Evaluation and Assessment Summary

This is the second year CMMAP has offered this two-day course. For 2015 we partnered with Victoria Jordan, who teaches 7th grade science in Wellington, to pare down traditional lectures to a minimum. Lecture content is down to just 27% of total course time. We trimmed PowerPoint presentations added structured activities during which pairs or small groups of teachers learned together and "processed" that science content. Many of the new activities are based on materials from Kagan Publishing and Professional Development (www.kaganonline.com).

Pre- and Post- Instruction Content Test

We developed a set of written learning targets and objectives (attached) for each of the 8 course "blocks," and administered a short test (also attached) before and after the two-day course. Tests were anonymous but paired so that we could compare pre- and post- answers for individual teachers without collecting names. A summary of the pre- and post- scores is shown below.

	Objective	pre-test	post-test	wrong-right	right-wrong	right-right	wrong-wrong
Q 1	1c	27%	93%	67%	0%	27%	7%
Q 2	2d	7%	53%	47%	0%	7%	40%
Q 3	2a	13%	37%	20%	0%	13%	53%
Q 4	2c	40%	60%	40%	20%	20%	20%
Q 5	1d	27%	87%	60%	0%	27%	13%
Q 6	3c	33%	87%	53%	0%	33%	7%
Q 7	4c	47%	73%	47%	20%	27%	7%
Q 8	5b	33%	80%	33%	0%	20%	0%
Q 9	5d	27%	67%	40%	0%	13%	7%
Q 10	5e	40%	60%	33%	13%	27%	27%
Q 11	6c	27%	53%	33%	7%	20%	33%
Q 12	6c	27%	20%	13%	20%	7%	60%
Q 13	7c	50%	67%	20%	7%	27%	20%
Q 14	8b	77%	90%	7%	0%	53%	0%
ALL		34%	66%	37%	6%	23%	21%

The test shows that we were generally successful in achieving the course objectives: overall scores rose from 34% correct in the pre-test to 66% correct in the post-test. Only two questions of 14 asked garnered fewer than 50% correct answers on the post-test. Even better, we successfully addressed high-priority misconceptions: an average of 37% of respondents changed from incorrect to correct answers, but an average of only 6% of respondents changed from correct to incorrect answers.

Yellow highlighting in the table above indicates problematic data bearing extra attention.

Although participants showed a huge improvement from the pre- to post-test on Question 2 (7% to 53%), 40% of respondents still got this question wrong after the course. Question 2 read "The Earth radiates energy back to space approximately like a blackbody with a temperature of …" Four multiple-choice answers were offered. The correct answer was -18 C. This question was intended to address learning objective 2d: *calculate the Earth's radiation temperature* as part of our essential learning target 2: *I can explain how energy flows in the climate system*. The value of Earth's radiating temperature is not important as a "factoid," but we spent considerable time in lecture and on group activities learning that this temperature results from energy balance at planetary scale. Perhaps we need a better question to assess this learning target.

Respondents had more trouble with Question 3, whose correct answer was "*Carbon dioxide is a powerful* ***greenhouse gas*** *because (b) it has many vibrational states.*" This question targeted learning objective 2a: *Model the vibrational energy of various gasses in the atmosphere.* Respondents answered correctly 13% of the time on the pre-test compared to only 37% on the post-test, with a surprising 20% changing from a correct to incorrect answer. During the group activity we emphasized the behavior of temporary electrical dipoles in stretched or bending CO2 molecules, but fundamentally it's the availability of multiple modes of vibration that allow the temporary dipole moments to emerge. CO2 is not a polar molecule like water vapor. We will be careful with this misconception in modifying the course next year.

Respondents showed only moderate improvement on Question 4, whose correct answer was "*The total radiation received by the Earth's surface (a) is about 2/3 emitted infrared from the atmosphere and 1/3 from the Sun.*" This question is quite fundamental to understanding how climate works, and was intended to address essential learning target 2: *I can explain how energy flows in the climate system.* We're concerned that only 60% of respondents answered this question correctly after the course and worse, that 20% changed from a correct to an incorrect answer! The most common incorrect answer was that downward radiation from the atmosphere was half of the energy received at the surface rather than 2/3, so maybe we succeeded in transmitting qualitative but not quantitative understanding of this concept.

Another area of concern is indicated by the 20% of respondents who changed from a correct to an incorrect answer on Question 7, whose correct answer is "*The timing of major ice ages has been governed by subtle changes in Earth's orbital geometry over the past few million years.*" This question was intended to assess learning objective 4c "*Demonstrate how the tilt of Earth's axis and orbit influence climate.*" The most popular incorrect answer was "*volcanic eruptions throughout* *geologic time.*" When we revisit course content and pedagogy next year, we will need to pay special attention to this content area.

Finally, we note that respondents had a lot of trouble with Question 12, whose correct answer was "*If China, India, and Africa build industrial economies based on fossil fuels, atmospheric CO2 will reach approximately 1000 ppm by 2100."* Only 20% of respondents correctly answered this question on the post-test, and 20% changed from the correct to an incorrect response. This question was intended to assess learning objective 6c: *I can explain the relationship between* CO_2 *emissions, concentrations and climate.* The numerical value of the CO2 concentration is not important, but we're concerned that this content area was not successfully learned. Of the 8 content blocks in the course, this was the only one presented without any formal lecture. The class broke into small groups to read short articles and teach one another about emissions and CO2. We might need to revisit this content delivery area next year, or perhaps the question was not a good gauge of student learning on this topic.

Class Evaluation (open-ended questions)

These evaluations were overwhelming positive. Many participants gave kudos for the quality of the content, the combination of different teaching methods, and the many classroom activities that were offered through the website. The assistance of Erin and Aaron was very much appreciated.

Many people commented that the course was too fast-paced, and that they needed more time to "process" what they were learning. Several specifically suggested that the course be expanded to three days in future years. The overall feeling was that the first day was much too fast, and that the second day was more appropriately paced.

Two people thanked us for the inclusion and modeling of pedagogical techniques, especially the Kagan activities, but a number of others objected. A common suggestion was that these are adult learners who want climate science content rather than a teaching methods workshop. Several respondents asked for more climate science content and "Explain" time.

Another repeated suggestion was that we honor both lunches and breaks and refrain for overloading these times with journaling or other class activities. Several people asked for a longer lunch break.

Climate Changes of the Past and Future
Pre & Post Test

1. About what percentage of the **solar radiation reaching the Earth is absorbed** at its surface?
   (a) 80%   (b) 70%   (c) 60%   (d) 50%

2. The Earth radiates energy back to space approximately like a **blackbody with a temperature of**
   (a) 22 °C   (b) 13 °C   (c) 0 °C   (d) -18 °C

3. Carbon dioxide is a powerful **greenhouse gas** because
   (a) black carbon absorbs visible radiation
   (b) it has many vibrational states
   (c) it has a strong dipole moment
   (d) it is a symmetrical molecule

4. The total **radiation received by the Earth's surface**
   (a) is about 2/3 emitted infrared from the atmosphere and 1/3 from the Sun
   (b) comes only from the Sun
   (c) is about half emitted infrared from the atmosphere and half from the Sun
   (d) is about 80% emitted infrared from the atmosphere and 20% from the Sun

5. **Blackbodies emit thermal radiation** at a rate proportional to
   (a) their temperature
   (b) their internal kinetic energy
   (c) the square of their temperature
   (d) the fourth power of their temperature

6. Over tens to hundreds of millions of years, **climate is fairly stable** because
   (a) ice sheets melt and grow to compensate temperature changes
   (b) changes in the Earth's orbit balance changes in the Sun
   (c) CO_2 emitted by volcanic activity is balanced by CO_2 consumed by erosion and chemical weathering of rocks
   (d) plant and animal extinctions regulate the Earth's albedo

7. The **timing of major ice ages** has been governed by
   (a) Subtle changes in Earth's orbital geometry over the past few million years
   (b) Occasional impacts of asteroids or comets
   (c) Continental drift which brings land near the North Pole
   (d) Volcanic eruptions throughout geologic time

Climate Changes of the Past and Future
Pre & Post Test

8. Give two examples of natural **radiative forcing** of Earth's climate

9. Give two examples of **positive feedback** mechanisms in the Earth's climate system

 ____

 ____

10. Past climate change and modern climate models agree that the Earth's **climate sensitivity** is about
    (a) 0.2 °C per W m^{-2} of radiative forcing
    (b) 0.4 °C per W m^{-2} of radiative forcing
    (c) 0.8 °C per W m^{-2} of radiative forcing
    (d) 1.2 °C per W m^{-2} of radiative forcing

11. **Fossil fuel emissions** account for about
    (a) Half of the increase in atmospheric CO_2 over the past 50 years
    (b) All of the increase in atmospheric CO_2 over the past 50 years
    (c) Twice of the increase in atmospheric CO_2 over the past 50 years
    (d) 10% of the increase in atmospheric CO_2 over the past 50 years

12. If China, India, and Africa build industrial economies based on fossil fuels, atmospheric CO_2 will reach **approximately what concentration by 2100?**
    (a) 450 ppm
    (b) 700 ppm
    (c) 1000 ppm
    (d) 2000 ppm

13. List **three major expected impacts** of climate change on the US economy in the absence of strong policy to mitigate CO_2 emissions

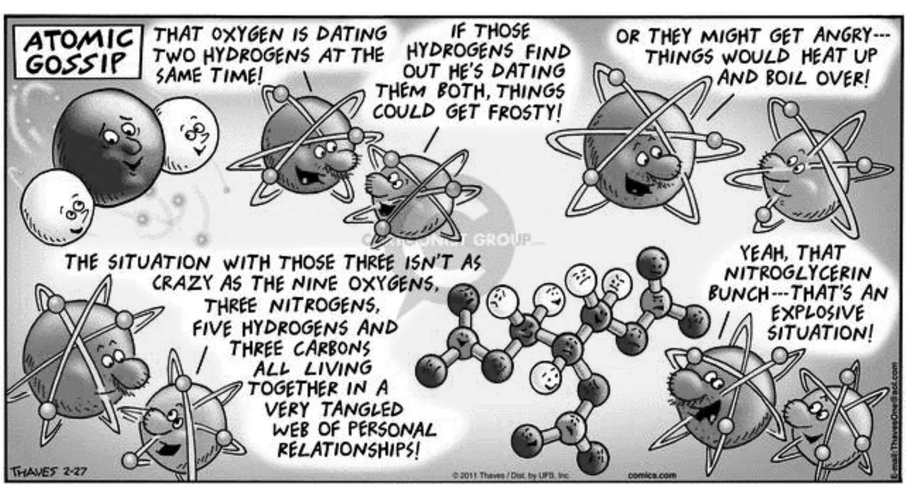
14. Identify **two strategies for reducing global CO_2 emissions**, and list an advantage and a disadvantage for each one.

Objectives: Climates Past and Future – Day 1

Big Question: How do past climates help us predict future climates?

Before each Essential Learning is taught, give yourself a "pre" score of 0-4 (0= I've never heard of this; 4= I can teach this.) After each learning set, give yourself a "post" score.

MAIN LEARNING TARGET	OBJECTIVE	Lessons Involved	Pre	Post
Essential Learning #1: **I can explain how energy flow affects the Earth's temperature.**	1a. Use concepts of energy, conservation of energy, heat transfer, and electromagnetic radiation to describe what controls the Earth's temperature.	*Heat packs* *Rainbow glasses* *IR camera* *EM spectrum* *Lecture: Energy & EM Radiation*		
	1b. Compare and contrast the blackbody nature of the sun and the Earth.	*Lecture: Energy & EM Radiation*		
	1c. Draw a diagram showing solar energy being absorbed, transmitted, reflected, and emitted by the Earth.	*Lecture: Energy & EM Radiation*		
	1d. Calculate the radiating power of objects given their temperature.	*Lecture: Energy & EM Radiation* *People Power*		
	1e. Define and give examples of energy, power, transmission, emission, reflection, absorption, emission, heat, and temperature.	*Heat packs* *Rainbow glasses* *IR camera* *EM spectrum* *Lecture: Energy & EM Radiation*		
Essential Learning #2: **I can explain how energy flows in a climate system.**	2a. Model the vibrational energy of various gasses in the atmosphere.	*Greenhouse molecules dancing*		
	2b. Explain using physics why the atmosphere influences Earth's temperature. Include concepts of absorption, emission, molecular motion of greenhouse gasses, and the Earth's energy balance.	*Greenhouse molecules dancing* *Glass Plates Atmosphere model* *Lecture: Earth's Energy Budget* *Rally Coach* *Q Tic-tac-toe*		
	2c. Draw a diagram that shows how the atmosphere emits radiation to warm the surface of Earth.	*Glass Plates Atmosphere model* *Lecture: Earth's Energy Budget*		
	2d. Calculate Earth's radiation temperature.	*Lecture: Earth's Energy Budget*		



MAIN LEARNING TARGET	OBJECTIVE	Lessons Involved	Pre	Post
Essential Learning #3 **I can describe climates of the deep past and the properties and processes that have influenced climate through geologic time.**	3a. Using plate tectonics, explain where the carbon dioxide in volcanic emissions comes from.	*Video: Plate tectonics*		
	3b. Describe how weathering and erosion contribute to a cooling climate.	*Sparkling Water and the Climate Cycle*		
	3c. Explain how plate tectonics acts as a long-term thermostat that regulates Earth's temperature.	*Lecture: Climate Changes of the Deep Past*		
	3d. Plot Earth's major climate changes on a geologic timeline, and explain the most likely reasons for each change.	*Lecture: Climate Changes of the Deep Past* *Guided Notes*		
	3e. Compare and contrast catastrophic climate changes to gradual climate changes in Earth's past.	*Lecture: Climate Changes of the Deep Past*		
	3f. Draw a diagram of ocean circulation and explain how oceans influence climate.	*Lecture: Climate Changes of the Deep Past*		
Essential Learning #4 **I can differentiate between processes that cause climate change over thousands of years vs. millions of years.**	4a. Model a climate reconstruction using tree ring data.	*UCAR: Dendrochronology interactive*		
	4b. Describe the life cycle of a glacier or ice sheet, and what evidence scientists use to identify where glaciers and ice sheets have existed in the past.	*Viceo: Ice Cores* *Lecture: Ice Age Climates*		
	4c. Demonstrate how the tilt of Earth's axis and orbit influence climate.	*Spin a Top* *Lecture: Ice Age Climates*		
	4d. Use graphs to identify patterns in Earth's eccentricity, tilt (obliquity), and precession and correlate those patterns to patterns in Earth's ice ages.	*Lecture: Ice Age Climates*		
	4e. Explain why it takes longer to cool down the planet than it does to heat it up.	*Lecture: Ice Age Climates*		
	4f. Evaluate a Quaternary CO_2 graph, and make inferences about properties and processes that were happening at various times on the graph.	*Graphing Quaternary Climate*		
	4g. Explain why there have been ice age cycles over the past couple of million years, but not over most of geologic time.	*Lecture: Ice Age Climates*		

Objectives: Climates Past and Future – Day 2

Big Question: How do past climates help us predict future climates?

Before each Essential Learning is taught, give yourself a "pre" score of 0-4 (0= I've never heard of this; 4= I can teach this.) After each learning set, give yourself a "post" score.

MAIN LEARNING TARGET	OBJECTIVE	Lessons Involved	Pre	Post
Essential Learning #5: **I can use climate forcing and feedback information to determine Earth's climate sensitivity.** ***(Simple)***	5a. Create a timeline of discoveries about global warming throughout history.	*Global Warming Card Sort*		
	5b. Identify sources of climate forcing.	*Lecture: Climate Forcing*		
	5c. Describe how both positive and negative feedback systems work to impact climate.	*Lecture: Climate Forcing* *Kagan Corners*		
	5d. Identify sources of positive and negative feedbacks to a climate system.	*Lecture: Climate Forcing* *Kagan Corners*		
	5e. Calculate how many degrees of warming happen with each W/m^2 of heating.	*Lecture: Climate Forcing*		
	5f. Explain where estimates of Earth's climate sensitivity derive from, and identify the most likely increase in temperature for a doubling of CO_2 based on current data.	*Lecture: Climate Forcing* *Kagan Corners* *Observations of Climate Change*		
Essential Learning #6: **I can explain the effects of changing the carbon cycle on Earth's climate.** ***(Serious)***	6a. Calculate my personal carbon footprint and determine strategies for reducing my personal carbon emissions.	*Carbon Calculators*		
	6b. Identify sources and sinks of carbon in the biogeochemical carbon cycle.	*Jigsaw: Carbon Cycle*		
	6c. Explain the relationship between CO_2 emissions, concentrations and climate.	*Jigsaw: Carbon Cycle*		
	6d. Predict and justify how long extra CO_2 will last in the atmosphere.	*Jigsaw: Carbon Cycle*		
	6e. Demonstrate how fossil fuel emissions are driven by economic growth.	*Jigsaw: Carbon Cycle*		

MAIN LEARNING TARGET	OBJECTIVE	Lessons Involved	Pre	Post
Essential Learning #7 **I can evaluate climate models.** ***(Serious / Solvable)***	7a. Explain inputs to a climate model that allow scientists to predict future climates.	*Climate Model Board Game* *Computer Carbon Calculator*		
	7b. List what climate models can predict.	*Climate Model Board Game* *Computer Carbon Calculator* *Lecture: Future Climate*		
	7c. Describe how scientists generate climate models, and list possible sources of error in developing climate models that accurately predict climates of the past and future.	*Video: Ostrich- Warming* *Lecture: Future Climate* *Emissions Calculator*		
Essential Learning #8 **I can describe Earth's current climate change as "simple, serious, and solvable."** ***(Solvable)***	8a. Identify and evaluate 15 changes humans can make to significantly reduce carbon emissions.	*Video: Birthing a Solar Age* *Climate Wedges Game* *Lecture: Solving the Climate Problem*		
	8b. Compare the costs & benefits of a variety of CO_2 emission reduction strategies.	*Climate Wedges Game* *Lecture: Solving the Climate Problem*		
	8c. Describe some policy options for mitigating climate change.	*Climate Wedges Game* *Lecture: Solving the Climate Problem*		
	8d. Explain strategies individuals can implement in their lives and communities that will reduce CO_2 emissions on a global and local scale.	*Climate Wedges Game* *Inside/Outside Circle*