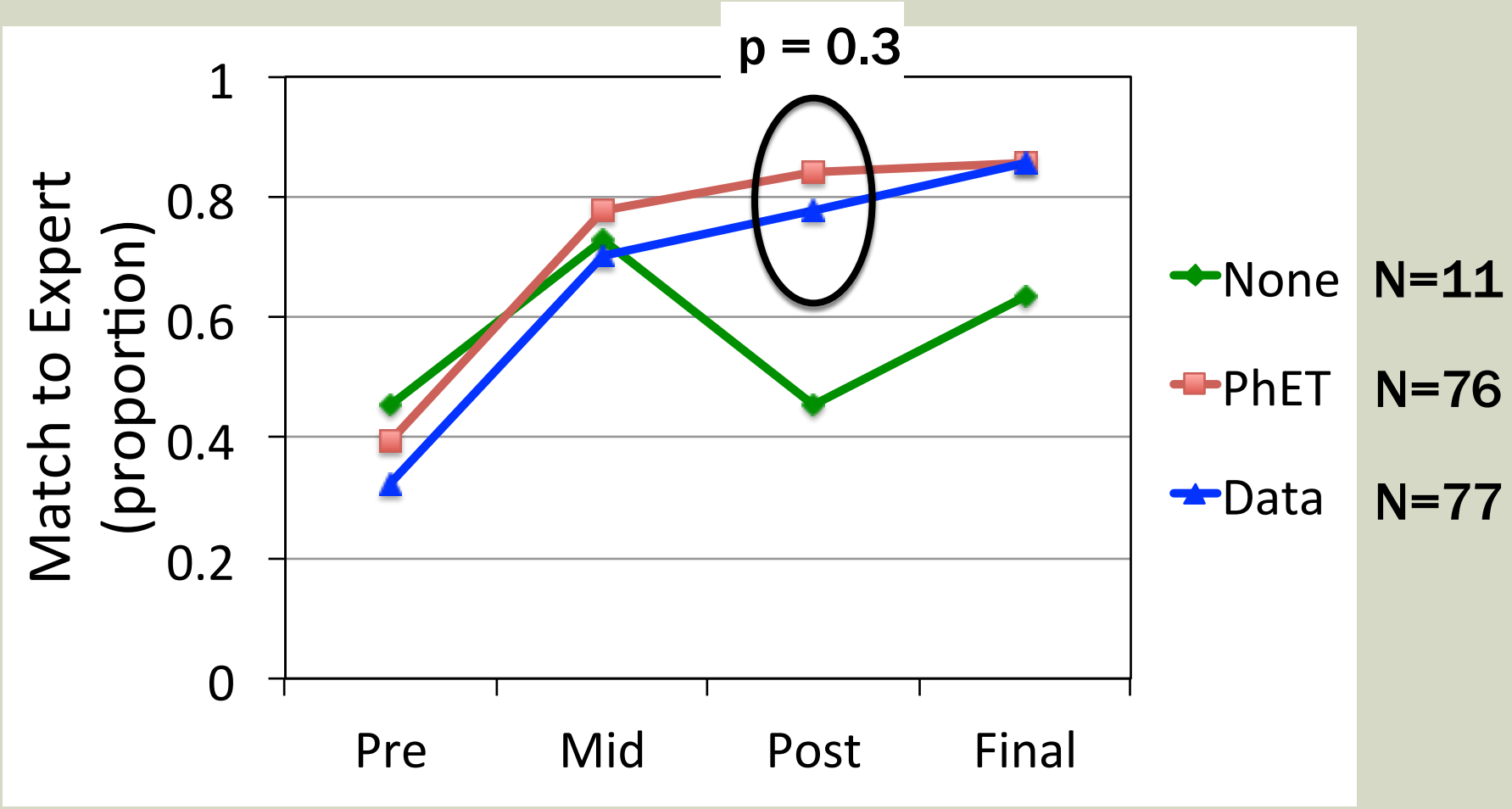


Data lesson should have made a difference….

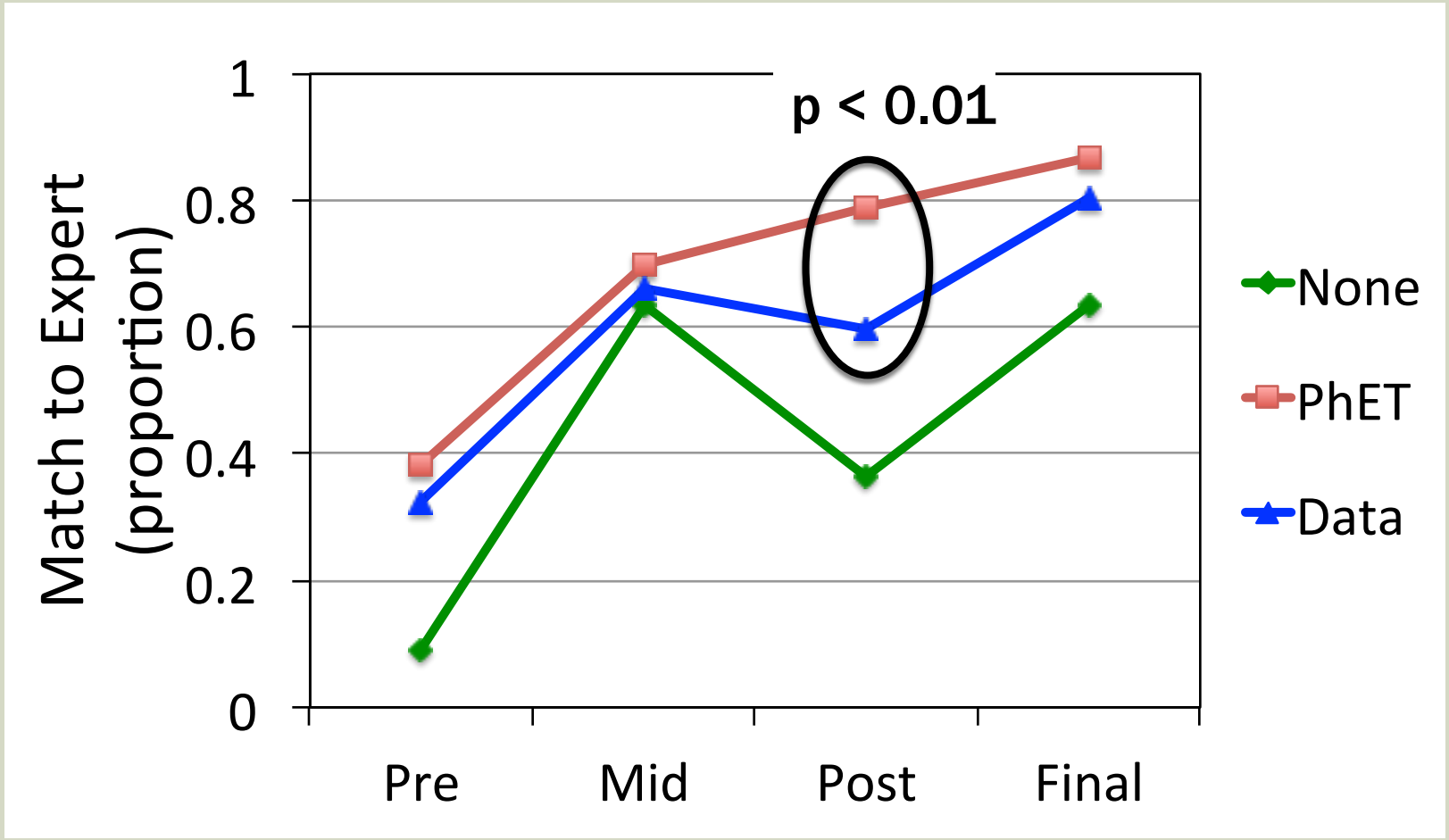
STUDENTS' MENTAL MODELS

- What are the key concepts in understanding of greenhouse effect? And which ones stick over time?
- What are key factors that build student understanding of the greenhouse effect?
- Which intervention is more effective in teaching key concepts?
- Ultimate goal: Informing instruction about the key facts and which ones are retained over time.

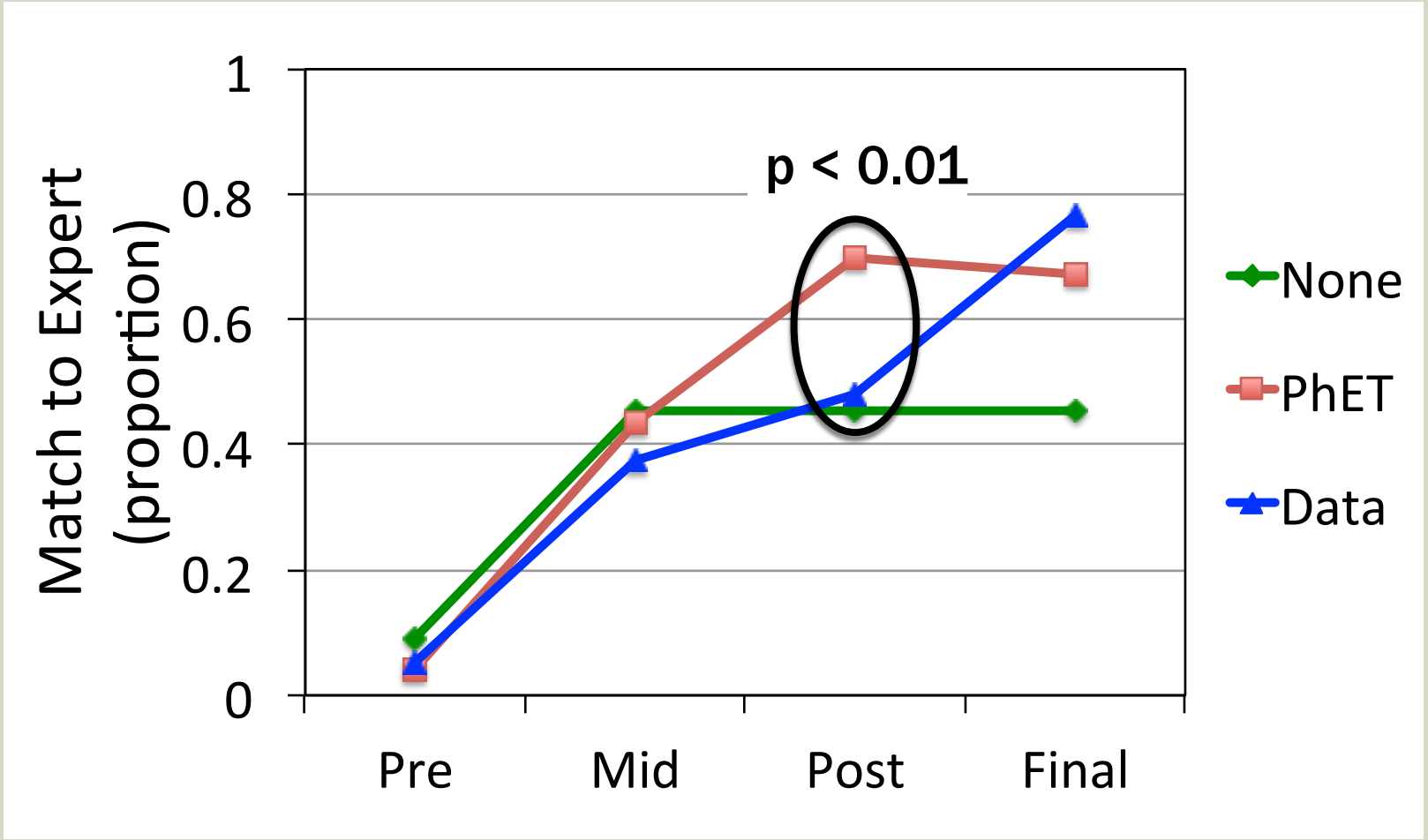
GHGs absorb radiation
(average scores)



GHGs emit radiation
(average scores)



GHGs emit in any direction
(average scores)

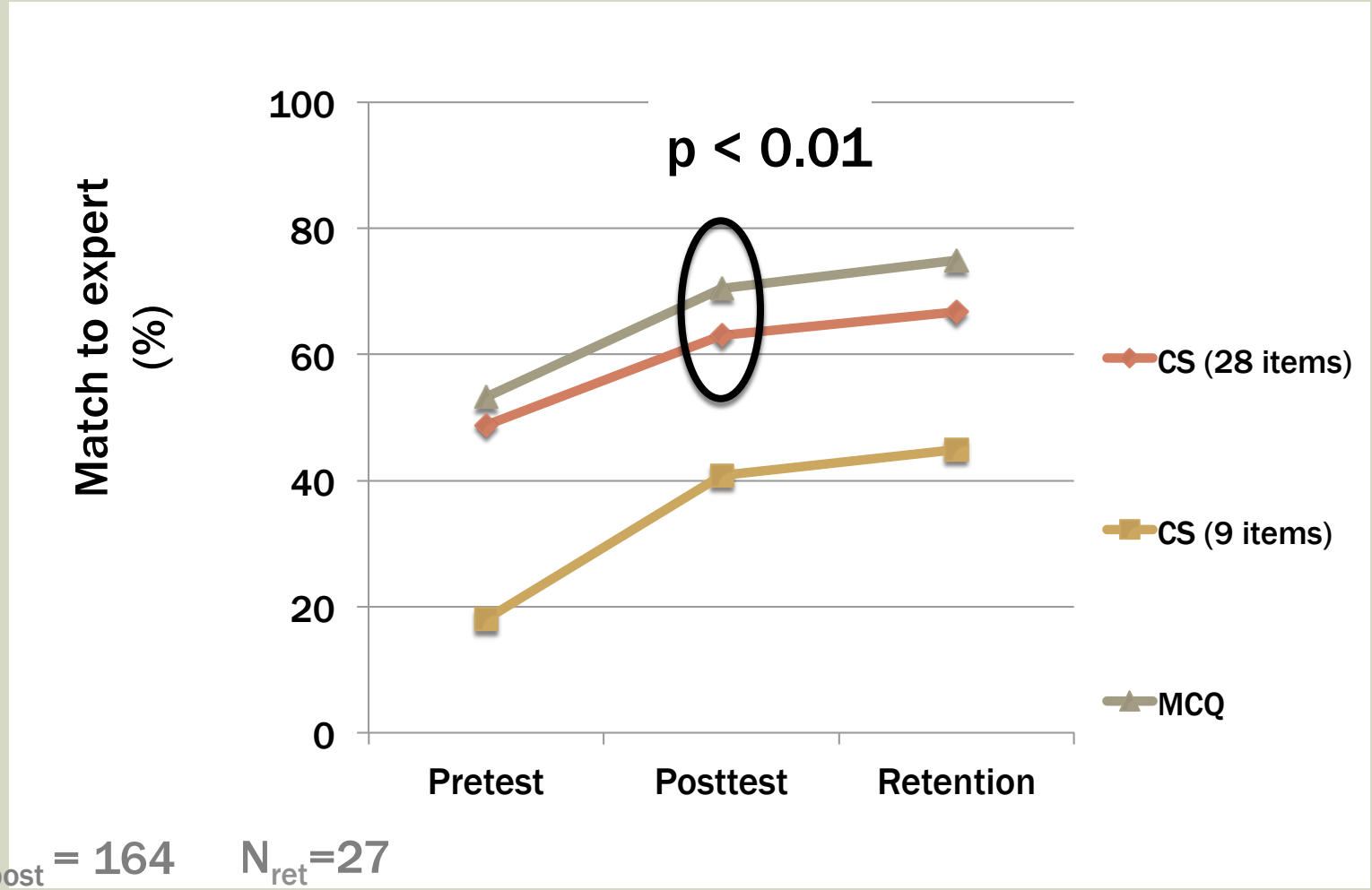


COMPARISON
MULTIPLE CHOICE – CONCEPT SKETCH

- Difference in assessment of MCQ and concept sketch as higher order cognitive reflection of understanding

- Do students get concept right when they are prompted (MCQ) or is the concept part of their mental model (CS)?

MULTIPLE CHOICE – CONCEPT SKETCH SCORES

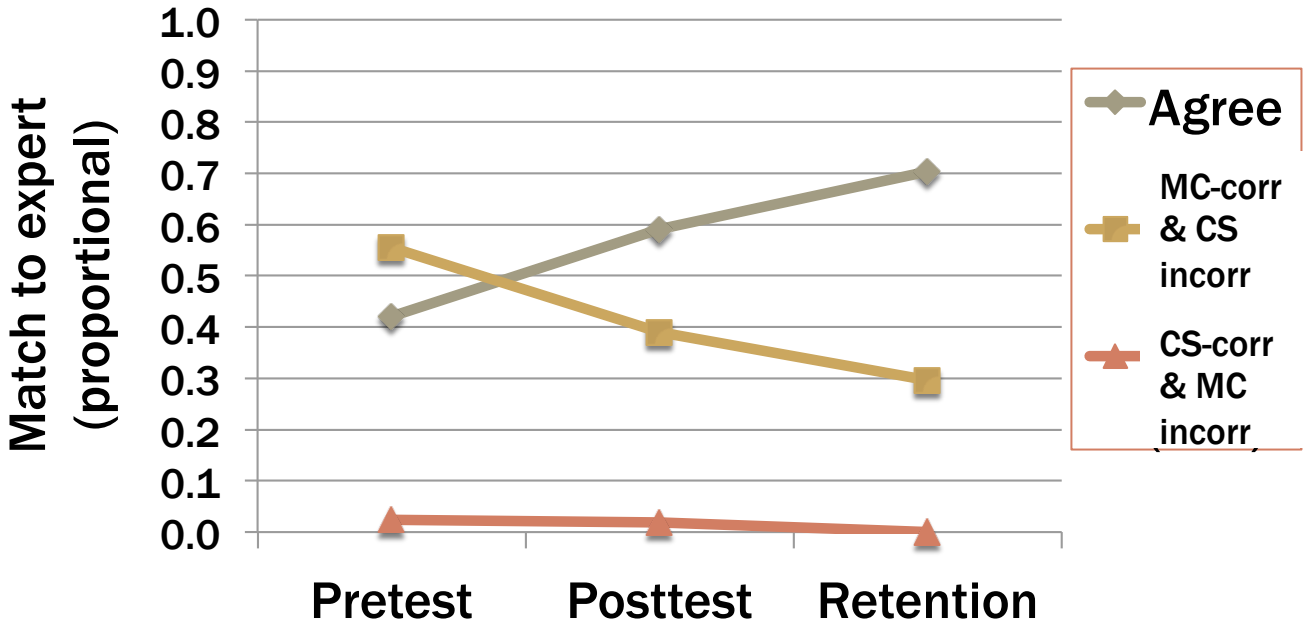


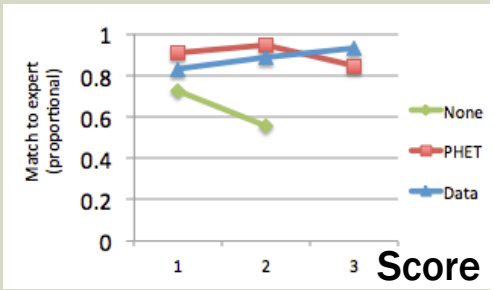
$N_{pre/post}$ = 164 N_{ret}=27

WAVELENGTH AT WHICH EARTH EMITS

1. **During the nighttime, Earth's surface mainly gives off (radiates) which form of energy?**
   - A. radio waves
   - B. ultraviolet radiation
   - C. visible radiation
   - D. infrared radiation
   - E. Earth's surface does not give off energy during the nighttime

CS-Code: Earth's surface gives off/ emits LW radiation (include infrared).

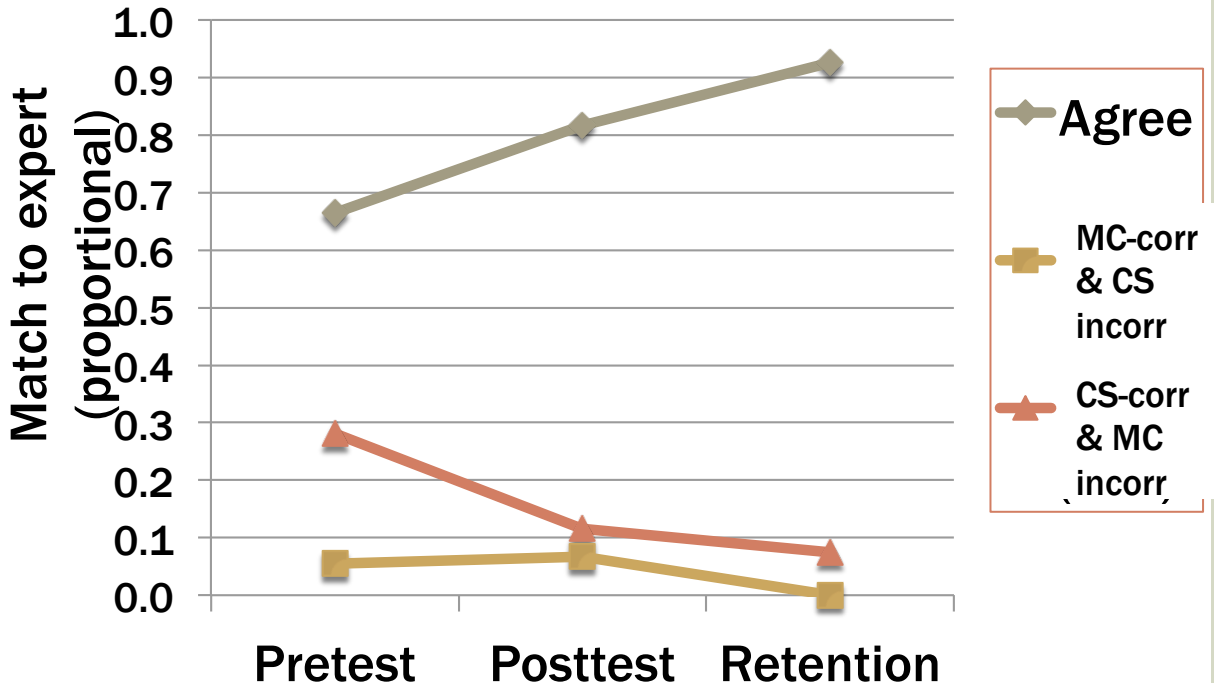




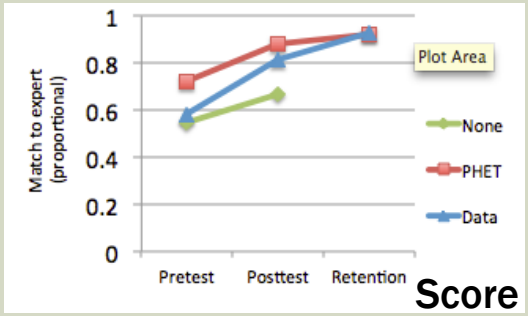
$N_{pre/post}$=164;
$N_{retention}$= 27

ABSORPTION OF SOLAR RADIATION

5. **The reason that greenhouse gases cause warming is that they absorb energy coming in from the Sun.**
   A. I am sure this is right
   B. I think this is right
   C. I don't know about this
   D. I think this is wrong
   E. I am sure this is wrong



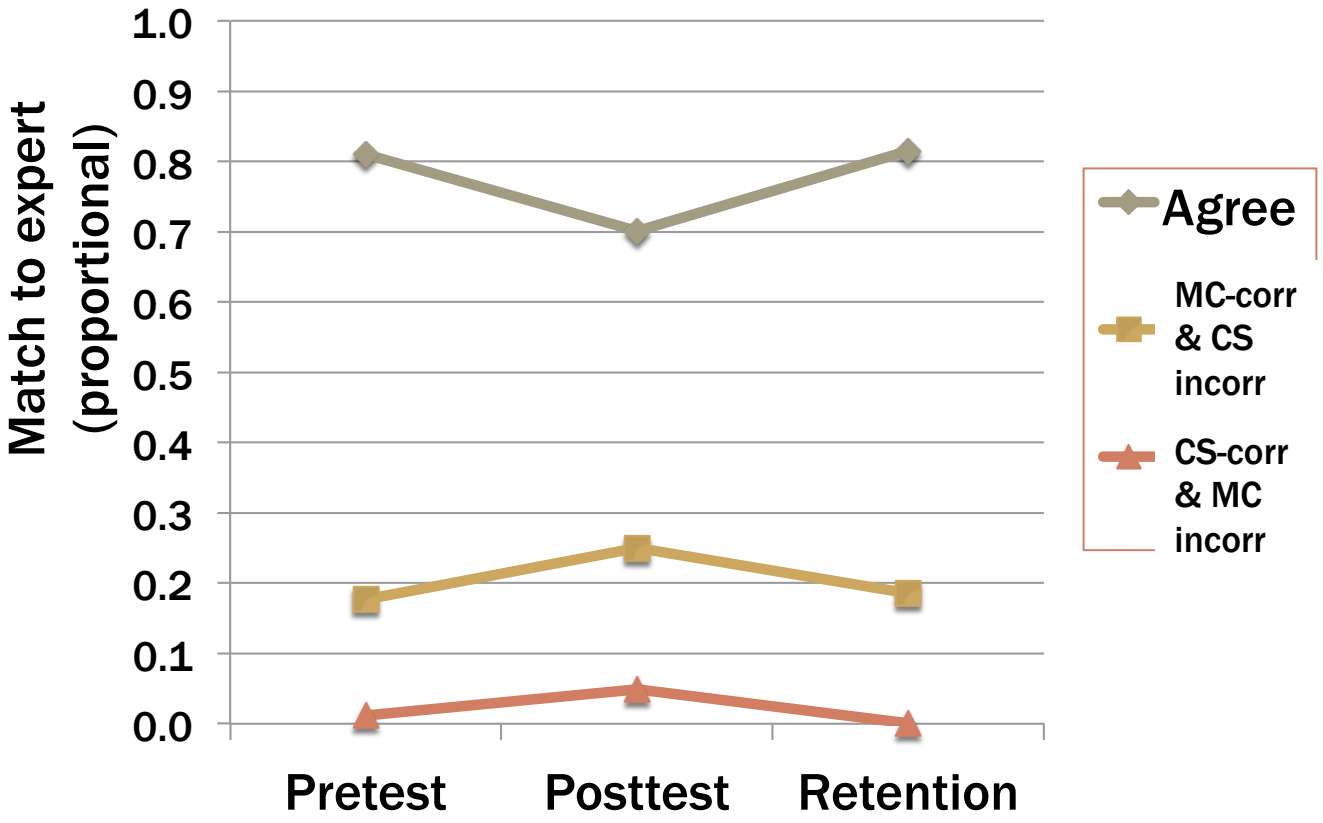
CS-Code: Incoming radiation travels through the atmosphere – interaction with GHG explicitly described or shown (merely an arrow is not enough).



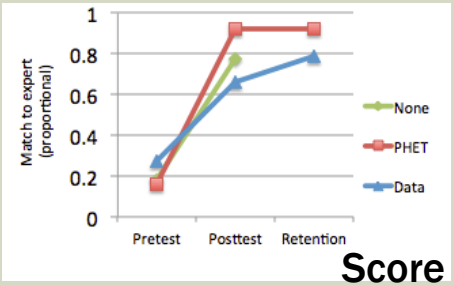
$N_{pre/post}$=164;
$N_{retention}$= 27

DIRECTION OF PHOTON EMISSION

7. **If a greenhouse gas molecule absorbs, then emits, a photon, where will the photon most likely go?**
   It'll most likely _____.
   A. get emitted upward away from Earth's surface
   B. get emitted back towards Earth's surface at the same angle that it hit the molecule.
   C. get emitted at an unknown angle, but back toward Earth's surface
   D. get emitted at an angle parallel to Earth's surface
   E. get emitted in an angle that is impossible to predict



CS-Code: Energy from GHG goes in any direction. Arrow or text=1. Could be via reflection or emission. Direction is the key idea here.



$N_{pre/post}$=164;
$N_{retention}$= 27

Next steps

- Groundtruth “expert” mental model with experts and instructors who teach the greenhouse effect.

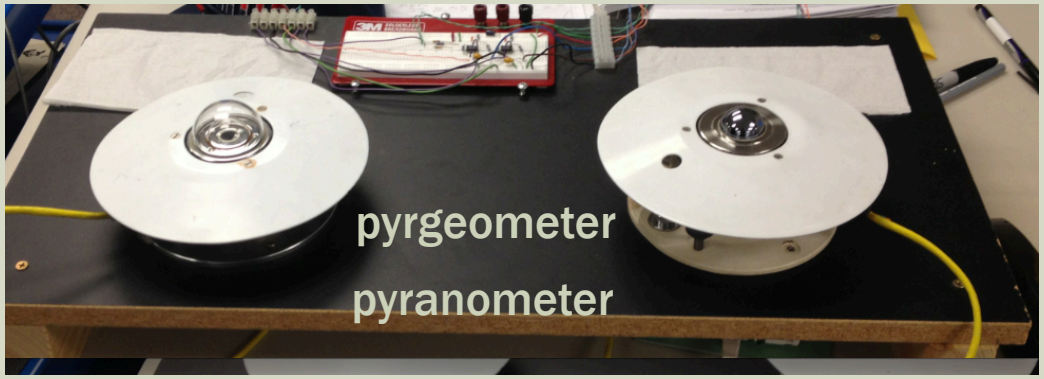
- Determine which concepts are key for understanding
  > Identify conceptual targets for future instruction

- Compare multiple choice to concept sketching

- Develop hands-on lesson around greenhouse effect

DEVELOPING HANDS-ON ACTIVITY

W/ SCOTT KITTELMAN



Focus on infrared radiation vs. solar radiation and their interactions with matter

IR Camera