Student Mental Models of the Greenhouse Effect: Retention Months After Interventions

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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...

1. **Pre-Test**
   - 3 days

2. **Common Lesson**
   - Same day

3. **“Mid”-Test (sketch only)**
   - 4 days
   - 2 days

   - Simulation Lesson (PhET)
     - 5 days
   - OR
     - 3 days
     - (randomly assigned)
     - Data Lesson (Absorption Spectra)

4. **Post-Test**
   - 7 weeks

5. **Final Exam (sketch only)**
   - 7 weeks
   - 3 months

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

GHGs absorb radiation

The longwave IR is absorbed by GHGs like O₃, CH₄, H₂O, CO₂ and then re-emitted at random directions.

GHGs re-emit radiation

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

Energy from GHGs goes in any direction

when the IR is absorbed by GHGs, eq CO₂, then CO₂ re-emits the absorbed energy in random directions. Some of it goes back to the earth. This is how it needs to maintain equilibrium.
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

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

Learned & Lost ↔ Learned & Retained

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

Learned & Lost $\leftrightarrow$ 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)
Key Statements Not Learned

- Earth warms up because of incoming radiation
- Some energy leaves one GHG molecule, then interacts with another
- Specific gases interact with specific wavelengths of radiation
- GHGs wiggle or vibrate when interacting with radiation

PhET = 9; Data = 9
PhET = 5; Data = 10
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?