Connections between student explanations and arguments from evidence about plant growth

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Abstract

In this paper we focus on how students connect explanations and arguments from evidence about plant growth and metabolism—two key practices described by the *Next Generation Science Standards*. This study reports analyses of interviews with 22 middle and high school students post-instruction, focusing on how their sense-making strategies lead them to interpret—or misinterpret—scientific explanations and arguments from evidence. The principles of conservation of matter and energy provide a framework for making sense of phenomena, but our results show that students often reason about plant growth as an action enabled by water, air, sunlight, and soil rather than a process of matter and energy transformation. Many of these students re-interpret the hypotheses and results of standard investigations of plant growth such as von Helmont's experiment to match their own understanding of how plants grow. We also observed that students often improved their explanations and arguments when provided with scaffolds during the interview. We use these analyses to show how student beliefs and habits of mind can lead to alternate interpretations of both arguments from evidence and instructional explanations. We describe our progress and challenges developing teaching materials with scaffolding to improve students' understanding of plant growth and metabolism.

Introduction

The principles of conservation of matter and energy provide a framework for making sense of phenomena such as plant growth by helping students to identify the changes in matter and transformations of energy and to account for all of the atoms and energy in a system (Richmond et al., 2010). The *Next Generation Science Standards* (NGSS Lead States, 2013) identified "energy and matter: flows, cycles, and conservation" as one of seven crosscutting concepts that students can use as organizational tools as they develop and check their growing understanding. Similarly, *Vision and Change in Undergraduate Biology Education* (Brewer and Smith, 2011) identified "pathways and transformations of energy and matter" as one of five core concepts of a 21st century biology curriculum.

However, student thinking about matter in plant growth varies in several ways from this accepted scientific framework of principles of conservation. It is well documented that students from K-12 to college struggle to explain where the matter that makes up plants comes from. Most students do not understand that the dry mass of plants comes mostly from carbon dioxide and instead consistently indicate that soil or water is the source of matter for plant growth (Canal, 1999; Driver et al., 1994; O'Connell, 2008; Wilson et al., 2006). Students generally give little attention to where matter comes from and where it goes, other than stating CO_2 comes from humans and animals and is used by plants that, in turn, produce O_2 to be used by humans and animals (Brown and Schwartz, 2009; Driver et al., 1994; Wilson et al., 2006). These naïve conceptions persist in students who have studied photosynthesis and cellular respiration and who conduct matter tracing investigations that show that growing plants gain far more mass than the soil loses, similar to Von Helmont's famous experiment (Hershey, 1991; O'Connell, 2008). Even after taking an undergraduate biology course, students still struggled to conceptualize the process of photosynthesis in terms of matter tracing and matter conservation (Brown and Schwartz, 2009; Hartley et al., 2011; Parker et al., 2012). The core of the problem is that students lack a systems view of the natural world that incorporates a model of matter and energy at the atomic-molecular scale. Instead students tell simplified stories that help them make sense of their world (Driver et al., 1994; Mohan et al., 2009; Wilson et al., 2006).

Students' evolving language and ideas about matter and energy in carbon-transforming processes has been described previously in an empirically-based learning progression framework (Jin and Anderson, 2012; Mohan et al., 2009). The learning progression framework is a description of increasingly sophisticated knowledge and practice (National Research Council, 2007) that students use to account for matter and energy in carbon transforming processes like photosynthesis and biosynthesis. It includes four levels of achievement, or stages in the transition from informal or force-dynamic explanations (Pinker, 2007; Talmy, 1988)to scientific reasoning:

- *Level 1: Pure force-dynamic explanations:* Students' explanations focus on actors and enablers, using relatively short time frames and macroscopic scale phenomena. Events are connected by cause and effect rather than by tracing matter and energy.
- *Level 2: Elaborated force-dynamic explanations:* Students' explanations continue to focus on actors and enablers, but they add detail and complexity, especially at larger and smaller scales. They include ideas about what is happening inside plants and animals when they grow and respond, for example, and they show awareness of larger scale connections among phenomena such as food chains. Level 1 explanations are most common in elementary school students (Mohan et al., 2009), so for this paper, we combine level 1 and level 2 explanations into a single category; level 2 force-dynamic reasoning.
- *Level 3: Incomplete or confused scientific explanations:* Students show awareness of important scientific principles and of models at smaller and larger scales, such as atoms and molecules, and relationships among populations in ecosystems. They have difficulty, though, connecting accounts at different scales and applying principles consistently.
- *Level 4: Coherent scientific explanations:* Students successfully apply fundamental principles such as conservation of matter and energy to phenomena at multiple scales in space and time. They give complete and accurate accounts of all of the matter and energy in a system before and after an event and constrain their explanations by laws of conservation of matter and energy.

Students from middle school to college provide explanations in a range of learning progression levels, even within the same classrooms. For example, Mohan et al. (2009) found that only 10% of explanations given by high school students were Level 4 responses, while approximately 35% were Level 3 and 52% were Level 1 or 2 explanations. At the college level, even after instruction in introductory biology or upper-division ecology courses, only 27% of the explanations were Level 4 type responses, while 50% were Level 3 and 16% of student responses were Level 2 (Hartley et al., 2011). For the purpose of this paper, we examine middle and high school students after introductory biology instruction, a group who may display qualities that are very similar to beginning students in an introductory biology course in college in that many use informal rather than scientific ways of reasoning about carbon transforming processes.

Even when they are scientifically incorrect, students' everyday ideas and conceptions can be used to establish a foundation to build new knowledge (Howe, 1996; Murphy, 2012). A student's everyday understandings are often cogent stories about the world that *make sense* to the student and are embedded in everyday experience and discourse (Gee, 1996; Pozo and Gómez Crespo, 2005). These initial intuitive ideas can be used as starting points for constructing more complete and complex scientific understandings. This assumption follows the constructivist theory that students build sophistication in their knowledge by integrating new ideas into their "conceptual ecologies" (Posner et al., 1982) rather than simply replacing old ideas with new ones (Maskiewicz and Lineback, 2013; Smith III et al., 1994). In this paper we explore how students' stories and interpretations of the world are reflected in their explanations of the process of plants growing, and their reasoning about investigations of plant growth.

Historically, instruction about plants, and science in general, has emphasized content knowledge. More recently science education reform has emphasized learning of science practices embedded in content learning. The *Next Generation Science Standards* (NGSS Lead States, 2013) integrate science and engineering practices with disciplinary core ideas and crosscutting concepts. Likewise, *Vision and Change in Undergraduate Biology Education* (Brewer and Smith, 2011) outlines core competencies and disciplinary practices as well as core concepts. Both of these standard setting-documents send the message that knowledge and practice are inherently interconnected and to truly build science understanding students need instruction that integrates content and practice, instead of teaching practices or content in isolation.

In this study we focused on two key practices described by the *Next Generation Science Standards* (NGSS Lead States, 2013): constructing explanations and engaging in argument from evidence during experimentation. An explanation is an attempt to make sense of phenomena by reasoning from scientific models or theory. Arguments from evidence are attempts to justify claims using evidence and reasoning connected to a scientific model or theory (Krajcik and McNeill, 2009). The use of the arguments from evidence is usually required of students during investigations. Arguments from evidence differ from explanations in that they stem from some degree of uncertainty about a phenomenon (Osborne and Patterson, 2011). The two practices are similar in that they require students to connect a model or theory with natural phenomena. Using evidence from an investigation to make an argument of a phenomenon is an important component of scientific literacy, as well as a primary practice of scientists. In classrooms, the goal of educators is for students to use reasoning to connect explanations about "how plants grow" and arguments from evidence during experiments of plant growth, hence using both practices to build their understanding.

The reasoning that connects investigations to scientific explanations is obvious to scientists. Scientists interpret the purpose of investigations as a way to test a claim that relates to a model, and data as evidence to support or refute a claim or model. But, students do not always interpret a classroom investigation as a scientist would; often students have different purposes for their investigations, for example, to explore, to make something happen by manipulating variables, or to solicit attention (Rath and Brown, 1996; Schauble et al., 1991; Windschitl et al., 2008). And for students, explanations have lots of different meanings, including citing a law, or a simple cause and effect relationship, that do not include an explanation using scientific models (Braaten and Windschitl, 2011). This disconnect between students' interpretations of investigations in the classroom and the scientific practice of investigation for the purpose of theory-building can result in classroom inquiry activities that do not serve to build students' understanding of plant growth and metabolism.

In this study we investigate the relationship between students' explanation and argument from evidence practices in the context of plants growing. In an interview setting, we asked students to explain how plants grow in two scenarios and to reason through two claims and sets of evidence about the source of matter for plant growth. In our analysis, we focused on the consistency between students' explanations and interpretations of arguments from evidence. We discuss how students' sense-making strategies and level of understanding of chemical change lead them to interpret—or misinterpret—investigations and arguments from evidence.

Method

Data collection

To study the relationship between students' explanation and argument from evidence practices, we coded and analyzed post-instruction interviews of middle and high school students (n = 22) from states including Michigan, Washington, California, Maryland, Colorado, and Pennsylvania who had completed at least three out of six units about matter and energy (at least six weeks of instruction) called the *Carbon TIME* (Transformations in Matter and Energy) curriculum (Anderson et al., in prep). The purpose of these units was to help students learn to explain how chemical changes during carbon transforming processes (photosynthesis, cellular respiration, biosynthesis and combustion) are responsible for the structure and function of all living systems and support our lifestyles. The students' biology teachers conducted the face-to-face interviews during the 2012-2013 school year. The teachers were instructed to choose two students of varying levels of understanding of carbon transforming processes.

Teachers were provided with semi-structured interview protocols. In the interviews, students were asked about plant growth in three contexts (Appendix), in this order:

1) The Oak Tree questions: students were asked what an oak tree needs in order to grow and how the tree uses those things to grow.
2) The Karen and Mike questions: students were asked to critique a claim and set of evidence about plant growth provided by two different fictional "students," Karen and Mike. First, students were presented with both Karen's and Mike's claims (Figure 1) and were asked which student they agreed with. Students provided a choice and often a justification of their choice. Second, students were presented with one of two follow-up cards describing an investigation (Figure 2). Students were presented with the card of the "person" whose claim they agreed with and asked to explain: the investigation and evidence presented on the card, how the evidence supports the claim, any weaknesses in evidence that would strengthen the argument. Then the second card was presented and the same questions were asked. Notice, both Karen and Mike provide claims about matter tracing (not cause and effect), with Mike claiming that the weight of growing plants comes mostly from the soil while Karen claims that the weight comes mostly from the air. The evidence provided by both Karen's and Mike's investigations is deliberately inconclusive. Karen's investigation provides evidence that essentially replicates von Helmont's experiment (and resembles an investigation the students did in class). The evidence from her investigation contradicts Mike's claim, but does not account for other possible sources of mass such as water. The evidence from Mike's investigation actually contradicts his claim, since only 3 grams of added fertilizer cannot account for 15 grams of plant growth. The reasoning for both investigations is deliberately missing. We wanted to see what kinds of reasoning students would propose to connect claims and evidence, both for claims that they agreed with and claims that the disagreed with.
3) The Pound of Wood questions: students were asked where the matter in a pound of wood comes from when a tree grows.

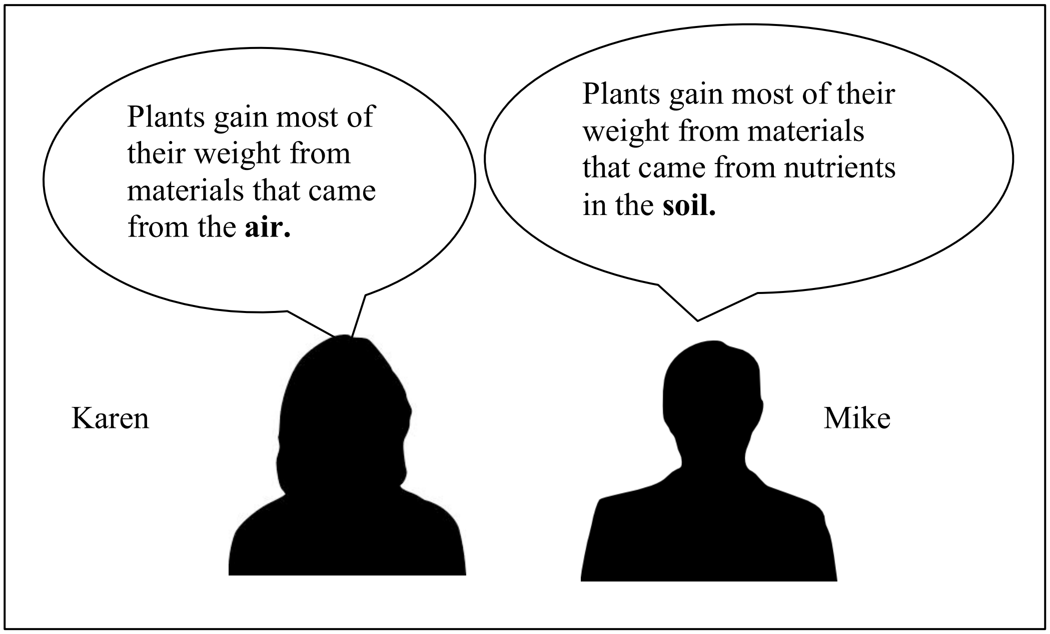

Figure 1: Initial claim card used in the Karen and Mike argumentation question. The card was presented and the student was asked to indicate which of the two claims they agree with.

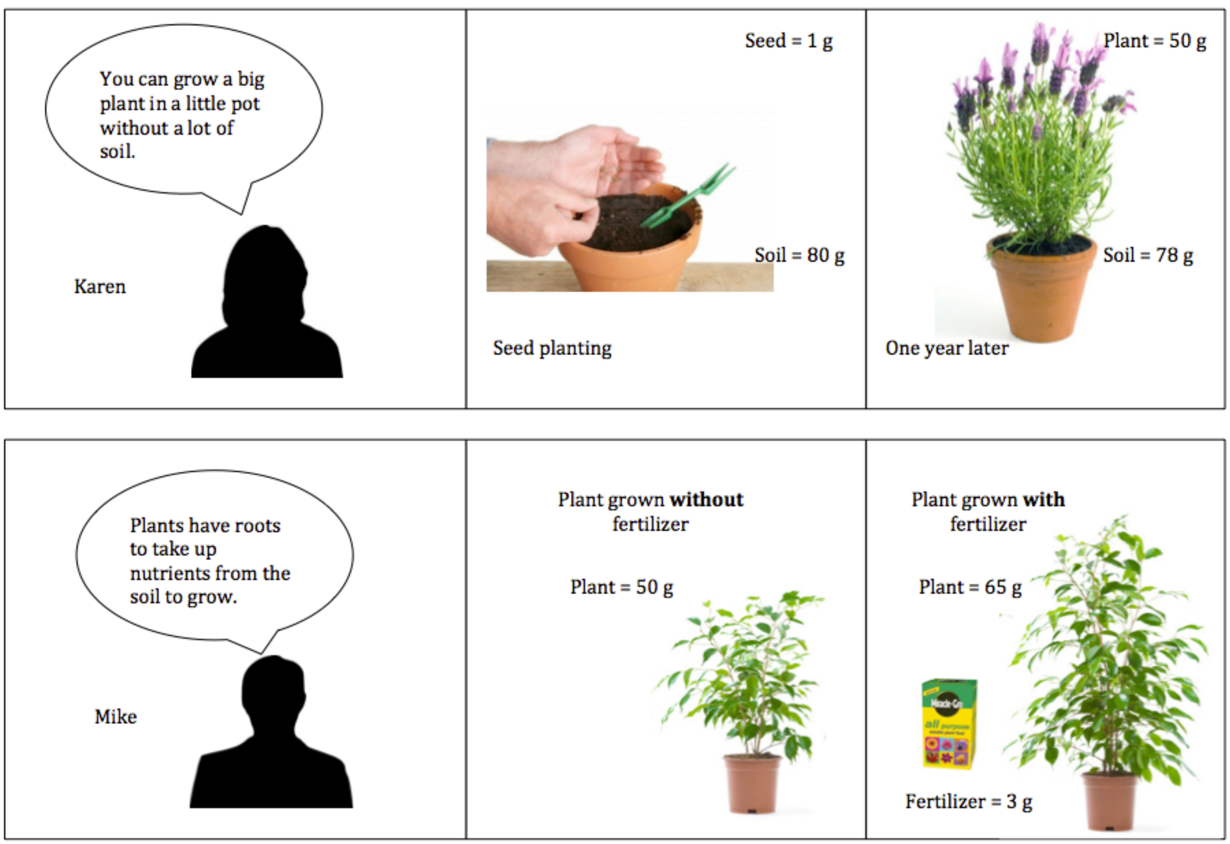

Figure 2: Two follow-up cards used in the Karen and Mike argumentation interview question that were presented one at a time to a student. Students were presented with either Karen's or Mike's card first, starting with the person whose claim the student thought was correct. Students then were asked to explain: the investigation presented on the card, how the evidence supports the claim, the weaknesses in the investigation, and what evidence that would strengthen the argument. Then the second card was presented and the same questions were asked about either Karen's or Mike's investigation.

Data Analysis

The interviews were video recorded and transcribed for analysis. The interview tasks were coded based on a framework following The Three Questions about carbon transforming processes:

1) The Location/Movement Question: Where are atoms moving? Where are atoms moving from? Where are atoms going to?
2) The Carbon Question: What is happening to carbon atoms? What molecules are carbon atoms in before the process? How are the atoms rearranged into new molecules?
3) The Energy Question: What is happening to chemical energy? What forms of energy are involved? How is energy changing form one form to another?

These Three Questions were originally developed as a teaching tool for middle and high school instruction and implemented in the *Carbon TIME* Curriculum (Anderson et al., in prep; Dauer et al., 2013a). The Three Questions were used in the curriculum to scaffold student explanations, for example, a student must answer all three questions in order to give a complete account of photosynthesis and biosynthesis in growing plants. We used these questions to structure our interview analysis, however, for this paper we narrowed our focus to only matter so we just considered answers to the Location/Movement and Carbon Questions.

For the two interview questions prompting for student explanations (Oak Tree and Pound of Wood), we gave each a learning progression level code. The learning progression levels were used to describe levels of sophistication in student practices including explaining chemical change at the atomic-molecular level (Carbon Question) and tracing materials to and from the plant (Location/Movement Question). In Table 1 we indicate how the learning progression levels relate to the Carbon Question and the Location/Movement Question.

Table 1: Learning progression levels and their relationship to the Carbon Question and Location/Movement Question

	Learning Progression Level		
	2	**3**	**4**
Carbon Question	Hidden mechanisms, no description of chemical change	Describes transformation of matter but with inconsistencies including matter-energy conflation or otherwise breaking the law of conservation of matter.	Describing transformation of matter at the atomic-molecular level including specifically describing the breaking and rearrangement of molecules
Location/Movement Question	Tracing cause and effect	Traces using atoms and molecule language, but with mistakes or inconsistency at the atomic-molecular level	Traces atoms and molecules even when prompted at the macroscopic level

For interview questions prompting for interpretations of arguments from evidence (Karen and Mike) we coded all of the transcripts with three categories: 1) *Purpose of the investigation 2) Agreeing with Karen or Mike and reasons why* 3) *Use of evidence*. These categories emerged after multiple rounds of coding and based on previous analyses on the Mike and Karen question (Dauer et al., 2013b). We coded the "*Purpose of the investigation*" based on how students' described Karen and Mike's experiments and students' implicit conception of why the investigation was being performed. We also found that students' view of the purpose of the experiment influenced how they interpreted claims and evidence (Dauer et al., 2013b). For example, instead of tracing matter using the mass data as evidence, students were trying to find the cause of an event by reasoning about multiple enablers that are important for plants to grow, or trying find the winner or best strategy for growing plants by focusing on a comparison of experimental factors (sunlight, water, soil, air) that influence plant growth. The levels of sophistication in this coding category include:

a) Tracing matter by applying principles of conservation of matter to constrain the argument similar to Level 4 type of tracing.
b) Strategies for plant growth (an experiment or comparison *is* needed to answer the question).
c) Identifying needs/enablers (no experiment is needed to answer the question) similar to Level 2 force-dynamic reasoning.

The students' view of the purpose of the investigation may influence who they consider to have a better argument and what data are valid in the argument, leading to our second and third category for coding students' arguments from evidence.

We coded for the students' choice between Karen and Mike as being more correct, and their comparison of the two sets of claims and evidence for the category, "*Agreeing with either Karen or Mike and reasons why.*" All arguments from evidence have at least two different arguments that are being compared and result from uncertainty between the two claims. The levels of sophistication of students' responses in this coding category includes that the student agreed with either Karen or Mike:

a) Because of different answers to the Location/Movement Question—tracing matter into the plant from different locations.
b) Because of different strategies for getting plants to grow.
c) Because of different (and not necessarily incompatible) needs or enablers.
d) No reason given.

The third category "*Use of evidence*" describes the students' use of observations or data in their interpretation of the argument from evidence from Karen or Mike, and the role of the observations or data in the students' reasoning. Observations include the mass data provided by the interview, or the students' reference or implicit use of the images provided, or prior personal experience. The levels of sophistication in this coding category include:

a) Noticing the provided mass data and interpreting the purpose of the data as for tracing.
b) Noticing the provided mass data and interpreting the purpose of the data as to show successful growth.
c) Noticing the provided plant images and interpreting the purpose of the images as to show successful growth.
d) Using personal experience preferentially or in addition to data.
e) Not using evidence.

Each transcript was coded by at least two of the authors. If there was a discrepancy in our coding we discussed the transcript at length resulting in reconciliation in codes and/or refinement of our coding scheme. After coding the transcripts, we compared codes across types of interview questions to determine if students who were successful in their explanations of the Carbon Question and Location/Movement Questions in terms of "how plants grow" were also successful in interpreting the purpose of the experiment about growing plants, and thus their interpretation of claims and evidence.

Results

We begin our results by describing three students who illustrate patterns that we saw across the full set of interviews. In particular, we analyze how these students' explanation and argumentation practices compare across interview contexts. Then we discuss how these patterns were observed across the remaining transcripts by comparing learning progression level codes for student explanations in Oak Tree and Pound of Wood to students' interpretations of Karen and Mike's claims and evidence.

Three exemplar students

Three students we describe below represent a range of responses and trends we saw among the student interviews. All three students were interviewed at the end of a 9th grade biology class that included instruction on matter and energy in plant growth. The three students, Erika, Spencer and Olivia (pseudonyms), were at different schools with different teachers. All three students had instruction on photosynthesis, cellular respiration and biosynthesis in plants and had performed experiments with growing plants in the classroom that resembled von Helmont's experiment.

Table 3: Student responses to Oak Tree

Interviewer Prompts in Oak Tree	Olivia Explanations at a Level 4	Spencer Explanations at a Level 3	Erika Explanations at a Level 2
What does the tree need in order to grow?	*It needs sunlight and then necessary building blocks for the molecules in there…. Like carbon dioxide, water and then like certain nitrogen and then those P's, S's and O's.*	*It needs sunlight and water and soil.*	*Sunlight, water and air…. Maybe soil*
How does a tree use soil (or nutrients) to grow?	Not asked by interviewer.	*I'm not sure.*	*I think there are special nutrients that the soil has to help the tree get bigger…. I think the roots take in the nutrients from the soil to help it grow.*
How does a tree use air to grow?	*It uses the carbon dioxide to grow because through photosynthesis it takes the carbon dioxide and water and the sunlight in order to create glucose. And then in the glucose it has energy stored in there.*	*Yeah, it needs oxygen to create photosynthesis I think. You have to have sunlight and water and oxygen to make that… Oh no—carbon dioxide, sorry. That's what … we use oxygen, trees use carbon dioxide, sorry.*	*There's carbon in the air, which the plant needs to create photosynthesis along with the sunlight.*
How does a tree use water to grow?	*Yeah, it uses that in the same process [photosynthesis].*	*I think, doesn't it use hydrogen and carbon dioxide to create, doesn't it like turn it into glucose somehow?*	*It uses water I guess to help the roots.*
How does a tree use sunlight to grow?	*Sunlight provides the energy that goes into the molecules, it like, provides energy for photosynthesis to happen … like all the energy for the tree basically.*	*I don't remember, but it uses something from the sunlight to help turn to glucose.* *INTERVIEWER: What would the sunlight provide that might help in that process?* *Spencer: Oh, energy.*	*It uses sunlight to create energy for it to live because the energy is sugar for the tree…. The tree uses carbon dioxide and the sunlight to make sugar for the tree, which is also energy, and it helps the tree live.*
Does the tree do anything with the air that surrounds it?	*Yeah, that's where it gets the carbon dioxide from.*	*Yeah, it takes in carbon dioxide and then it gives off oxygen.*	*It takes in the oxygen in the air and it makes more, I mean it takes in carbon and makes more oxygen.*
Is there a connection between exchanging gases and growing for the tree?	*That's how all the carbon dioxide gets into the tree to build the glucose and then also how the oxygen gets in to perform cellular respiration in order to, like, give the tree energy… then since oxygen is a byproduct of photosynthesis too it releases both oxygen and* CO_2.	*Yeah, because parts of the carbon dioxide, like, once it's broken down, it's used with the hydrogen to make glucose, which helps it grow.*	*The more oxygen it breathes out, I mean the more carbon … the trees take in the carbon and makes more oxygen.*

Table 4: Student responses to the Karen and Mike question.

Interviewer Prompts in Karen and Mike	Olivia	Spencer	Erika
Who do you think is right?	*Karen because a lot of the carbon and stuff, it comes from the air, and also the plant could get water from*	*… I think maybe soil because I don't know that the stuff from the air would give it much mass. But then*	*I think that Karen is right because without the air the plant wouldn't be able to make food, energy for itself*

	the air too …	*I also know that it takes the carbon dioxide from the air to make glucose … Probably Karen because I'm not really sure what nutrients they would use from the soil.*	*for it to grow… Mike is kind of right too, he says that the materials, I mean the nutrients in the soil help it grow. I don't know if there is anything special in the soil that it makes it grow.*
How does Karen's argument support her idea that the plant gains weight from materials that came from the air?	*…because the soil only, like, its mass only decreased by two grams while the plant's mass increased by forty-nine grams so forty-seven of those grams had to come from some place. Forty-seven of the grams that the plant's mass increased had to come somewhere else besides the soil.*	*…there's only a little bit of soil and her plant still gained a lot of mass, the soil isn't what gives it most of its mass it's the air."*	*That the plant got bigger … and the soil amount got smaller. If there wasn't any air that the plant wouldn't have gotten as big as it did.*
Are their some weaknesses in Karen's argument? Explain what they are.	*She doesn't say was anything added to the soil or no?... that's really the only thing I could think of.*	*Yeah, because she hasn't accounted for the fact that she watered it, or if she were to add anything to the soil that would change the mass of the plant.*	*Because of the soil amount went down it's possible that the plant could have used it to grow too.*
What evidence would strengthen Karen's argument?	*If she said what from the air helped it increase in mass…*	*…if she had a pot … one with less soil and one with more soil, and then maybe one that she fertilized and didn't, or one that she watered one she didn't, and then she could see which changing factor made it get biggest.*	*The amount of grams the plant grew which is a lot bigger.*
How does Mike's argument support her idea that the plant gains weight from materials that came from the soil?	*Because when something new is added to the soil the plant gained more mass.*	*…that most of the weight comes from the nutrients in the soil, because when he had less nutrients in the soil the plant was smaller and then when he added nutrients to the soil the plant got bigger.*	*The amount that the plant grew with the fertilizer was a lot bigger than the one without.*
Are their some weaknesses in Mike's argument? Explain what they are.	*Yeah, well the plant only gained three more grams… the plant gained fifteen more grams when only three grams were added from the soil so that means not all of its mass came from the soil it just helped it grow more.*	*I guess the same as with Karen's he didn't test any other factors other then just with and without fertilizer.*	*That the plant can't just grow with fertilizer it needs other things too.*
What evidence would strengthen Mike's argument?	*…showing … where the plant was at, at the beginning and the end of*	*Probably if he like if he … watered one didn't water one, like he changed more*	Not asked by interviewer.

	the experiment. And to show that the plants were grown over the same amount of time.	*factors, like, he hadn't changed, added or tested more factors besides just the one.*	

Olivia: explanations of chemical change and using mass data as evidence of movement of materials

Explanations: Olivia was able to give Level 4 explanations across all interview questions. During the Oak Tree interview question Olivia quickly moved into descriptions at an atomic-molecular scale (Table 3). For example, when asked what a tree needs in order to grow, Olivia stated that a tree "needs sunlight and then necessary building blocks for the molecules in there." Olivia's descriptions of transformations of matter during chemical change were good answers to the Carbon Question and also revealed her understanding of underlying mechanisms. She answered the Carbon Question by describing re-arrangement of molecules stating that the tree "…uses the carbon dioxide to grow because through photosynthesis it takes the carbon dioxide and water and the sunlight in order to create glucose. And then in the glucose it has energy stored in there." In the Oak Tree question Olivia identified nearly all of the reactants and products in the processes of both photosynthesis and cellular respiration in plants.

Olivia consistently included air or CO_2 as the primary source for materials for plant growth across all interview questions, correctly answering the Location/Movement question in a way that was connected to her understanding of the process of photosynthesis and biosynthesis. For example, in the Pound of Wood question, when asked where a pound of wood comes from, Olivia claimed "The air around it will lose weight and also the soil could lose some weight but it won't lose, like, a ton; the air will lose most of the weight." She speculated that the air contributed either 50% or 75% of the weight that made up one pound of wood, with the remaining coming from materials in the soil. She explained her reasoning by saying that "the main thing that it gained mass in was carbon dioxide and water, that's where they came from, in the cellulose of the wood. But it could also be from the soil… for the other components contained in the wood." While some of her understanding of what the soil contributes to tree materials in terms of micronutrients was missing, in this interview question she consistently explained how matter from the air and soil could be transformed into wood.

Interpretations of arguments from evidence: Olivia agreed with Karen, "Karen [is right] because a lot of the carbon and stuff, it comes from the air" (Table 4). Olivia implicitly interpreted the purpose of each of the investigations to be about tracing materials, and used mass data and the principle of conservation of matter to constrain the arguments. For example she stated that Karen's argument supports the claim that materials for plant growth come from the air because "forty-seven of the grams that the plant's mass increased had to come somewhere else besides the soil." Olivia successfully used the mass data provided in the interview to trace matter through the plant and soil system.

Olivia also noticed that the connection between the claim and evidence in both Karen and Mike's arguments were flawed. Olivia said that Karen's argument would be strengthened "if she said what from the air helped it increase in mass…" highlighting that while Karen only showed that soil did not provide the majority of plant mass, but did not show that carbon dioxide from the air is what contributed to the mass rather than water or some other source. Olivia also correctly pointed out that Mike's evidence actually contradicted to his claim that materials for plant mass come from the soil because "only three grams were added from the soil so that means not all of its mass came from the soil" (Table 4).

Spencer: disconnected reasoning between Movement/Location Question and Carbon Question

Explanations: Spencer was an example of a student who was early in his commitment to the idea that atoms and molecules are necessary for scientific explanations of phenomena. He understood that materials are made of atoms and molecules, but he was unable to use this idea with consistency and detail. Therefore, we classified Spencer's explanations at a Level 3 in the learning progression. In the Oak Tree question, Spencer described molecules that make up air, namely oxygen and CO_2, being used to "create photosynthesis," a response focused on cause and effect more often found in Level 2-type explanations. As the interviewer continued to prompt Spencer to talk about each enabler, Spencer improved in his explanation. Spencer eventually became more specific, talking about how molecules carbon dioxide and “hydrogen” or water “create… glucose,” but he did not regularly give complete reactants and products (Table 3).

Spencer did not convincingly trace materials by linking locations in the environment to processes in terms of atoms and molecules. His answer to the Location/Movement Question involved tracing at a macroscopic level by including soil, air and water as all places that contribute materials to plant growth, without clearly describing which molecules from those locations are the materials that contribute to plant mass. Therefore his answer to the Location/Movement Question was somewhat disconnected with his ideas about chemical change and the Carbon Question (i.e. the process of photosynthesis).

During the Pound of Wood question, when asked where one pound of wood comes from, Spencer initially included a list of multiple sources of material including water, nutrients from the soil, and carbon dioxide from the air. When prompted further to explain what in the environment would lose weight when that tree gains weight, Spencer became more thoughtful, initially focused on soil as the source of materials of plant growth: “possibly the soil, because I feel like the soil is holding water that the tree takes up and it’s holding nutrients that the tree takes up so it’s going to lose mass when the tree takes up those things.” When asked about any other places that might lose weight, Spencer speculated about air as a source of matter: “the air probably would, well actually no, I don’t think it would because when it takes in carbon dioxide it puts out oxygen so it probably would go full circle, but maybe at the time it would.”

Spencer correctly traced materials from air to the plant, but did not account for all atoms during chemical change resulting in an interesting, but incorrect, idea: chemical change processes that release other kinds of molecules into the air that balance each other out. Because of his reasoning along these lines he said that, “probably the soil would lose like about two-thirds of the weight because it would have the nutrients and water and then the air would probably lose about one-third of the weight.” Thus we conclude that Spencer did not fully understand the answer to the Carbon Question, particularly how carbon dioxide sequestered as glucose goes through biosynthetic processes to become the matter of the tree.

Interpretations of arguments from evidence: Spencer was unsure if Karen or Mike had the better claim. He deliberated between soil and air as the source of materials for plant growth: “I think maybe soil because I don’t know that the stuff from the air would give it much mass. But then I also know that it takes the carbon dioxide from the air to make glucose... Probably Karen because I’m not really sure what nutrients they would use from the soil” (Table 4). After consideration, Spencer chooses Karen, relying on his understanding of photosynthesis. However, Spencer displays uncertainty or lack of confidence about the air providing enough mass for plant growth, and also what kinds of molecules in the soil might be used for plant growth.

Rather than interpreting the claims in both the Karen and Mike interview questions to be about tracing matter, Spencer interpreted the claims to be about factors in creating big plant growth. Spencer was able to use the mass data provided in the interview, but only as evidence in terms of “what are the best strategies for plant growth?” rather than evidence that atoms have moved from one location to another. Therefore, Spencer did not use Karen’s data to constrain her argument and was not able to recognize that Mike’s data were actually contrary to his claim (Table 4).

During the Karen question, Spencer described Karen as making an accurate claim because “there’s only a little bit of soil and her plant still gained a lot of mass, the soil isn’t what gives it most of its mass it’s the air.” While Spencer’s conceptual interpretation of the experiment was correct, he did not discuss how the 2 grams loss in weight of the soil couldn’t account for the 49 grams of plant growth. The weaknesses Spencer pointed out are about missing information about accounting for water or adding anything to soil. Spencer went on to say that a better test of his interpretation of Karen’s claim as “which factors add to the weight of the plant” would be to test by altering the amounts of each factor (Table 4).

During the Mike question, Spencer traced matter only at a macroscopic level, disconnected from chemical change (the Carbon Question). So, the weight data were less important to Spencer as evidence compared to the overall macroscopic result of a larger plant (i.e. “when he had less nutrients in the soil the plant was smaller and then when he added nutrients to the soil the plant got bigger”), resulting in Spencer not noticing that Mike’s evidence was actually counter to his claim. The only weaknesses that Spencer pointed out in the experiment is about testing *all* of the factors for plant growth: “I guess the same as with Karen’s he didn’t test any other factors other than just with and without fertilizer.”

Erika: force-dynamic reasoning throughout explanations and interpretations of arguments from evidence

Explanations: Erika gave Level 2-type explanations, reasoning about how trees grow based on force-dynamic explanations that involved actors (the oak tree) and enablers (sunlight, water, air and soil) that help the tree to grow. Across all interview questions, Erika consistently gave explanations of the role of each of the "enablers" without answering the Carbon Question by reasoning about processes involved in chemical change at the atomic-molecular level.

In the Oak Tree question, although Erika could name "photosynthesis," she described carbon and sunlight as *creating* photosynthesis. So to Erika, carbon and sunlight are the causes in a simple story about a phenomenon called photosynthesis, rather than reactants in a chemical processes. When asked if a plant needs "air" to grow, or when asked about gas exchange, Erika frequently responded by talking about "carbon" rather than "carbon dioxide" molecules (Table 3). Thus we interpret her use of the word "carbon" as a description of a quality or property of air, rather than as the molecules that make up air. This lack of precision in language is evidence that Erika did not have a strong story about what materials are made of at an atomic-molecular level, which is necessary for understand for answering the Carbon Question. She described soil as important in order for a tree to "get bigger" rather than tracing materials (Table 3). Thus Erika consistently explained cause and effect rather than tracing matter to answer the Location/Movement Question.

Erika continued to provide general answers about how plants use enablers to grow, rather than tracing matter, during the Pound of Wood question. When asked where a pound of wood comes from, Erika responded, "I would assume the roots getting bigger and coming out of the ground..." She identified air as a place that would lose mass, but was not able to articulate why, or to speculate how much how much mass the air would lose for a tree to gain a pound of wood.

Interpretations of arguments from evidence: When evaluating Karen's and Mike's investigations, Erika interpreted the investigations to be about "what causes a plant to grow" rather than tasks requiring tracing of matter using evidence. Throughout both the Karen and Mike segments of the interview, Erika continued to account for plants growing using force-dynamic explanations and a cause-effect answer to the Location/Movement Question.

Erika was not able to easily decide whether Karen or Mike had a more correct claim. This is consistent with her force-dynamic reasoning that multiple enablers (sunlight, soil, water and air) all cause a plant to grow. To Erika, both were correct since both soil and air were needed for plant growth. "I think that Karen is right because without the air the plant wouldn't be able to make food, energy for itself for it to grow…. Mike is kind of right too, he says that the materials, I mean the nutrients in the soil help it grow." (Table 4). To Erika, if the question is "what does a plant need to grow bigger?" the answer is that both Karen and Mike had good ideas about what helps a plant to grow.

For Erika, the mass data provided in the interview did not play an important role in the argument. When asked about Karen's argument, Erika did not use the mass data to trace materials from the environment to the plants. Erika explained that Karen's argument showed "that the plant got bigger …and the soil amount got smaller," and that "if there wasn't any air that the plant wouldn't have gotten as big as it did." In fact, to Erika, the idea that the mass of soil decreased in Karen's experiment was a weakness because it showed that the soil probably contributed some to growing a bigger plant. She said, "Because of the soil amount went down it's possible that the plant could have used it to grow too." Likewise, evidence did not play an important role during the Mike question. Erika explained that Mike's experiment supported the idea that plants gained weight from materials that came from the soil because "the amount that the plant grew with the fertilizer was a lot bigger than the one without." To Erika, the weakness in Mike's argument was that "that the plant can't just grow with fertilizer it needs other things too" including "air and the sun and water," essentially naming all the enablers of plant growth.

Overall trends in the data

Most students responded to the Oak Tree or Pound of Wood Questions with Level 3 explanations of photosynthesis and biosynthesis of growing plants (Table 2). Of the 22 students, 12 students (54%) gave Level 3 explanations during either (or both of) the Oak Tree and Pound of Wood questions, with incomplete or confused answers to the Carbon Question vaguely explaining chemical transformation, and Location/Movement Question tracing materials only in terms of macroscopic location instead of materials at an atomic-molecular level. Of the remaining students, 3 students (14%) only achieved Level 2 explanations, describing plants growing in terms of actors and enablers, and simplified cause and effect; and 7 students (32%) achieved a Level 4 explanations describing chemical change during photosynthesis or biosynthesis and describing the origin of atomic-molecular level materials for plant growth during either (or both of) the Oak Tree and Pound of Wood Questions.

Table 2. Total student count in a comparison of learning progression level for explanations based on highest level of achievement during either Oak Tree or Pound of Wood interview question, and student's interpretation of the purpose of the investigation during the Karen and Mike interview questions.

		Purpose of the Investigation (count of students within each category)						
		Karen Question				Mike Question		
Type of explanations given:	Choice:	Uncodeable	tracing materials	strategies for plant growth	identifying enablers	tracing materials	strategies for plant growth	identifying enablers
Level 4	6-Karen 1-Mike		7	0	0	5	2	0
Level 3	11-Karen 1-Mike		10	2	0	6	4	2
Level 2	1-Karen 2- Mike	1	0	1	1	0	1	2
TOTAL		**1**	**17**	**3**	**1**	**11**	**7**	**4**

We found that none of the students who gave Level 2 explanations during either (or both of) the Oak Tree and Pound of Wood questions correctly interpreted the purpose of either Karen or Mike's experiments to be about tracing materials (Table 2). Instead they described Karen and Mike's experiments to be about "what do plants need?" Although they ultimately chose between "Mike" or "Karen" as correct, the Level 2 students agreed that both soil nutrients and air are important to plant growth.

The seven students who gave Level 4 explanations during either (or both of) the Oak Tree and Pound of Wood questions primarily chose Karen, consistent with their explanations of the movement of matter in Oak Tree and Pound of Wood questions and interpreting both Karen's and Mike's claims to be about tracing matter (Table 2). Two students who gave Level 4 explanations chose Mike as being more correct. Both students had a Level 4 explanation of the Carbon Question in at least one question, but weaker understanding of the Location/Movement question, and interpreted Mike's claim to be an argument about strategies for plant growth rather than tracing matter.

We interpret the Level 3 students to be "in transition," in Vygotsky's Zone of Proximal Development or ZPD (Howe, 1996; Murphy, 2012; Vygotsky, 1978). Students in the ZPD tend to be sensitive to the kinds of support or scaffolding available for their responses. For instance, if a teacher offers leading questions and shows different ways to solve problems, this assistance can help the student can solve new, more difficult problems that they could not solve individually. Table 2 shows that the Level 3 students interpreted Karen's and Mike's evidence differently, with 11 of the 13 interpreting Karen's investigation as about tracing materials, but only 5 interpreting Mike's investigation using this frame. The difference, we hypothesize, lies in the kinds of responses scaffolded by the evidence. Mike's experimental comparison encourages a "horse race" interpretation, focusing on factors that help plants grow. Karen's mass evidence without a comparison, on the other hand, encourages students to focus more on her matter tracing claim. Overall students performed better on the Karen interview question, with the majority of students recognizing that the purpose of the experiment is to trace the source of mass for growing plants.

Discussion

We have good reasons for advocating that empirical investigations should play an important role in teaching about plants. We want students to understand that the ultimate source of all scientific knowledge lies in our observations of phenomena in the material world, and we want them to gain knowledge through their own investigations, not simply by accepting textbook knowledge as authoritative. So when students like Erika and Spencer—the vast majority of high school and college students—incorrectly agree that "when *plants grow,* their added weight *comes from* nutrients in the soil," it seems obvious that von Helmont-type investigations could be useful in a classroom to serve as a discrepant event. In these investigations, like Karen in our interview, the difference between the mass that the plants gain and the mass that the soil loses make it obvious that the mass must be coming from somewhere else.

But *is* it obvious to students like Erika and Spencer that von Helmont's results contradict their beliefs? The answer to this question hinges on their interpretation of the two italicized phrases in the previous paragraph. For students like Erika, "plant growth" is an *action* rather than a process involving movement and transformation of matter, and "comes from" implies causality rather than movement of matter (as when we say "his brown eyes come from his mother"). Thus for Erika the statement above simply means that soil nutrients cause or help plants to grow. Mike's investigation supports this claim, and Karen's investigation seems pointless: "Of course plants need air to grow, but how can you find out about *air* by weighing the *soil*?" Students like Spencer recognize that plants are somehow transforming matter as they grow, but it seems obvious that plants turn "like into like." In other words, plants transform carbon dioxide into oxygen (both colorless, odorless gases) and soil nutrients into the materials that they are made of (both solids).

So what did Olivia understand that enabled her to interpret and critique the investigations more productively? Our results suggest three key ideas or commitments:

1) *Nature of gases:* Gases are materials like solids and liquids that have mass and can be changed into or created from solids and liquids.
2) *A sense of necessity about conservation of mass:* When a system like a plant gains mass, materials from somewhere else MUST have entered the system.
3) *Conservation of atoms in chemical change:* The chemical processes involved in plant growth and metabolism can rearrange atoms into new molecules, but cannot change the identities of the atoms themselves.

For Olivia, Karen's and Mike's investigations simply confirmed what she already understood about plant growth. So how could students like Erika and Spencer actually *learn* from von Helmont-like investigations, using the investigations to develop new and deeper understandings of plant growth? Our results suggest that in order to investigate how matter and energy are transformed in plant growth and metabolism, students need some foundational understandings about matter and energy, but not the contents of the typical "molecules of life" chapter in a biology textbook.

Instead, we need to help students like Erika and Spencer *use the three points above as interpretive frames.* We note that most middle school and high school students can state the first two point, at least, as facts: They can recite that gases are a state of matter and have mass, and they can state the Law of Conservation of Mass. But they tend to forget or ignore these facts when they are interpreting complicated phenomena like plant growth. So our instructional challenge is to help students understand these points as rules that always apply in every situation, including Karen's and Mike's investigations.

Teaching for High-level Student Practice

This study shows that, even after instruction, most students understood conservation of mass and atomic molecular theory as *facts* but not as *rules that govern practices.* That is, the students could correctly state the Law of Conservation of Mass, some molecular formulas, and some chemical equations, but the students did not use these ideas consistently or effectively in their explanations or arguments from evidence. We see three core challenges in designing instruction that enables students to learn more effectively from investigations focusing on plant growth and metabolism:

1) *Understanding the nature of scientific explanations:* Students need to value and engage in reductionist explanations of plant growth and metabolism as visible manifestations of underlying chemical changes.
2) *Using conservation laws and atomic-molecular theory as rules:* Students need to "follow the rules" whenever they engage in explanations and arguments from evidence.

3) *Understanding purposes of investigations:* Students need to interpret the hypotheses, procedures, and results of investigations in ways consistent with their purpose and design.

We feel that we have made significant progress toward instructional designs that address these challenges, both at the college level (Rice et al., 2014) and in our continued development of the *Carbon TIME* curriculum at the middle and high school level. Some key strategies are summarized below.

Understanding the nature of scientific explanations. There are multiple scientific ways to explain plant growth—evolutionary, genetic, developmental, and so forth. So students need to understand that in some circumstances tracing matter and energy provides a powerful approach to explaining biological phenomena and to value this approach to explanation. We approach the issue of understanding by using the Three Questions (Table 5) to define a good explanation, by telling students that one approach scientists use to explaining processes in living things is to figure out answers to the Three Questions. Thus the Three Questions are introduced as a tool for helping students know what a good answer to a question such as: "how do plants grow?" To answer this question students must explain the location and movement of atoms (Question 1), what is happening to carbon atoms (Question 2) and what is happening to chemical energy (Question 3). At first this kind of explanation may seem arbitrary and unsatisfying to students, but over time they can come to appreciate its power. This approach reveals hidden mechanisms, helps us to see connections among processes that are otherwise invisible, and helps us understand what plants do with the enablers that they need to grow. In *Carbon TIME* we use the "Powers of Ten" video (Eames et al., 1989) to introduce students to the invisible world of atoms and molecules inside every organism and PowerPoint animations to link visible processes such as plant growth to movements and changes in molecules.

Table 5: The Three Questions

Question	Rules to Follow	Connecting Atoms with Evidence
The Location and Movement Question: Where are atoms moving? Where are atoms moving from? Where are atoms going to?	**Atoms last forever** in combustion and living systems All materials (solids, liquids, and gases) are made of atoms	When materials change mass, atoms are moving When materials move, atoms are moving
The Carbon Question: What is happening to carbon atoms? What molecules are carbon atoms in before the process? How are the atoms rearranged into new molecules?	Carbon atoms are bound to other atoms in molecules **Atoms can be rearranged to make new molecules**	The air has carbon atoms in CO_2 Organic materials are made of molecules with carbon atoms • Foods • Fuels • Living and dead plants and animals
The Energy Question: What is happening to chemical energy? What forms of energy are involved? How is energy changing from one form to another?	**Energy lasts forever** in combustion and living systems C-C and C-H bonds have more stored chemical energy than C-O and H-O bonds	We can observe indicators of different forms of energy • Organic materials with chemical energy • Light • Heat energy • Motion

Using conservation laws and atomic-molecular theory as rules. We have found that the Three Questions alone do not provide sufficient scaffolding for student explanations, so the second and third columns in Table 5 provide more guidance. The "Rules to Follow" help remind students to follow the laws of conservation of matter and energy. Finally, "Connecting Atoms with Evidence" allows students to link mass data to the question "where are atoms moving?" So, if a plant gains weight, that means atoms MUST have moved into the plant from somewhere. We also use other representations to help students trace matter and energy through processes. In her college-level course, Jane Rice uses "clips and strips"—paper clips to represent atoms and paper strips to represent energy units. In *Carbon TIME* we rely on molecular modeling (with twist ties to identify high-energy bonds in molecules, Figure 3) and on animations showing how atoms are rearranged into new molecules.

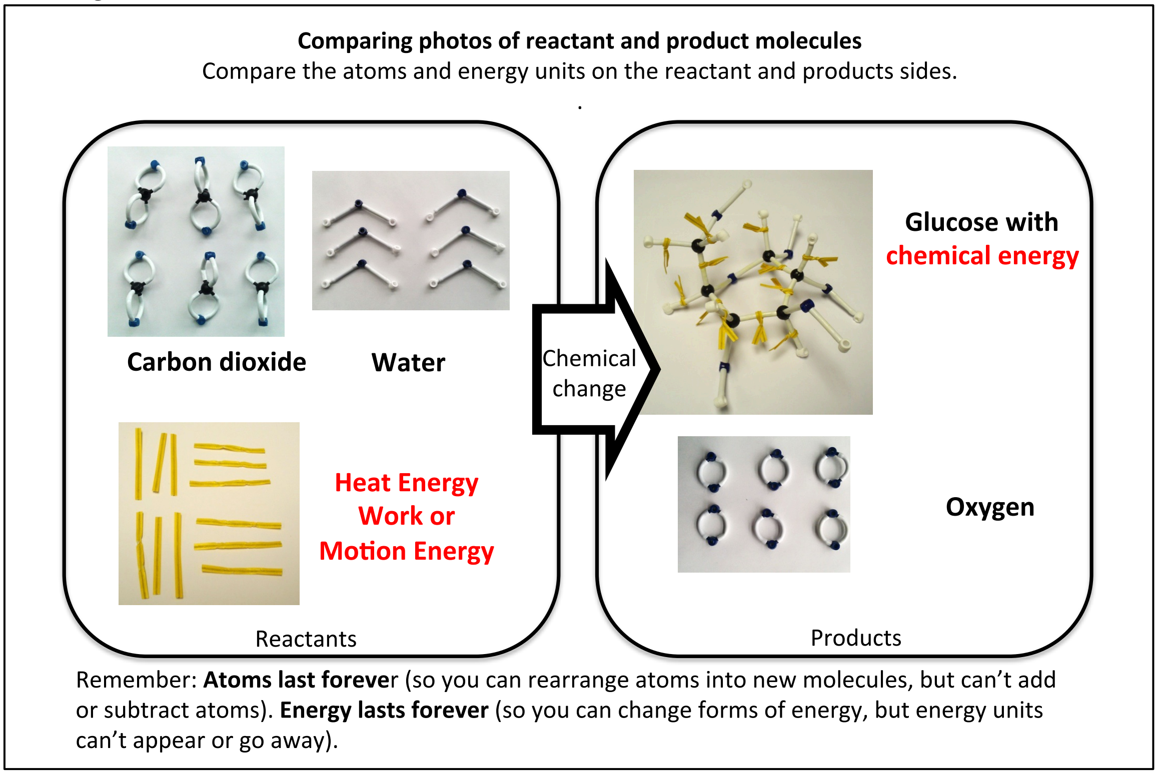

Figure 3: Twist ties to represent energy and molecular models during an exercise on photosynthesis, as they would be arranged both before (on the reactants side) and after (on the products side) modeling chemical change.

Understanding purposes of investigations. We found that both teachers and students often misunderstood the purposes of investigations in the *Carbon TIME* units, either using them to confirm what they had already been told or misinterpreting the results in ways similar to Erika and Spencer. We believe that the Three Questions Framework (Table 5) can provide important scaffolding for making the investigations meaningful to students, and connecting the investigation to student explanations of carbon transforming processes. So students who "follow the rules" can use mass changes as evidence relevant to the Location/Movement Question and bromothymol blue (BTB) as an indicator for carbon dioxide that provides evidence relevant to the Carbon Question. For example, if BTB turns from yellow to blue in a sealed container with a plant in the light, that means CO_2 must have been absorbed by the plant. Here, an *unanswered* question is what molecules the carbon atoms become part of after they enter the plant. A student must do a molecular modeling exercise to answer this question and learn that the carbon atoms in CO_2 can be traced to molecules of glucose and other organic materials. Finally, students may observe energy indicators like light during the inquiry investigations of plants. So, from the growth experiment or the experiment with the plant in the light, students may know that light energy is taken in by plants and is important for plant growth. But an *unanswered* question is what happens to the light energy once the plants absorb it? A student must do a molecular modeling exercise to answer this question and trace energy from light to chemical energy in glucose molecules in the plant. Thus students use the framework of the Three Questions to explore both the nature and the limits of scientific investigations and arguments from evidence.

The role of scaffolding. One of the fundamental premises of scaffolding is teacher responsiveness to student learning (Scott, 1998). While teaching students who are within the ZPD, one must be aware and respond appropriately to the differences between a student's present level of understanding about a topic and the level of performance outlined by the learning goals (Scott, 1998). Throughout the process of achieving learning goals, a teacher should respond by modifying assistance and scaffolding as appropriate. This process will include monitoring student progress, assisting and coaching students when necessary, and fading to let students apply their new knowledge to different situations. This may include referencing the Three Questions handout during instruction or encouraging students to think about what's happening to atoms in any given investigation or activity. The path to learning scientific concepts begins with the familiar, and over time as exposure to scientific concepts increases, concepts become more concrete and internalized (Murphy, 2012). This type of knowledge construction involves providing the time and space for students to move back and forth between their everyday and scientific understandings (Murphy, 2012). This process is an iterative one that includes negotiating between everyday and scientific knowledge, and support for students to integrate their everyday understandings into the scientific concepts (Murphy, 2012).

After some prompting, students at a Level 3 understanding, like Spencer may have the ability to provide sufficient explanations of carbon transforming processes but they still may not completely understand the purpose of an investigation regarding the same processes. They may revert back to their everyday or familiar understanding of a concept and disregard the new information (Howe, 1996). Eventually, with coaching and practice, students are able to internalize the use of scientific concepts as a way of thinking about and interpreting their everyday world. In turn, they will use their reorganized and reconstructed concepts to reason across multiple contexts and situations. Over time, as students are exposed to the Three Questions during instruction, the questions become part of their intellectual process and constrain their thinking when dealing with complex phenomena such as plant growth and other carbon transforming processes.

Conclusion

There are persistent problems for students from K-12 to college in explaining where the matter that makes plants comes from, and in understanding investigations about plant growth. We found that these persistent problems are associated powerful and appealing explanations that plant growth is an action and that water, air, sunlight, and soil are enablers of this action rather sources of matter and energy that are transformed in living systems. These informal explanations for plant growth also influence how students interpret the purposes of investigations of how plants transform matter and energy. Many students re-interpret the claims provided in interview questions to be consistent with claims about the best ways to grow plants, rather than claims about tracing matter. Thus learning about plants through investigations requires both careful coaching about the purposes of inquiry and a fundamental understanding of the nature of matter and energy.

We have developed a suite of teaching tools that we hope will be more effective at making investigations more meaningful to students and help them make connections between their explanations and the practices of inquiry. These tools support students by creating a framework for what should be included to a good answer to a question about what makes plants grow, and support for following atoms through a chemical change and connecting the atomic-molecular and macroscopic scales.

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Supplemental Material

Interview Script:
General Tracing Questions: Tree Growing

1. [Elicit a list of enablers: air, water, soil (nutrients), and sunlight.]
   "What does the tree need in order to grow?"

2. [For enablers not listed by students ask the following until all enablers, sunlight/soil/water/nutrients, are mentioned.]
   "Other students told me that the tree needs X to grow. Do you agree?"

3. [Follow up with specific probes about role of all the enablers in growing.]
   "How does the tree use air to grow?"
   "How does the tree use water to grow?"
   "How does the tree use soil (nutrients) to grow?"
   "How does the tree use sunlight to grow?"

4. *"Does a tree do anything with the air that surrounds it?"*
   [Possible alternate wording for lower-level students: Does the tree breathe?]
   "What does it do? (How does it do that?) What gases are involved?"

5. *"Is there a connection between exchanging gases (breathing) and growing for the tree?"* [If student says yes] *"What is the connection?"*

Arguments from Evidence Questions
[Show the image of Karen and Mike silhouettes.]

"We are interested in how people use evidence to support their ideas. We're going to talk about two students who disagree with each other about how plants gain weight when they grow. One student Karen said: "The plant gains most of its weight from materials that came from the air.'
"Another student, Mike said: 'The plant gains most of its weight from materials that came from nutrients in the soil.'

1. *"Who do you think is right?"*

"Now let's talk about the quality of their arguments that support their idea." [**Start with the argument that the student agrees with; either Karen or Mike could be first. Show the card associated with Karen or Mike one at a time.**]
Karen who you _____ [agree/disagree] with, explains, 'You can grow a big plant in a little pot without a lot of soil.' Karen adds some evidence to her argument and explains 'A seed weighing 1 g was planted in 80 g of soil. After two years the plant weighted 50 g and the soil weighed 78 g.'

1. *"Can you explain Karen's argument?"*
2. *"How does Karen's argument support her idea that the plant gains weight from materials that came from the air?"*
3. *"Are their some weaknesses in Karen's argument? Explain what they are."*
4. *What evidence would strengthen Karen's argument?*

Mike who you ____[agree/disagree] with explains, 'Plants have roots to take up nutrients from the soil to grow.' Mike adds some evidence to his argument and explains 'A plant grown with no fertilizer weighed 50 g, and a plant grown with 3 g of fertilizer weighted 65 g.'"

5. "*Can you explain Mike's argument*?"
6. *"How does Mike's argument support his idea that plant gains weight from materials that came from the soil?"*
7. *"Are their some weaknesses in Mike's argument? Explain what they are."*
8. *What evidence would strengthen Mike's argument?*

Mass and Energy Tracing Questions

1. *"The tree gains weight as it grows. Suppose the tree gains exactly one pound of wood. Where does that one pound of wood come from?"*

2. *"Does something in the tree's environment have to lose weight in order for the tree to gain weight?"*

   [Alternative explanation for lower level students: "When you gain weight, you use the food you eat, so it loses weight. Is there anything like that for the tree—the tree uses it so that it loses weight when the tree grows?"]

   [If the students answers "yes."] "*What loses weight when the tree gains weight? If the tree gains exactly one pound, can you predict how much weight [the materials named by the student] will lose?"*

3. *"What parts of the tree's environment will lose weight? How much?"*
4. "*Do you think that the tree needs energy?"*

   [If yes] *"Where does the tree get its energy? Out of the things that you named before [sunlight/soil/water/nutrients], which ones are sources of energy for the tree?"*

5. *"What is the difference between the things that give the tree energy and the things that don't?"*

6. *"Do different things give the tree different kinds of energy? Explain*."

7. *"Why does a tree need energy? Where does that energy go inside the tree? Is it still energy? Does it change into other things? How?"*