A Learning Progression Approach to Incorporate Climate Sustainability into Teacher Education

Hui Jin, Michele Elizabeth Johnson, and Nissa Rae Yestness

Abstract Research on climate sustainability investigates 1) global climate change, and 2) the natural and anthropogenic factors that affect it. In an ongoing, NSF-funded, environmental literacy project, we use a learning progression approach to study the teaching and learning of climate sustainability at the secondary school level. More specifically, we focused on promoting an environmental literacy goal in relation to climate sustainability: to use discipline-based reasoning to analyze and explain how human energy consumption activities (e.g., farming, electricity usage, and transportation) and natural processes (e.g., plant growth, human food consumption, dead organisms decaying) affect the carbon cycle. We conducted empirical research over a span of six years, engaging middle and high school science teachers from five states representing all four time zones of the country. We developed Learning Progression Frameworks (LPFs), curriculum, teacher professional development materials, and student and teacher assessments based on the LPFs. In this chapter, we provide suggestions for incorporating climate sustainability into teacher education programs, based on the data collected and findings discovered in several studies within the scope of the project. In particular, we discuss what pre-service teachers need to know in order to effectively facilitate their students' achievement of this goal. We also provide two specific suggestions for teacher education programs: using visualization tools to promote discipline-based reasoning and using scenarios to support pre-service teachers' understanding of students' intuitive reasoning patterns.

Keywords: climate sustainability, discipline-based reasoning, learning progression, pre-service teachers

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Our society is facing growing environmental challenges, including pollution, climate change, habitat loss, declining biodiversity, and land degradation. In such situations, sustainable development has become particularly pertinent. The World Commission on Environment and Development [WCED] (1987, p. 41) defines sustainable development as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs.”

Climate sustainability encompasses global climate change, and the natural and anthropogenic factors that affect it (Kajikawa, 2008). We argue that more effort should be devoted to promoting the teaching of climate sustainability in K-12 schools; this argument is based on two points. First, although the topic of carbon cycling in ecosystems has been emphasized in the secondary curriculum for many years (e.g., National Research Council [NRC], 1996), empirical studies have uncovered that students encounter considerable difficulties in using this knowledge to explain how natural events (e.g., plant growth, human food consumption, dead organisms decaying) affect atmospheric carbon (Barak, Gorodetsky, & Chipman, 1997; Barker & Carr, 1989; Barker & Malcolm, 1989; Canal, 1999; Jin & Anderson, 2012; Leach, 1996).

Second, there is an urgent need to enhance people’s understanding of how anthropogenic factors impact the carbon cycle (NRC, 2012; Next Generation Science Standards [NGSS] Consortium of Lead States, 2013). To demonstrate this point, we present findings from two strands of research: environmental research on humans’ impact on global climate sustainability, and large-scale surveys of how people understand climate sustainability. According to environmental research, since the Industrial Revolution, annual carbon emissions from fuel combustion dramatically increased from near zero to over 31 Gigatons of carbon dioxide in 2011 (International Energy Agency [IEA], 2013). Different energy sectors, such as electricity, heat generation, and transportation, produce nearly two-thirds of global carbon dioxide, and carbon emissions from these sectors almost doubled between 1990 and 2011 (IEA, 2013). Deforestation in developing countries is another major contributor to climate change, which has remained at high levels since 1990 (Intergovernmental Panel on Climate Change [IPCC], 2007). In short, while energy is driving global economic growth and development, an economy heavily reliant on fossil fuels and land-use accelerates global climate change.

While environmental research suggests an urgent need for responsible citizens to take actions to mitigate climate change, studies of large-scale surveys provide ample evidence that people's understanding of climate sustainability is far from satisfactory. A survey with a nationally representative sample of 1,503 Americans shows that just 12% of Americans passed a basic quiz on energy knowledge (National Environmental Education and Training Foundation [NEETF], 2002). An online survey with over 500 adults (Attari, DeKay, Davidson, & deBruin, 2010) found that people hold a variety of intuitive ideas about using electricity. Shelton (2008) found that, although consumers were becoming knowledgeable about renewable energy, they remained confused about some energy issues such as electricity generation. A nationally conducted interview, with a random sample of 1,001 adults over the age of 18, found that the knowledge level on energy topics is very low for the general public, with significant numbers who do not know some basic facts about how energy is produced (Bittle, Rochkind, & Ott, 2009).

To address these urgent needs, we conducted research on the teaching and learning of climate sustainability at K-12 schools. We wanted students to achieve the *environmental literacy goal* of using discipline-based reasoning (e.g., tracing matter, tracing energy, connecting scales) to analyze and explain climate sustainability issues. These issues concern how natural processes (e.g., plant growth, human food consumption, dead organisms decaying, etc.) and human energy consumption activities (e.g., changing diet, farming, using electricity, transportation, etc.) affect the carbon cycle. We used a learning progression approach to study teachers' and students' understanding and teachers' instructional approaches. Learning progressions are "descriptions of the successively more sophisticated ways of thinking about a topic that can follow one another as children learn about and investigate a topic over a broad span of time." (NRC, 2007, p. 214). A Learning Progression Framework (LPF) provides a framework that outlines scientific understanding and the learners' thinking regarding a particular topic. It often contains an Upper Anchor that describes scientific thinking and a set of lower levels that describe students' intuitive ideas.

In this chapter, we provide suggestions for incorporating sustainability education into teacher education programs based on the findings of our previous research. In particular, we focus on what pre-service teachers need to know and do in order to effectively facilitate their students' development of an understanding of climate sustainability. We begin with the background of our research project. Next, we present an environmental literacy goal as it relates to climate sustainability. Finally, we use examples of students' interview responses and teachers' survey responses to illustrate what the LPF tells us about what pre-service teachers should know about science and student thinking. Based on these examples, we further provide instructional suggestions for teacher education programs.

Background of the Research Project

The MSP (Math-Science Partnership) Learning Pathway project is an ongoing, NSF-funded environmental literacy project. Within the scope of the project, scientists and science educators (K-12 and collegiate) developed LPFs for various topics in environmental literacy such as carbon cycling, water cycling, and biodiversity. This partnership spanned institutions from across the country and engaged middle and high school science teachers (Grade 7 to 12) and their students from five states. The participating teachers and students came from diverse settings, including rural, suburban, and urban schools. The percentage of students who received reduced or free lunch ranged from 11.7% to 100%. The percentage of students from non-White European backgrounds ranged from 7% to 89%. Based on the theories of design-based research (Cobb, Confrey, diSessa, Lehrer, & Schauble, 2003), we conduct research in iterative cycles. Each cycle lasted for one year and contained five components:

- *Development of the Learning Progression Frameworks (LPF):* LPFs for explanations of climate sustainability issues were developed, revised, and refined based on student assessment data. The LPFs contained an Upper Anchor and three lower levels. The Upper Anchor represents the discipline-based reasoning that scientists use to analyze and explain sustainability issues. The lower-levels represent the intuitive ways of reasoning that students use to explain sustainability issues. The LPFs served as guiding frameworks that coordinated all other research activities.
- *Curriculum Development:* A set of teaching modules were developed to facilitate students in making the transition from a lower level to the Upper Anchor of the LPFs.
- *Professional Development:* Teachers who were interested in teaching sustainability issues participated in summer and/or school year workshops. The workshops focused on the LPFs and associated teaching modules, including the use of embedded formative assessment tools that help teachers elicit and respond to their students' ideas.
- *Teacher Knowledge Assessments.* Most teachers who participated in the professional development workshops also took a teacher knowledge assessment afterward. The teacher knowledge assessment included items about explaining sustainability issues (i.e., content knowledge) and items about analyzing student thinking and instructional strategies (i.e., pedagogical content knowledge). In the two most recent research cycles, 194 teachers (120 teachers in 2011-12 and 74 teachers in 2012-13) participated the professional development workshops and completed the teacher knowledge assessment.
- *Teaching Experiment.* A sample of teachers who participated the workshops and teacher knowledge assessments implemented the project curriculum in their classrooms. In each research cycle, different samples of teachers and their students participated

in the study. The participants in the two most recent cycles were: 25 teachers and 598 students in 2011-12 and 10 teachers and 380 students in 2012-13. The teachers used the curriculum with their students and implemented an assessment before and after the instructional intervention.

The development and implementation of the above research components were reported in several previous publications (Jin & Anderson, 2012; Jin, Zhan, Anderson, 2013; Jin, Johnson, & Kim, 2014, March; Mohen, Chen, & Anderson, 2009). In this chapter, we make suggestions for teacher education programs based on the data collected and findings uncovered in those studies.

Environmental Literacy Goal: Using Discipline-based Reasoning to Analyze and Explain Climate Sustainability Issues

In making suggestions for incorporating climate sustainability into teacher education programs, we focus on teaching and learning of one scientific practice: constructing scientific explanations about climate sustainability issues. Performing this practice requires solid understanding of several core ideas in the physical and life sciences: matter transformation and energy transformation in carbon-transforming processes. Note that carbon-transforming processes include photosynthesis, cellular respiration, digestion and biosynthesis, and combustion. These core ideas are built upon the crosscutting concepts of matter, energy, and scale. In this sense, our focus is aligned with the new vision of the NRC framework and NGSS (NRC, 2011; NGSS Consortium of Lead States, 2013): having students engage in scientific practices and apply crosscutting concepts to deepen their understanding of disciplinary core ideas.

It is widely agreed upon among the science education community that some scientific concepts and principles are particularly difficult for students because the scientific reasoning underlying them is counterintuitive (Chi, Roscoe, Slotta, Roy, & Chase, 2012; Jin & Wei, 2014; Lombrozo & Carey, 2006). Findings of our previous studies suggest that matter, energy, and carbon-transforming processes belong in this category (Jin & Anderson, 2012; Mohan, Chen, & Anderson, 2009). Therefore, teaching and learning of scientific explanation of sustainability issues should focus on promoting the reasoning underlying the science concepts and principles. This discipline-based reasoning can be elaborated in terms of three components:

- Tracing matter: Explain how matter transforms in chemical reactions, in terms of atom re-arrangement. Trace atoms within and across biological and chemical processes, in ways that follow matter conservation and atom re-arrangement.
- Tracing energy: Explain how energy transforms following the principle of energy conservation and the principle of energy degradation. Recognize that the total quantity of energy is conserved, while the amount of useful energy always decreases due to heat dissipation.
- Connecting scales: Connect macroscopic phenomena (e.g., tree growth, human food consumption, burning fossil fuels, etc.) with biological and chemical processes at the atomic-molecular scale (namely, photosynthesis, cellular respiration, digestion and biosynthesis, and combustion). Identify the large-scale patterns of matter transformation (namely, carbon cycling) and energy transformation (namely, energy flow) within and across natural and socio-economic systems.

We suggest that science teacher education programs address climate sustainability through helping pre-service teachers understand discipline-based reasoning and develop instructional strategies to teach discipline-based reasoning.

What Pre-service Teachers Should Know

In this section, we use students' and teachers' responses, collected in the project, to illustrate what pre-service teachers should know, and how well they know, about climate sustainability. In the project, we used clinical interviews and written assessment data collected from students to develop a LPF for matter (Mohan, Chen, & Anderson, 2009) and a LPF for energy (Jin & Anderson, 2012). Both LPFs show one typical progression of students: increasing sophistication from informal reasoning towards scientific reasoning about matter/energy. We integrated these two LPFs into one LPF for discipline-based reasoning. The Upper Anchor of this LPF presents the learning goal for high school graduates: using discipline-based reasoning to construct explanations of sustainability issues (namely, tracing matter, tracing energy, and connecting scales). It is elaborated in the environmental literacy goal. The other levels of the LPF describe reasoning patterns commonly used by K-12 students and sometimes their teachers. These levels include force-dynamic reasoning (Level 1), hidden mechanism reasoning (Level 2), and modified matter-energy reasoning (Level 3). In Table 1, we present six pairs of responses that illustrate how students' and teachers' intuitive reasoning patterns differ from the discipline-based reasoning at the Upper Anchor. Each pair contrasts a lower-level response with an Upper Anchor response, and each pair is about one component of the discipline-based reasoning (namely, tracing matter, tracing energy, or connecting scales).

Table 1

Contrasts between Intuitive Reasoning Patterns and Discipline-based Reasoning

<table>
<tr><th>Contrasts</th><th>Explanations Based on Intuitive Reasoning</th><th>Explanations Based on Discipline-based Reasoning</th></tr>
<tr><td rowspan="2">Force-dynamic Reasoning vs. Discipline-based Reasoning</td><td colspan="2">A Tracing Energy Interview Task: Explain the event that people use gasoline to power their cars.</td></tr>
<tr><td>Interviewer: What does the car needs in order to run?

Student A: The gas, because if it runs out, then it would just stop.

Interviewer: All right. It needs the gas. Otherwise you're not able to move it. Why do people fill it with gas? Why don't they fill it with water?

Student A: Because water would make the car, because it needs like, because the water would just make it, make the car fall apart and dysfunction.

… …

Interviewer: So, do you think the car is using the gas for energy?

Student A: [Nod].</td><td>Interviewer: Obviously, most of us who have gasoline-powered cars, we have to fill that tank up periodically. What is happening - why do we need to do that? What happened to the gas we put in there last time?

Student B: Basically how I think a car is supposed to work is you have a fuel tank; it has liquid gasoline. That gasoline is pumped out and sprayed into the cylinder of an internal combustion engine, where a very small amount of it is basically exploded in a controlled way in order to push the cylinder down to turn the engine and give the car motion.

Interviewer: Okay.

Student B: So you have chemical energy stored in the gasoline that is combusted - a small amount of it is combusted in a similar way as the candle.

Interviewer: Yes.</td></tr>
</table>

Interviewer: How is it using it for energy? Student A: It's using it for energy because it needs that to run. And then because how we need sleep or food to run, it needs gas; it's like food.	Student B: And that explosive combustion is harnessed at least in part by the - Interviewer: The piston? Student B: By the piston. And a lot of it is going to go to just waste, like heat. But some of that energy is harnessed by the engine, which lets the car move forward. And you just have to keep burning gas in order to keep the engine running, so if the car drives until the engine is empty then the car will have to stop. Interviewer: Okay. There would be no source for the motion energy… Student B: Yes. It needs the chemical potential energy of the gasoline to go.
A Tracing Energy Written Item: Do you think that a 13 W compact fluorescent light bulb and a 60 W incandescent light bulb will give off about the same amount of light? What evidence or facts would you give to support your view? Please also explain why the evidence/facts would support your view.	
Teacher A Yes. The two bulbs look visually to give off the same amount of light when used in the same room in the same lamp.	Teacher B Yes. Fluorescent bulbs are more efficient in that the mechanism inside the bulb allows for more conversion of initial electrical energy directly into light = less "lost" as heat. So, a lower wattage is needed to produce the same amount of light as what would be produced by an incandescent light bulb with a higher initial energy input (wattage).

Hidden Mechanism Reasoning vs. Discipline-based Reasoning	*A Connecting Scales Written Item: How is the carbon in plants and animals different from carbon in the atmosphere?*	
	Student C: Carbon in plants and animals are used for energy and living. Carbon in the atmosphere is 'raw' and waiting to be used for energy.	Student D: Because the carbon in animals is in the form of DNA and other organic compounds. In the atmosphere, it is in the form of CO_2
	A Connecting Scales Written Item: The graph given below shows changes in concentration of carbon dioxide in the atmosphere over a 50-year span (from 1958 to 2008) at Mauna Loa observatory at Hawaii. 1) This graph shows atmospheric carbon dioxide levels decreasing in the summer and fall every year and increasing in the winter and spring. Why do you think this annual cycle of change occurs?	
	Teacher C: From summer to fall there are more plants that are converting the carbon dioxide into oxygen than in the winter months.	Teacher D: Because the photosynthesis rate in the summer is higher, for the declination of the sun is higher in summer and the days are longer. Also, when plants are in the dark they reverse the photosynthesis process, turning oxygen and carbohydrates into carbon dioxide and water.

	A Tracing Matter Written Item: A mature maple tree can have a mass of 1 ton or more (dry biomass, after removing the water), yet it starts from a seed that weighs less than 1 gram. Which of the following processes contributes the most to this huge increase in biomass that is not water? Choose the correct answer. Explain why your choice is best. (If you think some of the other processes above also contribute to the mass increase, explain how.)	
	Student E: Choice: C. Incorporation of carbon dioxide gas from the atmosphere into molecules by green leaves. Explanation: Well, when photosynthesis occurs, the plant takes in carbon dioxide, and turns that energy into glucose, which adds mass. Of course, the plant needs water and sunlight to help it grow too.	Student F Choice: C. Incorporation of carbon dioxide gas from the atmosphere into molecules by green leaves. Explanation: The carbon dioxide and water work together with energy from the sun to create a process called photosynthesis. In this process the plants combine the atoms from carbon dioxide molecules and water molecules to make glucose (a sugar molecule).
Modified Matter-Energy Reasoning vs. Discipline-based Reasoning	*A Tracing Matter Written Item: Do you think that changing from a primarily plant-based diet to a meat-based one will result in more carbon dioxide in the atmosphere? What evidence or facts would you give to support your view? Please also explain why the evidence/facts would support your view.*	
	Teacher E Yes. It takes more plants to support organisms higher in a food chain. Only 10% of energy is available at each trophic level since 90% loss to atmosphere, organism, etc.	Teacher F Yes. It is less energy efficient to eat high on the food chain because 90% of available energy is lost as you move from one trophic level to the next one up (converted to thermal energy, which is not usable). Only 10% remains available in the form of organic matter (like glucose). This means that more farm equipment must be used (fossil fuel combustion = CO_2 release) and more forests must be clear cut (no more substantial CO_2 sink) to farm feed crops for the animals. The animals themselves al-

	so release CO_2 via cellular respiration. Overall, this means more CO_2 produced via cellular respiration, less CO_2 uptake via photosynthesis.

Contrast 1: Force-dynamic Reasoning vs. Discipline-based Reasoning

At Level 1 of the LPF, students/teachers exhibit “force-dynamic reasoning” (See Pinker, 2007, p.222). They do not use matter or energy to explain phenomena, but instead tell stories about actors (e.g., cars) accomplishing tasks with the help of enablers (e.g., gas, sleep, food, etc.). In contrast, explanations at the Upper Anchor are based on discipline-based reasoning that traces matter and energy separately and with conservation. Table 1 provides two pairs of responses; each pair contrasts a Level 1 response with an Upper Anchor response to a tracing energy interview task or a tracing energy written assessment item. In the first pair, two students explained how gasoline is used to power a car in interviews. Student A described the needs of the car, in comparison to how people need sleep and food. His responses represented force-dynamic reasoning, and therefore were scored as Level 1. Student B explained how chemical energy provided by gasoline transformed into heat and motion energy during combustion. Her responses represented the scientific way of tracing energy, and therefore were at the Upper Anchor. In the second pair, teacher A and teacher B provided different explanations about whether a 13 Watt compact fluorescent light bulb and a 60 Watt incandescent light bulb would give off about the same amount of light. Teacher A provided a Level 1 explanation because she described the macroscopic observations but did not provide any causal mechanisms. Teacher B’s responses are based on the scientific way of tracing energy. She explained that, for both types of light bulbs, the input electrical energy transforms into light energy and heat. She justified that the fluorescent light bulb used less electrical energy to produce about the same amount of light, because it released less heat. In this sense, Teacher B provided an explanation at the Upper Anchor.

Contrast 2: Hidden Mechanism Reasoning vs. "Discipline-based Reasoning

At Level 2, students/teachers explain phenomena in terms of hidden mechanisms: invisible hidden structures or processes as the cause of phenomena observed at the macroscopic scale. In contrast, students/teachers relying on Upper Anchor reasoning are able to scale up to identify carbon-transforming processes in the global carbon cycle, discussing both anthropogenic and natural factors that affect it, and scale down to reason about what the molecules are doing through these processes. Table 1 contains two pairs of responses; each pair contrasts a Level 2 response with an Upper Anchor response to a connecting scales item. In the first pair, Student C and Student D provided explanations about how carbon in plants and animals differ from carbon in the atmosphere. Student C provided a Level 2 response, recognizing that carbon is somehow associated with energy but could not successfully connect the scales: how the carbon atoms at the atomic-molecular scale are related to the differences between living organisms (e.g., plants and animals) and a non-living substance (e.g. air). As this student recognized the hidden mechanism (carbon is used for energy), the response is scored as Level 2. Student D provided a Level 4 response to the same item. The student located carbon in organic compounds of living organisms and the carbon in the air (i.e., CO_2). In the second pair, two teachers explained the seasonal variation of carbon dioxide in the atmosphere. Teacher C's explanation is about a hidden process that happens at a microscopic scale: plants converting carbon dioxide into oxygen. As one can see, this hidden mechanism (one substance converting into another substance) is very different from the scientific idea about chemical reactions at the atomic-molecular scale—Substances *react* to produce new substances. Therefore, Teacher C's responses are at Level 2. Teacher D explained the annual change of carbon dioxide in terms of how matter transformed in the process of photosynthesis and cellular respiration. She explained, "They reverse the photosynthesis process, turning oxygen and carbohydrates into carbon dioxide and water." In this sense, Teacher D connected the large-scale pattern illustrated in the graph with processes at the atomic-molecular scale. Therefore, Teacher D provided an Upper Anchor explanation.

Contrast 3: Modified Matter-Energy Reasoning vs. Discipline-based Reasoning

At Level 3, students/teachers use matter and energy to reason about events. However, their explanations often indicate alternative conceptions. Researchers found that students often assimilate the information learned in science class into their existing, naïve knowledge structure (Chi & Roscoe, 2002). In the project, we found that many students and some teachers *modified* the concepts and principles about matter and energy in their explanations. Table 1 contains two pairs of responses; each pair contrasts a Level 3 response with an Upper Anchor response to a tracing matter item. In the first pair, two students explained where the mass of a maple tree came from. Student E provided an explanation based on *matter-energy conversion*; the carbon dioxide was converted into energy to make glucose molecules (Level 3). It appears that the student held the misconception that matter could be converted into energy. This is different from the scientific understanding that matter transformation and energy transformation are separated in chemical reactions. In matter transformation, the atoms of reactants are reorganized to form new products. In energy transformation, one form of energy transforms into other forms of energy. Matter cannot be converted into or from energy. Student F explained how the atoms of carbon dioxide and water were a part of the production of glucose molecules. He relied on the discipline-based reasoning that recognizes atom re-arrangement, and traces matter separately from energy. In the second pair, two teachers explained whether changing from a plant-based diet to a meat-based one would result in more carbon emission. Teacher E recognized that the energy pyramid is a principle that should be applied to this sustainability issue, but he did not identify and explain the relationship between energy and matter—that 90% of heat is lost through cellular respiration, a process that emits carbon dioxide. Unlike Teacher E, Teacher F clearly explained this relationship, tracing energy and explaining how it was related to carbon emission.

Humans are currently facing significant environmental challenges. There is a growing societal expectation that schooling should produce a *responsible and informed citizenry* who understand how human energy usage changes the climate overtime and what actions should be taken to mitigate climate change. As shown above, many students and teachers used intuitive ways of reasoning to explain climate sustainability issues. Their intuitive reasoning patterns hindered them from understanding how humans impact the climate and how to mitigate the impact. Therefore, there is an urgent need to integrate climate sustainability into teacher education programs, so that our future teachers will be able to educate their students about climate sustainability. In particular, it is critical for pre-service teachers not only to be able to use discipline-specific reasoning to analyze and explain sustainability issues but also to be able to anticipate and recognize common intuitive ways of reasoning in their students (i.e., the reasoning patterns at the lower levels).

Suggestions for Teacher Education Programs

We provide two suggestions for teacher education programs to incorporate sustainability education. For each suggestion, we present examples from our project. More details about the professional development and other resources from the project can be found on our website: http://www.pathwaysproject.kbs.msu.edu/

Suggestion 1. Using visualization tools to promote discipline-based reasoning

In a study on teacher knowledge, we found that although most teachers were able to describe carbon-transforming processes, they encountered difficulties in applying this knowledge to real-world situations (Jin, Johnson, & Kim, 2014, March). Some teachers also exhibited alternative conceptions as compared to their students. Therefore, we developed two tools for reasoning to help teachers and students visualize the discipline-based reasoning and organize their knowledge. These two tools are: the *Powers of Ten Tool* and the *Matter and Energy Process Tool*. Teacher education programs can incorporate these tools to help pre-service teachers construct discipline-based reasoning about climate sustainability. They can also introduce these tools as instructional tools that the pre-service teachers can use to teach climate sustainability. We present these two tools below.

Teachers can use the Powers of Ten Tool to help students locate a material object in a scale chart. By doing this, students will understand that objects and phenomena can be visualized from different scales. In the project, we generated a set of slides to show how to use the Powers of Ten Tool. For example, we designed a set of 17 PowerPoint slides to present the hierarchical organization of systems from galaxies to atoms in a leaf. These slides help students and teachers understand that plant growth can be thought about at the atomic-molecular scale and on a global scale. Four of these slides are presented in Figures 1, 2, 3, and 4: a landscape at a large scale, tree leaves at a macroscopic scale, cells of a leaf at a cellular scale, and a cellulose molecule contained in the wall of the cell at a molecular scale. On each slide, a reference table is provided on the left. It contains prefixes and decimal equivalents for a set of different scales. A picture that illustrates objects and phenomena is presented on the right. An arrow links the picture to a scale on the table; it helps students associate the visual image with a specific scale. A red box on the picture indicates the structure to be shown in the following slide. Therefore, a sequence of slides presents connections across different scales. For example, the first slide

(Figure 1) shows that a landscape is at a scale of 10^6 meters (1 mega-meter). The second slide (Figure 2) shows that, when zooming in, we see tree leaves at a macroscopic scale (100 meters). The third slide (Figure 3) shows that, when zooming into the leaves, we see cells at a cellular scale (1 millimeter). The last slide (Figure 4) shows that, when zooming into the wall of a cell, we see a cellulose molecule at a molecular scale (10^{-9} meters or 10 nanometers).

Southeastern United States

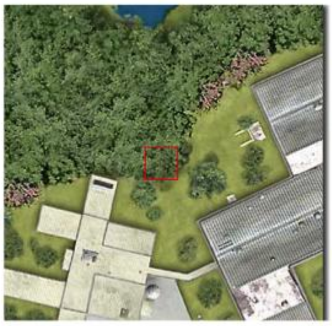
Prefix	symbol	10^n	Decimal equivalent in SI writing style
yotta	Y	10^{24}	1,000,000,000,000,000,000,000,000
zetta	Z	10^{21}	1,000,000,000,000,000,000,000
exa	E	10^{18}	1,000,000,000,000,000,000
peta	P	10^{15}	1,000,000,000,000,000
tera	T	10^{12}	1,000,000,000,000
giga	G	10^{9}	1,000,000,000
mega	M	10^{6}	1,000,000
kilo	k	10^{3}	1,000
hecto	h	10^{2}	100
deca	da	10^{1}	10
n/a	n/a	10^{0}	1
deci	d	10^{-1}	0.1
centi	c	10^{-2}	0.01
milli	m	10^{-3}	0.001
micro	µ	10^{-6}	0.000001
nano	n	10^{-9}	0.000000001
pico	p	10^{-12}	0.000000000001
femto	f	10^{-15}	0.000000000000001
atto	a	10^{-18}	0.000000000000000001
zepto	z	10^{-21}	0.000000000000000000001
yocto	y	10^{-24}	0.000000000000000000000001

Scale: 10^6 meters = 1 Mm = 1 mega-meter

Fig. 1. Landscape at a large scale.

Nearby trees, the lake and laboratory roof

Prefix	symbol	10^n	Decimal equivalent in SI writing style
yotta	Y	10^{24}	1,000,000,000,000,000,000,000,000
zetta	Z	10^{21}	1,000,000,000,000,000,000,000
exa	E	10^{18}	1,000,000,000,000,000,000
peta	P	10^{15}	1,000,000,000,000,000
tera	T	10^{12}	1,000,000,000,000
giga	G	10^{9}	1,000,000,000
mega	M	10^{6}	1,000,000
kilo	k	10^{3}	1,000
hecto	h	10^{2}	100
deca	da	10^{1}	10
		10^{0}	1
deci	d	10^{-1}	0.1
centi	c	10^{-2}	0.01
milli	m	10^{-3}	0.001
micro	µ	10^{-6}	0.000001
nano	n	10^{-9}	0.000000001
pico	p	10^{-12}	0.000000000001
femto	f	10^{-15}	0.000000000000001
atto	a	10^{-18}	0.000000000000000001
zepto	z	10^{-21}	0.000000000000000000001
yocto	y	10^{-24}	0.000000000000000000000001

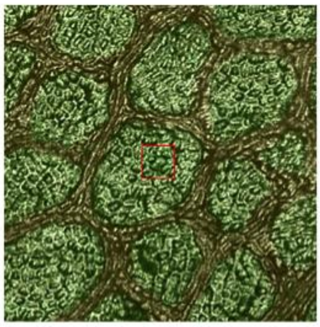


Scale: 10^2 meters = 100 meters

Fig. 2. Tree leaves at a macroscopic scale.

Cells on leaf surface

Prefix	symbol	10^n	Decimal equivalent in SI writing style
yotta	Y	10^{24}	1,000,000,000,000,000,000,000,000
zetta	Z	10^{21}	1,000,000,000,000,000,000,000
exa	E	10^{18}	1,000,000,000,000,000,000
peta	P	10^{15}	1,000,000,000,000,000
tera	T	10^{12}	1,000,000,000,000
giga	G	10^{9}	1,000,000,000
mega	M	10^{6}	1,000,000
kilo	k	10^{3}	1,000
hecto	h	10^{2}	100
deca	da	10^{1}	10
		10^{0}	1
deci	d	10^{-1}	0.1
centi	c	10^{-2}	0.01
milli	m	10^{-3}	0.001
micro	µ	10^{-6}	0.000001
nano	n	10^{-9}	0.000000001
pico	p	10^{-12}	0.000000000001
femto	f	10^{-15}	0.000000000000001
atto	a	10^{-18}	0.000000000000000001
zepto	z	10^{-21}	0.000000000000000000001
yocto	y	10^{-24}	0.000000000000000000000001

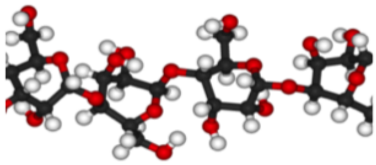


Scale: 10^{-3} meters = 1 mm = 1 millimeter

Fig. 3. Cells of a leaf at a cellular scale.

Cellulose

Prefix	symbol	10^n	Decimal equivalent in SI writing style
yotta	Y	10^{24}	1,000,000,000,000,000,000,000,000
zetta	Z	10^{21}	1,000,000,000,000,000,000,000
exa	E	10^{18}	1,000,000,000,000,000,000
peta	P	10^{15}	1,000,000,000,000,000
tera	T	10^{12}	1,000,000,000,000
giga	G	10^{9}	1,000,000,000
mega	M	10^{6}	1,000,000
kilo	k	10^{3}	1,000
hecto	h	10^{2}	100
deca	da	10^{1}	10
		10^{0}	1
deci	d	10^{-1}	0.1
centi	c	10^{-2}	0.01
milli	m	10^{-3}	0.001
micro	µ	10^{-6}	0.000001
nano	n	10^{-9}	0.000000001
pico	p	10^{-12}	0.000000000001
femto	f	10^{-15}	0.000000000000001
atto	a	10^{-18}	0.000000000000000001
zepto	z	10^{-21}	0.000000000000000000001
yocto	y	10^{-24}	0.000000000000000000000001



Scale: 10^{-8} meters = 10nm = 10naro-meters

Fig. 4. A cellulose molecule contained in the wall of the cell at a molecular scale.

Teachers can use the Matter and Energy Process Tool to help students visualize how matter and energy transform within and across different carbon-transforming processes. In the project, we generated a set of PowerPoint slides that use the Matter and Energy Process Tool to present matter transformation and energy transformation in photosynthesis at different scales. We present two PowerPoint slides here. The first slide (Figure 5) aids students in identifying matter inputs/outputs and energy inputs/outputs at the macroscopic scale. The second slide (Figure 6) aids students in tracing matter at an atomic-molecular scale. The video clip in the middle of the slide shows what is happening to the atoms between the matter inputs and the matter outputs: atoms of reactants (matter inputs) re-arranging to form new products (matter outputs).

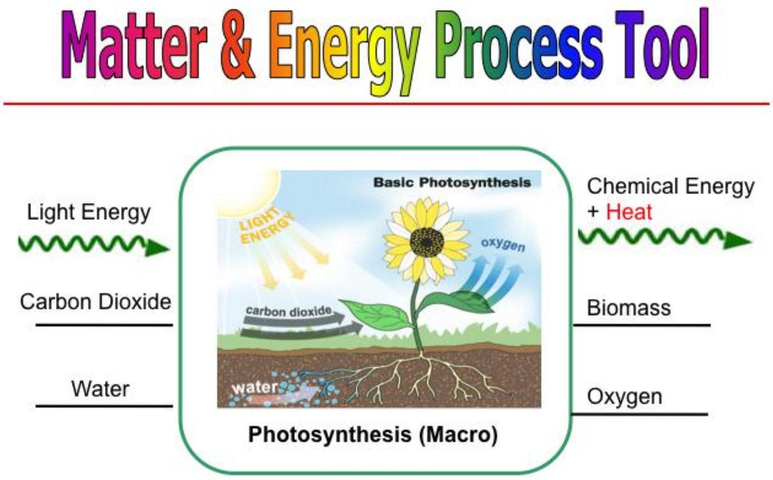


Fig. 5. Identifying matter inputs/outputs and energy inputs/outputs at the macroscopic scale.

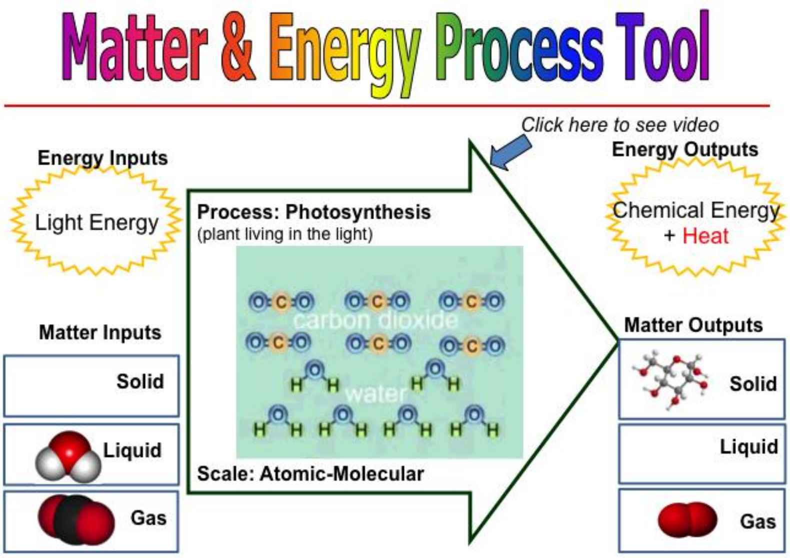


Fig. 6. Tracing matter at an atomic-molecular scale.

Suggestion 2. Using scenarios to support pre-service teachers' understanding of students' intuitive reasoning patterns

Promoting pre-service teachers' understanding of student thinking is a key component in many teacher education programs. Regarding climate sustainability, it is important that pre-service teachers are aware of the three typical reasoning patterns of secondary students (i.e., force-dynamic reasoning, hidden mechanism reasoning, and modified matter-energy reasoning) and understand how they differ from the discipline-based reasoning. In a previous study, we found although many teachers were able to identify incorrect descriptions of science content in students' responses, very few teachers understood students' intuitive ways of reasoning and how they differ from scientific reasoning (Jin, Shin, Johnson, Kim, & Anderson, 2014 March). It is very possible that pre-service teachers encounter the same challenges. Therefore, we suggest teacher education programs help pre-service teachers better understand students' intuitive reasoning about climate sustainability. To this end, scenarios of student thinking are very powerful.

In the project, we used an instructional aid to help teachers use formative assessments to monitor student progress as they are teaching the project-designed units. This instructional aid is a set of scenarios that depicting the learning of a typical Level 2 student named Adrienne. At the beginning of the teacher guide for the Plant Unit, we provide a scenario about three students answering a question: *Little acorns can grow into big, heavy oak trees. Where does all the mass of an oak tree come from?* Adrienne provides a Level 2 response, while the other two students provide a Level 3 response and an Upper Anchor response, respectively. Each lesson of the unit contains a scenario called "The Story of Adrienne Checkpoint," which provides detailed descriptions of Adrienne's intuitive ideas, learning experience, and learning difficulties around the content in that lesson. The checkpoints provide detailed depictions of typical students' understanding as they are learning the unit. Teachers use them to design classroom formative assessments. We present two examples of the Adrienne checkpoint below.

The Story of Adrienne Checkpoint (Lesson 1)

Refer to the 3 responses representing Learning Progression levels by Adrienne (Level 2), Beatrice (Level 3) and Carla (Level 4) in the introduction to this unit. Keep those in mind as you formatively assess your students' responses to the first 3 questions of activity 1. This should give you a rough idea of the percent of your class at each level.

The Story of Adrienne Checkpoint (Lesson 2 & Lesson 3)

Lessons 2 and 3 introduce Adrienne to the key idea of SCALE. Air and water are so obviously different from wood that it doesn't make sense to Adrienne that wood could be made from air and water. She can understand how this is possible only if she recognizes the existence of a "hidden world" of systems and processes too small for her to see. In particular, it is important that she come to think of gases as very much a state of matter like liquids and solids. In other words, as something that has mass. Lesson 2 introduces Adrienne to this hidden world, while

Lesson 3 centers around the key Tool for Reasoning (Powers of 10 Chart) that will help her to use the idea of scale to interpret and explain the world—to use the idea as a tool rather than just a fact. The first step in this process is to understand the relative sizes of objects and systems that she is familiar with and to compare them with molecules in particular (the key systems she will need to understand how carbon dioxide and water can become wood). The activity of placing objects on the Powers of 10 chart will help her to do this.

Scenarios of typical students' thinking and progression are particularly helpful for pre-service teachers, who have little or limited experience teaching students. Instructors of teaching methods courses often ask pre-service teachers to design unit plans. It would be very difficult for pre-service teachers to design a unit plan on sustainability, as traditionally it is not taught in science classrooms. In such situations, the instructor can use scenarios of students' thinking about sustainability issues to help pre-service teachers make sense of students' typical reasoning patterns and design unit plans to target those reasoning patterns.

Summary

In this chapter, we discussed our research on using the learning progression approach to promote teaching and learning of climate sustainability issues and provided suggestions for teacher education programs. More specifically, we focused on promoting an environmental literacy goal in relation to climate sustainability: to use discipline-based reasoning to analyze and explain how natural processes and human energy consumption activities affect the carbon cycle, and what actions should be taken to mitigate climate change. We elaborate discipline-based reasoning in terms of three key components: tracing matter, tracing energy, and connecting scales. We describe a LPF that uses an Upper Anchor to present discipline-based reasoning, and three lower levels to present intuitive reasoning patterns of students (namely force-dynamic reasoning, hidden mechanism reasoning, and modified matter-energy reasoning). We used response pairs from students and teachers to illustrate the contrasts between intuitive reasoning patterns and discipline-based reasoning. These contrasts provided the basis for our suggestions for teacher educators to incorporate climate sustainability into teacher education programs. Two specific suggestions include the use of visualization tools and scenarios of student learning. The visualization tools are intended to promote pre-service teachers' disciple-based reasoning. They can also be provided to pre-service teachers as instructional tools to teach climate sustainability. The scenarios of student learning are intended to promote pre-service teachers' understanding of typical reasoning patterns of students.

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