Climate Change Education: Validation of Assessment Questions and Retention of Concepts

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Abstract

Misconceptions about climate science are widespread amongst university students. Assessment questions to measure student knowledge were developed, validated using student interviews, and administered in pre-tests and post-tests to undergraduate students enrolled in a climate science course. Student interviews revealed common climate science misconceptions held by university science students. Pre-test, post-test and one-year retention tests revealed significant knowledge gains and during the course, and retention of concepts one year later. Results from interviews and assessment administration were used to make recommendations for assessment questions and teaching strategies.

Study Goals

The purpose of this study is to inform teaching and assessments of key climate science concepts, targeting common student misconceptions about climate science. This study focuses on four key parts of the climate system:

1. Climate feedback loops affecting global temperature
2. System dynamics of carbon stocks and flows to and from the atmosphere
3. The size of reservoirs and the magnitude of flows of carbon to and from the atmosphere
4. The distribution of greenhouse gases in the atmosphere

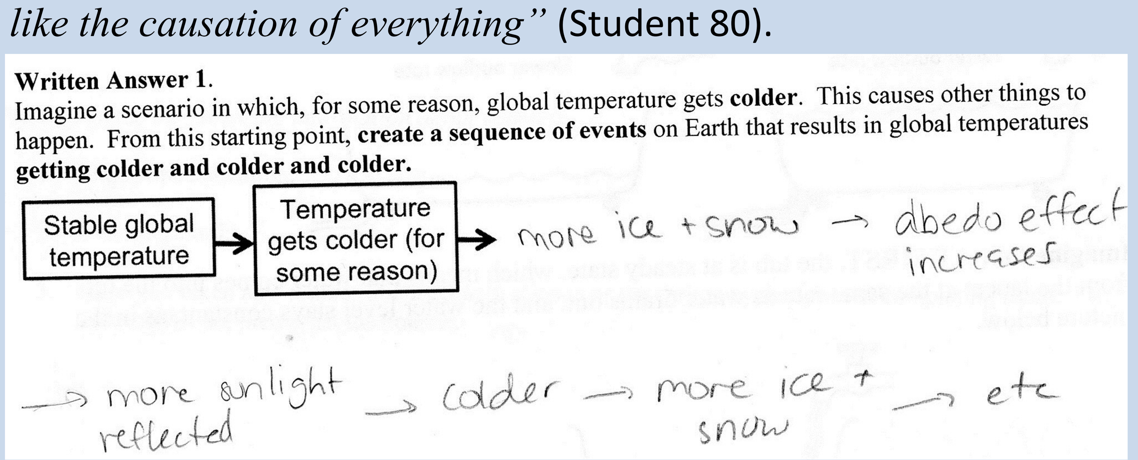
Methods

Assessment questions about four key climate science concepts were developed using learning goals or common misconceptions, and were validated with 16 student interviews. Assessment questions were administered to undergraduate students in pre– and post-tests in the climate science course EOSC 340. Knowledge gains were measured by comparing pre- and post-tests scores. Knowledge retention was measured by administering assessment questions to 23 students, one year after they completed EOSC 340.

Climate Feedback Questions

Learning Goals
Predict what happens to stocks and flows when a system is perturbed
Generate feedback loops by connecting a logical set of processes

"I want to say that for it to get warmer again, some like random thing just has to happen, for it to kind of like, recycle back to the stable temperature. I'm just not sure how to link that into, like the causation of everything" (Student 80).



Code	
All sequential steps are actually related	+1
Loop leads back to decreasing T	+1
All steps involve internally consistent time-scales	+1
an incorrect statement	0
Total	3

Figure 1. Coded student answer to the amplifying feedback question. Scores ranged from –1 to 3, and each student received a summed score for the two questions between –2 and 6

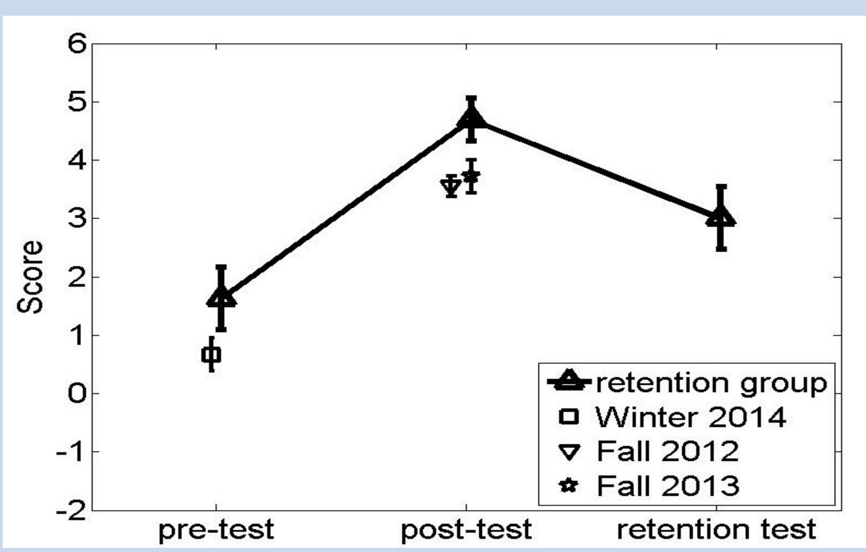
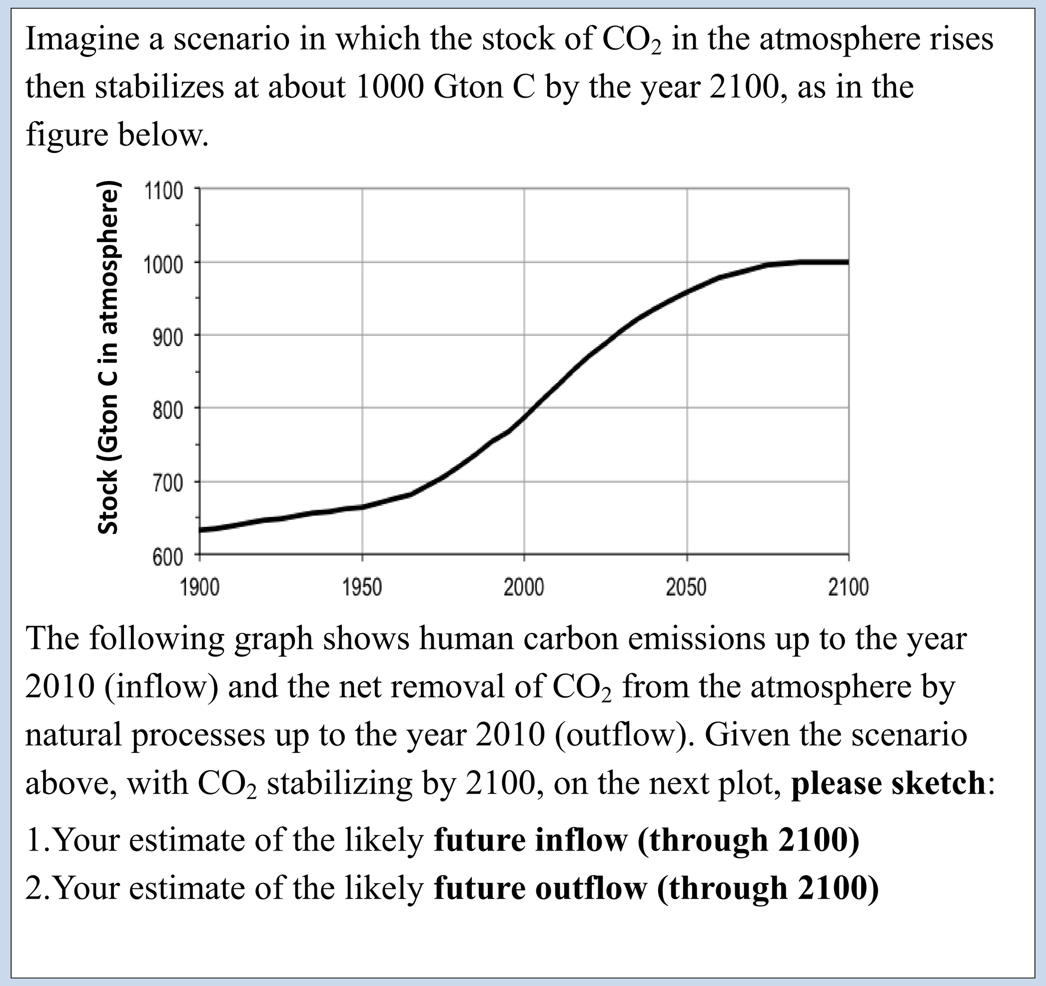


Figure 2. Pre-test, post-test and retention test scores on the feedback questions. Pre-post knowledge gain is large with an effect size of 1.5. Post-retention knowledge loss is smaller than knowledge gain, with and effect size of 0.66, demonstrating retention of knowledge one year after the completing the course.

CO_2 Trajectories Question

Misconceptions
A stock can stabilize even if inflows and outflows are unequal (violation of conservation of mass) (Sterman and Booth Sweeney 2002).
Trajectories of flows to and from a stock are likely proportional to the trajectory of the stock (Sterman and Booth Sweeney 2002).

"Logically, I don't think it makes sense for an outflow to be higher than an inflow" (Student 80).



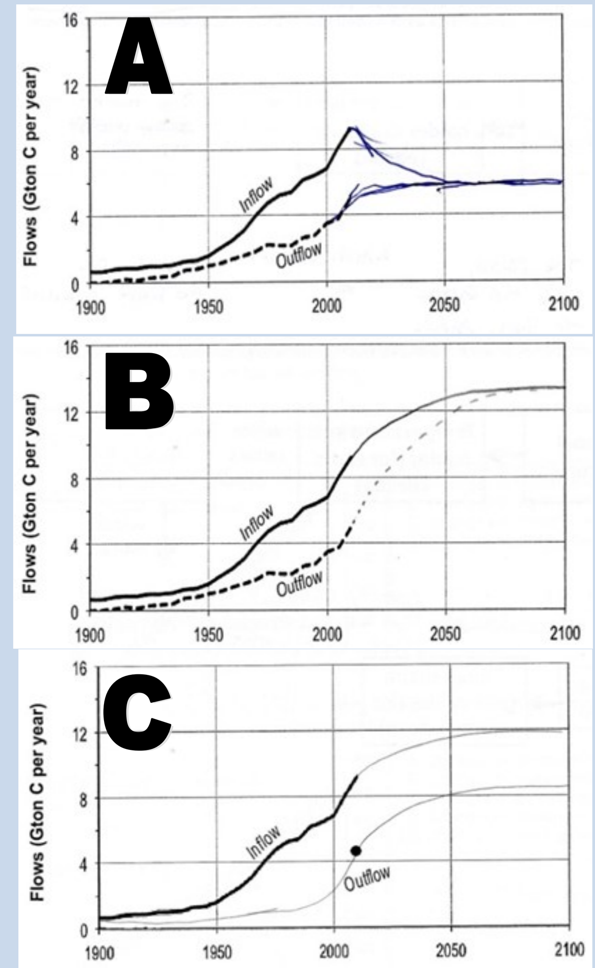


Figure 3. The CO_2 trajectory question and examples of student answers. **A** shows the correct answer, where inflow=outflow at the end, and outflow doesn't increase after 2010. B shows correct mass balance, but outflow increases unrealistically after 2010, and C shows incorrect mass balance, where inflow and outflow don't meet when stock is stabilized. Few students in pre-or post-tests drew A. More students drew B than drew C in the post-tests and retention tests than in the pre-test, demonstrating knowledge gain about climate system dynamics.

Carbon Cycle Rankings

Misconceptions
The magnitude of flows between reservoirs is proportional to the size of the reservoirs (interviews)
Concentration in a reservoir and reservoir size are proportional (interviews)
Familiarity with a reservoir or flow and its size are proportional (interviews)
When plants respire, the carbon goes into the soil, not the air (Ebert-May et al., 2003)
Human greenhouse gases inputs must be very large to affect climate (Gowda et al., 1997)

"I'm not familiar with weathering rocks, so I'm going to put that as least" (student 84).

"So the largest flow would mean, I guess the largest flow would come from the biggest reservoirs, and oceans are also pretty big." (Student 81)

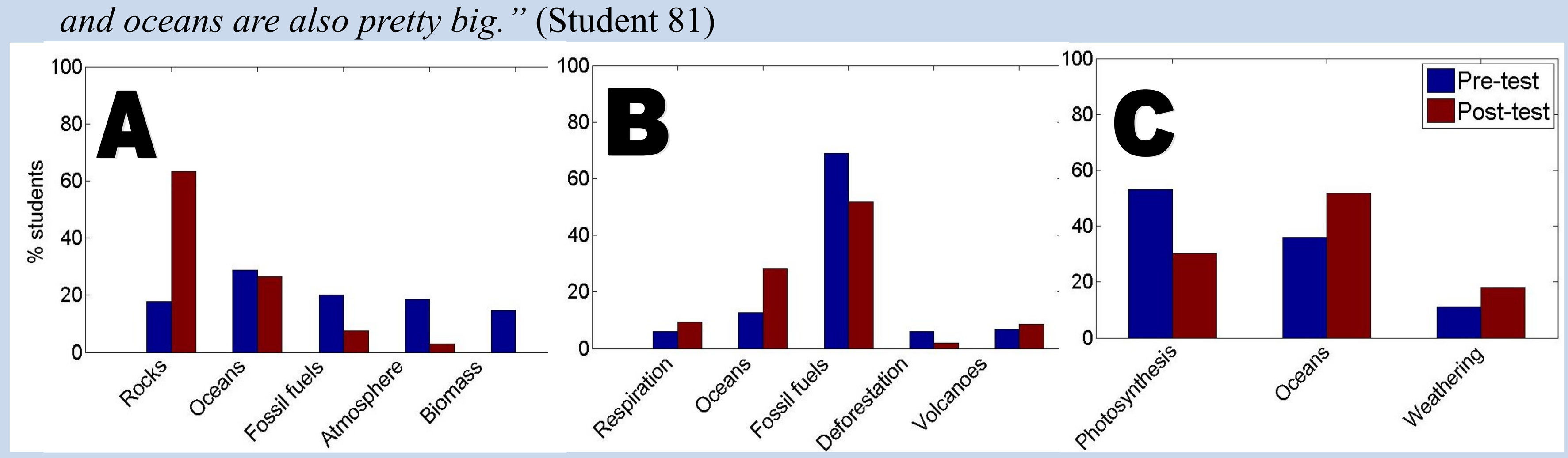


Figure 4. Pre-test and post-test answers for: largest reservoir (**A**), largest carbon inflow to the atmosphere (**B**), and largest carbon outflow from the atmosphere (**C**). Correct rankings for each question are largest to smallest from left to right along the x-axis. During the course, Students showed knowledge gains about carbon reservoirs, as most correctly ranked rocks as the largest reservoir in the post-test. Students persistently ranked the size of anthropogenic inflows greater than natural inflows. Students picked outflows based on familiarity with the process, rather than their knowledge of the magnitude of the outflow.

Greenhouse Gas Distribution

Misconceptions
Greenhouse gases are a layer in the atmosphere that traps in heat (Shepardson et al., 2010)
Greenhouse gases are only generated by anthropogenic processes (Niebert and Gropengeisser, 2011)
CO_2 causes a hole in the ozone layer. (Niebert and Gropengeisser, 2011)

"China is one of the biggest contributor to the carbon dioxide, and it says, the distribution of carbon gases, so I think it should be thicker in front of, like above Asia. But for Canada, like the sky is so blue, and you know the air is relatively fresh" (Student 85)

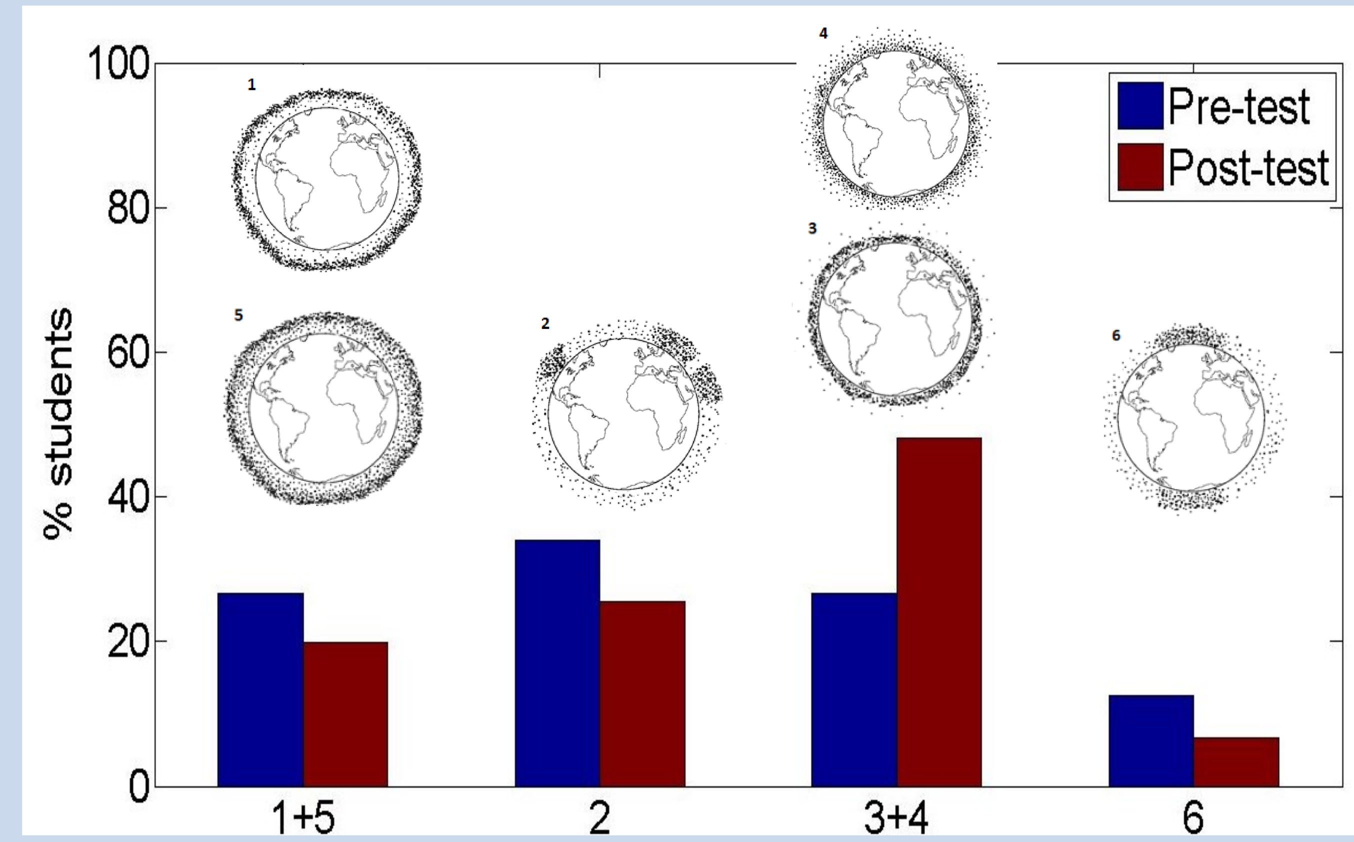


Figure 5. Answers to the question "Which diagram shows the distribution of greenhouse gases in the atmosphere?" Options that appeared similar to students (1 and 5, and 3 and 4), are grouped together. Options 3 or 4 are the most correct options, and students showed knowledge gain by more frequently picking 3 or 4 in the post-test. but many still thought greenhouse gases concentrated in high population centers (option 2).

Recommendations

1.Students demonstrated knowledge gain about climate feedbacks, especially the ice-albedo feedback (Fig.1). Future teaching could focus on Planck's feedback and lapse rate, as few students remembered these one year later.

2.Future teaching could focus on the capacity of natural outflow processes to balance continued human inputs, as after the course students tend to understand mass balance (Fig.3B), but not the capacity of natural outflows (Fig.3A).

3. Future teaching could focus on the magnitudes of human and natural flows of carbon to and from the atmosphere (Fig. 4).

4.The options in the greenhouse gas distribution question could be edited so options 1 and 5 and options 3 and 4 are more easily distinguished by students.

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