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)
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 (randomly assigned)

Data Lesson (Absorption Spectra)

Post-Test

Final Exam (sketch only)

Retention Test
Earth's surface emits longwave radiation. GHGs absorb radiation. GHGs re-emit radiation.

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

The absorbed energy is re-emitted by the Earth's as long-wave infrared radiation. When the IR is absorbed by GHGs, like 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.

Energy from GHGs goes in any direction.
Concept Sketch Scores Over Time
(average scores)

Match to Expert (out of 28)

Pre  Mid  Post  Final

n=11  n=76  n=77

p < 0.01

None  PhET  Data

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Pre  Mid  Post  Final

n=11  n=76  n=77

p < 0.01

None  PhET  Data

Match to Expert (out of 28)
1 Item: GHGs absorb radiation
(average scores)

\[ p = 0.3 \]

- **Pre**
- **Mid**
- **Post**
- **Final**

- **None** n=11
- **PhET** n=76
- **Data** n=77
1 Item: GHGs emit radiation (average scores)

Match to Expert (proportion)

Pre | Mid | Post | Final

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

p < 0.01
1 Item: GHGs emit in any direction (average scores)

![Graph showing match to expert proportion over time with p < 0.01 significance]

- **Pre**: GHGs emit in any direction (average scores)
- **Mid**: GHGs emit in any direction (average scores)
- **Post**: GHGs emit in any direction (average scores)
- **Final**: GHGs emit in any direction (average scores)

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

*p < 0.01*
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