These two sets of slides are from two conference presentations

Harris, Sara and Anne Gold, 2013. *University students’ mental models of the greenhouse effect: a comparison of two learning activities in moving students toward expert thinking*, Geological Society of America Meeting, Denver.

University Students’ Mental Models of the Greenhouse Effect: A Comparison of Two Learning Activities in Moving Students Toward Expert Thinking

Sara Harris and Anne Gold
The setting & participants

- Large research university
- 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.
1. PhET Interactive Simulation (Greenhouse effect)

2. “Data” lesson (Absorption Spectra)

- Radiation emitted by a blackbody at the average temperature of Earth’s surface
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

Questions developed and modified from existing questions. Validated with student interviews and expert review.

*Johnson and Reynolds, 2005
On a Friday...

- **Pre-Test**
  - 3 days

- **Common Lesson**
  - Same day

- **“Mid”-Test (sketch only)**
  - 2 days
  - OR (randomly assigned)
    - 5 days

- **Simulation Lesson (PhET)**
  - 5 days

- **Data Lesson (Absorption Spectra)**
  - 4 days

- **Post-Test**
  - 3 days

- **Final Exam (sketch only)**
  - 7 weeks

- **Retention Test**
  - 3 months
Earth’s surface emits longwave radiation

Energy from GHGs goes in any direction

GHGs absorb radiation

GHGs re-emit radiation

The long wave IR is absorbed by GHGs like O_3, CH_4, H_2O, CO_2, and then reemitted at random directions.

The absorbed energy is reemitted by the Earth’s as long-wave infrared radiation.

When the IR is absorbed by GHGs, e.g., CO_2, then CO_2 reemits the absorbed energy in random directions. Some of it goes back to the Earth. This is how it needs to maintain equilibrium.

The Earth’s surface emits longwave radiation.
Concept Sketch Scores Over Time
(average scores)

Match to Expert (out of 28)

- None, n=11
- PhET, n=76
- Data, n=77

p < 0.01
1 Item: GHGs absorb radiation
(average scores)

p = 0.3

Match to Expert (proportion)

None n=11
PhET n=76
Data n=77

Pre Mid Post Final
1 Item: GHGs emit radiation
(average scores)

- Pre
- Mid
- Post
- Final

Match to Expert (proportion)

p < 0.01

- None n=11
- PhET n=76
- Data n=77
1 Item: GHGs emit in any direction
(average scores)

Match to Expert (proportion)

Pre | Mid | Post | Final
--- | --- | --- | ---

p < 0.01

None n=11
PhET n=76
Data n=77
Next steps

• Statistically generate student mental models
• Groundtruth “expert” mental model with experts and instructors who teach the greenhouse effect.
• Evaluate progression of learning, including retention
• Compare multiple choice to concept sketching
• Identify conceptual targets for future instruction
Student Mental Models of the Greenhouse Effect: Retention Months After Interventions

Sara Harris and Anne Gold
The setting & participants

• Large research university
• Intro course: “Atmospheres and Oceans”
• Open to all: wide diversity of backgrounds
• Enrollment = 248 (average course grade=75%)
• 164 students wrote 4 assessments during term (average course grade = 81%)
• 27 students wrote an additional “retention” assessment (average course grade = 86%)
1 Common lesson + 2 Contrasting Lessons

1. PhET Interactive Simulation (Greenhouse effect)

2. “Data” lesson (Absorption Spectra)
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

Questions developed and modified from existing questions. Validated with student interviews and expert review.

*Johnson and Reynolds, 2005
On a Friday...

Pre-Test

Common Lesson

“Mid”-Test (sketch only)

Simulation Lesson (PhET)

OR

Data Lesson (Absorption Spectra)

(posted
randomly
assigned)

Post-Test

Final Exam (sketch only)

Retention Test
Coding Concept Sketches (39 statements)

1. The long wave IR is absorbed by GHGs like O\textsubscript{3}, CH\textsubscript{4}, H\textsubscript{2}O, CO\textsubscript{2} and then re-emitted at random directions.

2. The absorbed energy is re-emitted by the Earth's as long-wave infrared radiation.

3. Energy from GHGs goes in any direction.

Earth’s surface emits longwave radiation.

GHGs absorb radiation

GHGs re-emit radiation

when the IR is absorbed by GHGs, e.g. CO\textsubscript{2}, then CO\textsubscript{2} re-emits the absorbed energy in random directions. Some of it goes back to the Earth. This is how it needs to maintain equilibrium.
Concept Sketch Scores Over Time
(average scores)

2 groups have statistically the same average on each of the first 4 tests
**Concept Sketch Scores Over Time**
(average scores, retention group only)

2 groups have statistically the same average on each of the 5 tests
Learning Gain
Between Pre- and Final
Average Gain ~0.45
Learning Gain
Between Pre- and Final
Average Gain ~0.45
Learning Gain/Loss Between Final and Retention

Average Loss ~0.3

6 students scored higher on Retention than on Final

Score on Pre-test (of 28)
Learning Gain/Loss Between Pre- and Retention

Average Gain ~0.3

Low performers: No Change

A few high performers: Large Losses

Pre-Final Learning Gain vs. Course Grade

PhET
Data
Key Statements most strongly Learned (after Pre-test) & Retained

Learned & Lost ↔ Learned & Retained

- Energy from GHGs goes in any direction
- Earth’s surface absorbs incoming radiation
- GHGs absorb radiation
- GHGs re-emit radiation
- GHGs re-emit longwave or infrared radiation

# Students (of 27)
Key Statements most strongly
Learned (after Pre-test) & Lost

Learned & Lost \(\iff\) Learned & Retained

- **Incoming radiation is shortwave or visible**
- **The radiation GHGs absorb is longwave or infrared**
- **GHGs wiggle or vibrate when interacting with radiation**
- **Specific gases interact with specific wavelengths of radiation**

# Students (of 27)
Earth warms up because of incoming radiation

Some energy leaves one GHG molecule, then interacts w/another

Specific gases interact with specific wavelengths of radiation

GHGs wiggle or vibrate when interacting with radiation
Implications for Instruction?

• 3-4 months after the course ended, students retained about 2/3 of their ideas acquired after the pre-test.
• No large difference between PhET and Data students
• “Stickier” components learned and retained:
  • GHGs absorb & re-emit radiation (in random directions)
• “Slippery” components learned and lost:
  • Specific gases interact w/specific wavelengths
  • Gases wiggle and vibrate
• Lessons may not be reaching low performers (but n is small)

Questions:

• How good is good enough?
• What statements/concepts do we really care about?
• Are there “threshold” concepts, i.e. if they learn and retain ___ they don’t lose as much?