Matter and Energy Transformation: An Investigation into Secondary School Students' Arguments

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Abstract

Arguments are important to both the construction of scientific knowledge and development of skills as well as tools to assess this knowledge. That is, arguments are central to, for instance, scientific practices. Whereas research on arguments continues to accumulate, there is little evidence that this work focuses on the development of both instructional and assessment tools to support students in using empirically verifiable data, how these connect to claims about natural phenomena, and assess that learning. In this paper, we use a modified version of Toulmin's (1958) model of argument analysis to examine the kinds of Data and Warrants, and sometimes Backing (elements of argument) students use to support the Claims they make about matter and energy (e.g. see Jin & Anderson, in preparation) in their oral arguments about CTPs.

Our findings suggest that students use different kinds of elements to support their Claims. More sophisticated students tend to use those elements that appeal to scientific principles. However, less sophisticated students tend to use elements that are, for example, analogical, and/or tautological, as well as personal beliefs to support the Claims they make about these process.

Introduction & theoretical perspectives

Important educational documents on reform-based science (e.g. National Science Education Standards, 1996) have focused on and advocated for helping students to achieve scientific literacy. Research on science literacy, especially in learning progressions (e.g. Alonzo & Steedle, 2008: Mohan, Chen & Anderson, 2009), is expanding. Besides, school curricula have been developed partly in response to the call focused on helping students to achieve proficiency in science (NRC, 2007). This regards knowing, using, and interpreting scientific explanations of phenomena (NRC, 1996).

Our study aligns with these goals for science teaching. This study is part of our larger project work that focuses on the quality of students' accounts (Claims) of natural phenomena: in this case carbon-transforming processes. In the project, we analyze claims they make relating to the role of matter and energy in individual processes, such as tree growing, baby girl growing, girl running, tree decaying, flame burning, car running, lamp lighting, and cross processes and how these connect to claims they make about larger environmental issues, for instance, global climate change.

The primary cause of global warming is the current worldwide imbalance among three classes of carbon transforming processes (CTPs): (a) organic carbon generation (photosynthesis), (b) organic carbon transformation (biosynthesis, digestion), and (c) organic carbon oxidation (cellular respiration, combustion). Mohan et al. (2009) have analyzed students' accounts of these processes. This paper is focused on the nature of arguments (Carlsen, 1997; Erduran et al., 2004; Gotwals et al., 2009; Newton et al., 1999) they (students) construct in support of their claims.

Recent research on learning progressions (e.g. Alonzo & Steedle, 2008; Covitt et al., 2009; Jin & Anderson, 2008; Mohan, Chen, & Anderson, 2008) has shown that students have difficulties with the practice of tracing matter and energy in socio-ecological systems. Often, and as Mohan et al. report, students have matter and energy disappearing in their accounts of processes involving changes in states or forms. If research has to serve the goal of achieving science literacy for all students, then the practices relating to student reasoning about matter and energy should be explored in-depth as a way of informing both research and instruction. This way, it is possible to make sense of the challenges students face in learning science and use or design matching programs for supporting them in their efforts to overcome these challenges.

In this study, we examine students' reasoning in relation to argumentation as inquiry in their responses to questions about CTPs. But before we proceed with the larger discussion on practices, we wish to note the link between argumentation and inquiry.

Argumentation as Inquiry

Literature on science education (e.g. Driver, Newton, & Osborn, 2000; McNeill, 2009) presents scientific argumentation, as it does explanations, as a practice of scientific inquiry. Indeed, the treatment of argument as a practice of inquiry is emphasized in current reform-based science (NRC, 1996): That is, with a focus on promoting scientific literacy among students, reform efforts point to the idea that in order to support inquiry, science instruction and learning should be anchored on argument and explanation. Moreover, researchers (e.g. Berland & Reiser, 2009; Clark & Sampson, 2007) view argumentation as being a central practice of science upon which inquiry and instructional goals are developed. Berland and Reiser, as well as other researchers (e.g. McNeill, 2009;

Sandoval & Millwood, 2005) contend that argument and explanation are interrelated scientific practices of inquiry in that these not only emphasize building toward sense-making and articulation, but also persuasion regarding phenomena.

The view of argument as an aspect of *inquiry or investigation* (we use these terms interchangeably in this study) points to an age-old notion that substantial scientific knowledge is gained and developed through argumentation (Clark & Sampson, 2007). In fact, Kilbourn (2006) contends that studies that aim to contribute to knowledge tend to "make claims…that are supported … by argument and evidence." And that these are "opposed to claims based on unwarranted opinion, ideology, dogma, power, and authority" (p 531). Again, this is suggestive: That argument is an integral part of inquiry.

The NRC (1996 & 2000) emphasizes the need to support students in the practice of developing deep understanding of scientific knowledge and skills. Zembal-Saul (2009) views this emphasis as supporting students in engaging in evidence-based scientific arguments, a shift from merely engaging them in a less effective exploration and experimentation focused on ascertaining scientific ideas which might be already known to students. Additionally, Zembal-Saul notes that this shift signals a "relationship between the goals of scientific inquiry and the practice of argumentation, constructing and evaluating scientific arguments as an aspect of engaging in school-based scientific inquiry" (p. 691). This is in line with other literature (e.g. Duschl, et al., 2007; Songer, Lee, & McDonald, 2003; White & Frederiksen, 1998) which indicate that students who engage in the practice of scientific inquiry of, say, identifying a problem, gathering data and evaluating it, as well as drawing data-driven conclusions demonstrate higher gains in science learning. These students too, according to literature (e.g. Mercer et al., 2004), are likely to engage in scientific arguments and in effect learn the practice itself.

Furthermore, literature has indicated that learners who are engaged in the practices of scientific inquiry are likely to be motivated to learn science (Mercer et al., 2004; Mistler-Jackson & Songer, 2000; Okhee & Brophy, 1996; Tobin et al., 1999). To illustrate, Mercer et al.'s study about teacher scaffolding of student argumentation reported that those students who were engaged in argumentation contributed more to discussions and collaborated to reach consensus (based on scientific reasoning) than those who were not. Moreover, and as Bell and Linn (2000) inform us, students who engage in the practice of inquiry-based arguments are likely to not only promote knowledge integration but also that their belief of science as dynamic would likely be related to the development of more complex arguments.

An equally important finding from the literature is that students who delve into the practice of scientific inquiry are not only likely to improve their metacognitive skills but also experience conceptual change (e.g. Yore & Treagust, 2006; Duschl et al., 1999). Additionally, these students are likely to engage in intellectual development (Vygosky, 1986) based on, say, analytical (Toulmin, 1958) rather than rhetoric arguments (e.g. Driver, Newton, & Osborn, 2000). Consequently, these and other reasons arguably provide the impetus to use inquiry practices in both science learning and instruction. In order to move toward a more complete understanding of students' responses to items about socio-ecological processes, therefore, we elected to use practices of responsible citizenship framework as proposed by Covitt et al. (2009).

Practices of Responsible Citizenship

This association between argumentation and inquiry is consistent with Covitt et al.'s (2009) account of practices associated with decision-making in citizens' roles. As Covitt et al. inform us, people tend to ignore experts' perspectives on important issues such as global climate change because they either do not understand, for instance, the practices resulting in necessary decisions or simply tend to perceive the decisions as uncomfortable. Besides, some individuals may base their decisions on sources of information they believe to be reliable with little/no regard for investigation. A consequence of this would be two or more individuals/groups with opposing viewpoints regarding environmental decisions with far reaching environmental implications.

On the one hand, if decisions are narrowly conceived, they are likely to lead to negative individual and citizenship choices, suggesting a challenge to science education---how might all learners be prepared to work toward making (or influence the making of) responsible decisions now and in the future? For example, individuals, especially those in influential positions, may make or influence others to make little/no data-based decisions regarding, say Biofuel production (e.g. Gerbens-Leenes, et al., 2009) with a likely result of planting certain crops that are unlikely to deliver the results as claimed. To illustrate, these decisions may potentially lead to serious food shortages in the long run (e.g. see Wadhams, 2009). On the other hand, if well conceived, decisions are likely to lead to responsible citizenship choices, for example, why choosing energy efficient appliances over those that are energy inefficient as it relates to carbon footprint makes sense.

While it is important to focus on source of information and/or data as an aspect of making environmental decisions, it is equally important to see beyond source and consider quality of arguments based on those data. Thus, our other study of the process of decision-making regarding socio-ecological issues suggests an in-depth analysis of students' claims about these processes and the quality of arguments they construct in support of the claims made. An important step toward scientifically literate citizenry is to engage students in constructing arguments as they make sense of the world around them.

In this study, we use Covitt et al.'s (2009) Practices of Responsible Citizenship framework which lays emphasis on the practice of inquiry and argumentation. This theoretical framework relates to student involvement in intellectual work in the sense that it advocates for, to illustrate, students' engagement in socio-ecological issues in ways that likely lead to making environmentally responsible decisions. In their own words, Covitt et al. (2009) have argued that "when we judge that we don't know enough to make an informed decision, we investigate the problem, by inquiring directly into a situation or by relying on inquiry conducted by others" (p. 8).

Covitt et al. thus conceive supporting students in engaging in evidence-based scientific investigation and argumentation as practices of responsible citizenship and use them to frame our understanding of students' work regarding socio-ecological issues. We present this conceptual framework in figure 1 below. This view presupposes that students do not necessarily make decisions about socio-ecological systems based primarily on scientific reasoning. Rather, that they do so based on "many other factors—students' family and personal values, their common family practices, their identities, economic and social considerations, etc…" (p. 5). This framework lays emphasis on four dimensions: *Investigating, Explaining, Predicting, and Deciding.*

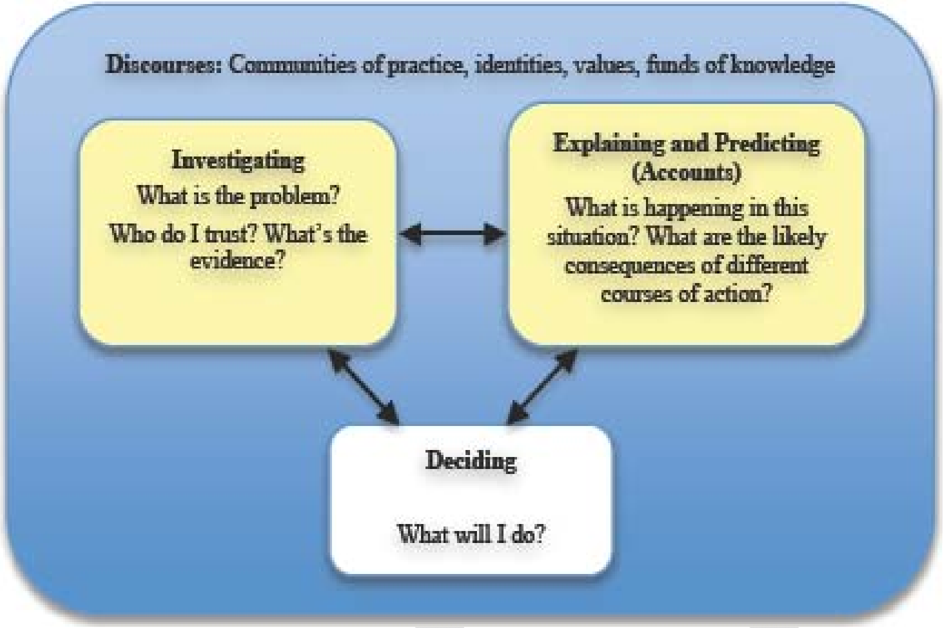

Figure 1: Practices of responsible citizenship

Although we make frequent reference to the accounts students make in their reasoning about CTPs, this study mainly focuses on the dimension of investigating. This is because our larger project work has covered the explaining and predicting dimensions as it relates to, for instance, water (e.g. Gunckel, Covitt & Anderson, 2009) and carbon (Mohan et al., 2009). Specifically, our focus is on how students use Data to defend the Claims they make in their oral work about transformations in matter and energy.

Research has shown that, although scientific practices are advocated in major education documents [e.g. American Association for the Advancement of Science (AAAS), 1993 & NRC, 2007], students and other people as well, face challenges in carrying out this practice (Covitt et al., 2009; Lee & Songer, 2003). In this study, we use the inquiry dimension of responsible citizenship to inform data analysis and interpretation. Our hope here is to work toward contributing a possible solution to the challenges of practice that students face. This dimension has three main constructs: Identifying a problem, information source and trust, and evaluating evidence.

Identifying a problem: is the first construct and its function is to guide the proposed investigation. This could be in terms of teasing out information about an issue at hand by asking such questions as what the problem is, what is known about that problem and what needs to be known about it. Covitt et al. (2009) have noted that students struggle with this construct when, to illustrate, investigating socio-ecological issues. This could be because they lack the necessary skills for using scientific information (Duschl et al., 2007) and therefore merely resort to, with little/no questioning, using social information sources and in effect treating these as authority.

Information source and trust: is the second construct and it regards reasoning about sources of information. This may be in terms of identifying, teasing out and selecting relevant sources of information needed for solving the identified problem. This amounts to making decisions about what sources of information to trust. Although important education documents (e.g. NRC, 1996) recognize that encouraging students to be skeptical and engage them in critically evaluating sources of information is important in making "personal and community decisions about issues in which scientific information plays an important role" (Duschl, et al., 2007 p. 7), the pedagogy, curriculum and standards unlikely help students to achieve this. This is because they tend to treat science as consisting "of solved problems and theories to be transmitted" (p. 3).

Evaluating evidence: is the third construct and it regards evaluating and using evidence in support of the claims made about the identified problem (Covitt et al., 2009): That is, in carrying out investigations about a clearly identified problem, this ought to be in concert with making decisions about what sources of data should be trusted, as well as how compelling the evidence is for use in solving the identified problem. Our study focuses in particular on this aspect of investigating: using and evaluating evidence.

Purpose of the study

The purpose of this study, therefore, is to seek to understand how students use evidence in constructing arguments. This involves analyzing elements of arguments (Toulmin, 1958) such as Data and Warrants, treated more fully under the analysis section, to support Claims regarding scientific processes about matter and energy transformation as a way of learning to talk science (Lemke, 1990). The view of learning to talk science encompasses "observing, describing, comparing, classifying, discussing, questioning, challenging, generalizing, and reporting among other ways of talking science" (p. 1). The idea of learning to talk science in educational settings presupposes that, besides helping learners to learn how to use scientific practices in their specific forms, it is important too that their use do not impede such learning.

Before describing participants and data sources we include in this study, we would like to briefly explain the specific arguments we address in this study. Scientific studies present the nature of science knowledge as attempts to persuade others of the validity of their claims, rather than consensus based on democratic processes (e.g. Tippett, 2009). Indeed, other studies refer scientific argumentation to as the language of science in which claims are made in one way or another, and supported by data of some sort (Duschl, Ellenbogan & Eduran, 1999, in Tippett, 2009). Whereas there are different forms of arguments, for instance, rhetorical/didactic arguments which present one point of view (Driver et al., 2000), and dialogical/dialectical arguments which explore different viewpoints during debate or discussion (Tippett, 2009), this study is focused on (we will return to this in the data analysis section) analytical argument as proposed by Toulmin (1958). This form of argument follows the rules of logic and is advocated for in reform-based science (e.g. Duschl & Osborn, 2002): That is, it is opposed to opinions and/or ideology. This study therefore, lays emphasis on the quality of arguments students construct and diverges from the traditional rhetorical arguments characteristic of classrooms (Yore, 2003).

For purposes of expanding on what is known about how students use arguments, we examine, in this paper, the quality of secondary students' arguments in their oral responses to questions about matter and energy transformation. This study is guided by the following *Research Question*:

> What is the nature of secondary school students' arguments about carbon transforming processes (CTPs) such as photosynthesis, biosynthesis, digestion, cellular respiration, and combustion?

Methods

This study is part of a larger multi-year project work that draws from a learning progression perspective (Mohan, Chen, & Anderson, 2009; NRC, 2007; Popham, 2007; Smith, Wiser, Anderson, & Krajcik, 2006).

Participants

In this study, we followed 16 secondary school students from four secondary schools in rural southwest Michigan. These students participated in one- to two-month long learning progression intervention as they were taught using designed instructional tools about carbon transforming processes. The schools included two public middle schools, one public high school, and a math and science center for gifted high school students (These students return to their public schools for other subject matter areas). All of the four teachers were science majors with at least a bachelor's degree. The selected teachers and students came from school districts with a largely Caucasian student population (approximately 88%). In these schools, an average of 37% of the students received either free or reduced lunch.

Data sources

We used data from clinical interviews regarding eight carbon-transforming processes, including photosynthesis, biosynthesis, digestion, food chains, cellular respiration and combustion (Mohan, Chen, and Anderson, 2009; see also interview protocol below). This data was from student pre-post clinical interviews conducted during the 08-09 academic year. Student interviews lasted for approximately 40 minutes. Our specific focus here was on students' use, if at all, of elements of arguments (Toulmin, 1958) described in detail in the analysis section below.

Our analysis focused on the portions of the interviews that addressed three processes: Tree Growing (TG), Flame Burning (FB), and Car Running (CR). Although the interview protocol itself for these three processes is included in the Appendix, we offer its brief description here below.

Interview Protocol

For both our large project on learning progression and this study, we developed an interview protocol to elicit students' understanding about eight focus environmental events: tree growth, baby girl growth, girl running, tree decaying, flame burning, car running, lamp lighting, and cross processes. Our interviews were generally based on the idea that the primary cause of global warming is linked to the current worldwide imbalance in carbon cycling through organic carbon generation, transformation, and oxidation. All eight events were designed based on these three carbon cycling processes.

The interview protocol contains a set of semi-structured questions for each focus event. For each event, we start the interview with a set of *general questions*—questions that use everyday language to ask about the actor and its enablers. For example, the major general questions for tree growth are:

- What does a tree need in order to grow? How does sunlight help the tree to grow?
- Do you think that water will change into other materials inside the tree's body?

However, these general questions are not effective for eliciting higher-level accounts. Hence, we also ask follow-up higher-level questions which are more specific about matter, energy, and processes. One example is:

- You said that the tree needs Carbon dioxide and breathes out oxygen. Where do the carbon atoms of CO_2 go?

Teaching experiments (e.g. see Jin & Anderson, in preparation): Before the intervention, the selected students responded to these questions. Depending on class schedules, the start of the intervention varied from school to school. During the intervention, teachers of these students used designed instructional tools to help them (students) work toward constructing scientific explanations of what happens to carbon during the aforementioned processes. After the intervention, the selected students respond to the same pre-interview questions. The purpose here was to seek students' reasoning about the same processes before and after more targeted instruction. We analyzed pre-post interview data from 16 students (a total of approximately 32 interviews) for the CTPs of TG, FB, and CR (a total of up to 83 arguments-some students did not complete all interviews): This was likely sufficient data for responding to our research question.

Data analysis

In this study, we used student interview texts (transcribed verbatim), to examine how they used data to defend their claims about how matter and energy are involved in CTPs. First, we used Excel to organize data based on CTPs. This helped us follow students' reasoning in each process. Second, we used elements of Toulmin's analytical framework to color code (e.g. see examples 1 & 2 below) data for each process. This was useful in moving toward responding to our research question in terms of identifying the nature of arguments students construct in the identified texts.

Research Question and Toulmin's analytical framework: For purposes of this analysis therefore, we used a modified version of Toulmin's (1958) model of argument analysis to help us code transcripts in terms of their role in students' arguments. The interviews were designed to elicit students' accounts or *Claims (C).* In particular, we were interested in the claims that students made about transformations of matter and energy during CTPs. We therefore sought to understand how students supported their *Claims* with *Data (D)* and usually *Warrants (W).* These three elements constitute what Toulmin calls a *basic argument*.

We also examined how students used *Backing (B)*, *Qualifiers (Q)*, and/or *Rebuttals (R),* if at all, to construct arguments relating to CTPs. Together with a basic argument, B, Q, and R constitute what Toulmin calls a *complete argument*, but the interview protocols elicited complete arguments only rarely. We provide descriptions of these elements in table 1 below (rubric), which we first generated from preliminary data analysis. A possible reason why the interview protocol rarely elicited complete arguments could be the nature of questions we asked--- we rarely challenged students to justify their Claims in detail. So, although our analysis focuses on basic arguments, we include analysis based on the element of *Backing*.

Table 1: Rubric for coding for elements of an argument

Element	**Toulmin's Description**	**Our Description**
Claim (C)	The conclusion whose merits the proponent of the claim seeks to establish	Statement(s) students make about how matter and/or energy are involved in CTPs: Relate to hidden mechanisms
Data (D)	Evidence that the proponent of the argument clearly appeals to as a basis for the identified claim	Visible observation(s) about CTPs, regarding a claim that students may make: May include verbal observations--- typically statements about needs of organisms or conditions for processes to occur and statements about visible results of processes.
Warrant (W)	General, hypothetical statements, which can act as bridges, and authorize the sort of step to which our particular argument commits us	Universal premises students make that link either one type of data and/or different types of data to the claim regarding specified CTPs.
Backing (B)	The credentials which are designed to certify the beliefs of the warrant	Universal premises students make that link warrants to theoretical frameworks which explain hidden mechanisms of CTPs
Qualifier (Q)	Statements which signal the strength of the warrant	Statements which signal the strength of the warrant (same as Toulmin's)
Rebuttal (R)	Statements suggest the context for which the general authority of the claim does not merit	Statements which suggest the context for which the general authority of the claim does not merit (same as Toulmin's)

In our work, Toulmin's framework (see also Erduran et al., 2004) seems to align with our interview protocol. Thus, it was not only useful in framing the data analysis for this study, but also in the interpretation of the resultant findings. For example, through the questioning process, we began by asking students to provide what Chi (1997) calls "messy" data in the sense that it is in the form of verbal observations. In this study, we operationalize (Feest, 2005) Data to refer to information relating to visible observations (inputs and outputs) about given CTPs. Then, we probed students to explain how that Data linked to the claim they made (Warrants). Whereas we were particularly interested in Warrants that mention principles such as conservation of matter and energy or hidden mechanisms, we were also interested in analyzing other types of Warrants that students generated. Following this, we asked them to provide further information that supported the connection they made between data and claim (Backing). In the next section, we illustrate the kind of analysis we present in this study by discussing two examples.

Examples of analysis

Example 1 illustrates a student's work (transcript) that uses Data and Warrants to support the Claims made in ways consistent with scientific standards of argument. By contrast, example 2 illustrates a student's work (transcript) that uses Data and Warrants in a more analogical sense to support the Claims made. All two transcripts focus on the process of flame burning (FB). In this process, we provided students with two pictures: one represented a match burning, and another represented a candle burning.

Example 1: More sophisticated student

In the following interview transcript about match burning, we demonstrate how the dialogue between an interviewer (I) and a student (ANW) proceeded and how this not only likely aligns with Toulmin's analytical framework, but also how data analysis proceeded. The color codes, in the two examples below, represent specific elements as shown in the analysis after each transcript:

1. I: What does a flame need in order to keep burning?
2. ANW: It needs oxygen, wood, wax and wick in order to keep burning
3. I: What is in wood that makes it burn?
4. ANW: Wood has chemical energy and that's what makes it burn. You have to
5. have stored up energy to make it burn.
6. I: So, talk about chemical energy of the wood. So, when wood is burning,
7. where does that chemical energy to go?
8. ANW: It's what's being burned.
9. I: So, do you think the chemical energy still exists or somewhere or changing
10. to some other types of energy, or just burn up?
11. ANW: It changes into heat and light energy.

I: Oh, so chemical energy changing to heat and light energy. Very good. So, how about wood?
ANW: When wood burns the, it gives off the same things from the candle burn, carbon dioxide and water (inaudible).

Data: From this dialogue, ANW offers, what she considers to be needs/inputs of FB (**Data**) that it “needs oxygen, wood …in order to keep burning” (line 2, blue highlight). Noticeably, in this interview, the interviewer influences the direction of the dialogue in, for instance, focusing it on wood only with no mention of other needs for FB that ANW identifies. For this reason, the interviewer probes about the specific premise of the need for wood for the flame to keep burning. Wood, as a need for flame burning, is therefore presented both as a source of chemical energy and as a raw material for matter transformation. Indeed, when further probed about the material of wood, ANW proceeds to account for it saying that it is given off in the form of carbon dioxide and water (lines14-15). We regard these two products as Data in the sense that they are visible results of FB which ANW uses to make claims about energy and matter.

Claim: When the interviewer further probes about energy, ANW provides information about the energy of wood, that it “changes into heat and light energy” (line 11, green highlight). That is, ANW seems to draw a conclusion that when a match burns, the chemical potential energy of the wood is transformed into other forms of energy, in this case, heat and light.

In addition, she concludes that wood, on burning, chemically transforms, implicitly though, into water and carbon dioxide (lines 14-15, green highlight) in the argument she makes: That is, ANW suggests that some hidden mechanism happens to wood with the resultant observable water and carbon dioxide. We consider these two statements as **Claims**, one about energy (from the preceding paragraph), and another about matter, in the sense that the argument develops around both energy and matter: That is, these are the main parts of the argument around which the interview is developed.

Warrants and Backing: After being probed by the interviewer about how wood helps the flame to burn, ANW points to the idea that wood has chemical energy (line 4, yellow highlight). This statement suggests the notion that wood is a source of fuel necessary for the process of FB. This way, the statement would serve as a universal premise to link wood to the process of FB. Thus, this statement would be part of the **Warrant s**he provides to support the need for wood in this process. Moreover, she seems to more fully offer a universal premise in support of the idea that wood is needed for the flame to keep burning saying, “You have to have stored up energy to make it burn” (lines 4-5). This seems to be what Toulmin calls personal knowledge that wood has indeed energy necessary for the flame to keep burning. ANW therefore successfully links Data to the claim she makes regarding both energy and matter transformations. ANW’s work contrasts with JMJ’s work which we present in example 2 below.

Moreover, ANW correctly suggests the idea that both energy and matter are neither created nor destroyed during flame burning (lines 11, 13-15). Rather, though implicitly, that these are conserved during this process. That is, ANW seems to point to the idea that the energy and matter of wood are constrained by the laws of conservation of energy and matter which explains the hidden mechanisms, in this case, relating to FB. We interpret this implicit understanding and use of universal (scientific) laws in support of the identified warrant (see transcript above) as implicit **Backing.** This is on the basis that it supplies more information about not only warrants but also the claims ANW provides and in the process, validating them.

Example 2: Less sophisticated student

In this example, we provide and analyze an interview dialogue between an interviewer (I) and a student JMJ for the same process as in example 1above [flame burning (FB)]. This analysis pertains to how JMJ attempts to both use Data and link it to the Claims, about matter and energy, she attempts to make in the interview. Here is the interview dialogue:

16. I: What does a flame need in order to burn? ...
17. JMJ: It needs the gas that they put on it. Like…
18. I: What gas?
19. JMJ: The gas that burns … like for the candle or the match …like the wood on the match
20. I: Ok. So what happens to the air when the flame uses it to keep burning?
21. JMJ: The *air like gets taken over by all the gases* in the flame. And then it uses the air.
22. I: Now what do you mean by take over?
23. JMJ: It like … I mean *it already is a gas but it makes it like a burning gas.*
24. I: Ok. …Why does the flame need wax and wood …? What happens to them?
25. JMJ: *It will disappear* because …*wax and wood are kind of like flames' food*... *without it,*
26. *they'll just die off*.
27. I: Oh. Ok. …And then do you think the wax and the wood are kind of used up?
28. JMJ: *Yes.*
29. I: Ok. So do you think this burning is kind of related to energy?
30. JMJ: Yes.
31. I: Could you give me more explanation about that?
32. JMJ: burning using energy just to stay alive…*without …energy, it's going … die*
33. I: So do you think the energy is created… [or] comes from like a wax or a wood or air?
34. JMJ: I think it comes from – *it's created*. So *it's kind of chemistry*. So like when two
35. things come together, there's that energy to burn.
36. I: Ok. So energy is created.
37. JMJ: Yes.

Data: From this dialogue, and like ANW, JMJ provides what she considers to be an observation (**Data**) that the flame needs "gas" (line 17, blue highlight) which she likens to the candle, match, and wood (line 19, blue highlight) to keep burning. From this interchange, the interviewer takes it that JMJ is talking about air, candle, and wood (line 19) as needs, and therefore, in this case, constituting Data for the flame to keep burning. Moreover, after being probed about what happens to wax and wood (line 24), the student seems to think that they disappear. Thus, although JMJ's idea of wax and wood disappearing reveals her thinking, it suggests that this reasoning does little to conserve matter. With the assumption that JMJ is treating air, candle, and wood, as needs, the interviewer shifts his questioning from seeking ideas for more needs to focus on more information regarding these three needs.

Although the interviewer later uses wax in place of candle (line 24), he probes for JMJ's understanding regarding how (see dialogue above) the three needs relate to flame burning. Thus, air, wax, and wood are seemingly treated as raw materials in the sense that without, for example, wood and air (Oxygen), the process of flame burning will not proceed. The shift in focus seems to be about seeking to understand JMJ's thinking about how matter and energy are involved.

Claim: To further understand how JMJ reasons about FB, the interviewer explicitly focuses the student's attention on both matter (lines 27 & 28) and energy (lines 29 & 30). When JMJ responds to the interviewer's questions, she suggests, implicitly, two points. First, that the matter of wax and wood are used up in flame burning, and in effect implying that that is how it should be, a view that is force-dynamic (e.g. Mohan et al. 2009) in nature. Unlike ANW who perceives FB as constrained by transformations of matter and energy, JMJ perceives the flame as needing wax and wood (matter) to keep it alive (lines 25-26). Compared to ANW's perception, we consider JMJ's perception as constituting a different kind of Claim: That matter undergoes some mechanism with the result that, rather than change of form, it ceases to exist.

Second, JMJ acknowledges that burning is somehow related to energy (line 30). Nonetheless, when asked for further information regarding this relationship (line 31), rather than focus on energy transformation, she contends that burning uses energy "to stay alive" without which the flame will "die" (line 32). In contrast to ANW who treats energy as one of the constraints of FB, JMJ perceives energy as causing this process to happen and helping the flame to stay "alive." In addition, JMJ maintains, as she similarly did regarding wax and wood (line 25), that energy is "created" (line 34), rather than a manifestation of energy transformation.

Furthermore, JMJ points to the idea that some hidden mechanism, which she refers to as "chemistry," (lines 34 – 35) happens to result into the energy of burning. We interpret this, implicitly, as constituting the Claim about energy. Again, this Claim is of a different nature from ANW's in the sense that it presents hidden mechanism in a mysterious way (line 34, green highlight). In addition to specifically probing JMJ about matter and energy, the interviewer also seeks to understand how JMJ thinks the data (inputs and outputs) link to the claim made.

Warrants: When JMJ is asked by the interviewer about how air (lines 20 & 22), wax, and wood (line 24) help the flame to burn, she reasserts her original Data (lines 21 & 23, yellow highlights). In fact, rather than provide a scientific bridge (Toulmin, 1958) between these three needs and the Claim about matter and energy, JMJ provides human analogy that connects claims to data in an entirely different way (See yellow italicized texts). This is unlike ANW who points to the idea that wood has chemical energy (line 4, yellow highlight). JMJ uses a Warrant that is analogical in nature to link the identified Data to the Claims—fuel for the fire is like food for a person. Arguably, using Warrants that are analogical in nature, in contrast to ANW's responses, is less sophisticated.

These two examples raise important questions that relate to our research question. For instance, what is the nature of all other individual students' arguments? How do individual arguments relate to those of other students? These are among the questions we used in both guiding further data analysis and identifying patterns that arose. In order to identify patterns, we sorted and classified, based on Data, Warrant and sometimes Backing, analyzed data into levels of achievement (Mohan et al., 2009). This way, we moved toward responding to our *Research Question*. That is, after identifying elements in the arguments the participating students made, we tried to describe those characteristics associated with *Levels of Achievement* as defined by Mohan et al. (2009).

Mohan et al. define **"***Levels of Achievement* as patterns in learners' knowledge and practice that [extend] across processes" (p 8). In this study, we focused our description of levels of achievement on students' knowledge and therefore use of elements of arguments as described in table 1 above to construct their arguments regarding CTPs: That is, for each level, we tried to describe how each of the identified element is factored into the students' arguments.

Mohan, et al. (2009) and other papers from the environmental literacy project provide rubrics for sorting claims into levels of achievement. For example, Table 3 presents the rubric we are currently using to designate levels of explanations in students' claims (from Jin, Zhan, & Anderson, in preparation).

Table 3: Levels of Claims	
Level 4. Linking processes with matter and energy as constraints	Linking carbon-transforming processes at atomic-molecular, macroscopic, and global scales with matter and energy as constraints

Level 3. Changes of Molecules and Energy Forms with Unsuccessful Constraints	Link macro-processes with change of molecules and/or energy forms at atomic-molecular or global scale, but cannot successfully conserve matter/energy.
Level 2. Force-dynamic accounts with hidden mechanisms	Link macro-processes with unobservable mechanisms or hidden actors (e.g., decomposer), but the focus is on enablers, actors, abilities, and results rather than transformation of matter and energy.
Level 1. Macroscopic force-dynamic accounts	Describe macro-processes in terms of the action-result chain: the actor use enablers to accomplish its goals; the interactions between the actor and its enablers are like macroscopic physical push-and-pull that does not involve any change of matter/energy.

Our analysis sought to find similar patterns in Data, Warrants and sometimes Backing. In this paper, we report initial results based on analysis of arguments from all the 16 students. However, we note here that some students did not complete all the interviews---some completed pre only, others post only, yet others partially completed pre-post interviews. We coded arguments for the processes of Tree Growth, Flame burning, and Car Running from pre-and-post interviews for each student—a total of 83 arguments. Because we were specifically interested in how students justified claims about matter and/or energy, we did not include elementary students in the analysis. We looked for patterns of association between the Levels of Achievement in students' accounts described in more detail in Jin and Anderson (in preparation), and the nature of the Data and Warrants (and sometimes Backing) they used to support their claims. Because Level 1 accounts did not include specific Claims about matter and energy, they were not included in our analysis.

Findings

Our analysis show patterns in students' Data, Warrants (and sometimes Backing) as well as their Claims. These patterns are summarized in Table 4, below. The nature of the differences in Data, Warrants, and Backing are summarized after Table 4.

Table 4: Descriptions of characteristics associated with levels of achievement

Level	**Statements contain:**		
4	**Data** that consist of: • Specific **Matter and/or Energy Needs** but also **hardly any related Other/General observations** • Specific **Matter and /or Energy Results** but also **hardly any related Other/General observations**	**Warrants** characterized by: • **Special Properties of Matter** to link **Data** to an empirically verifiable **Claim** • **Special Properties of Energy** to link **Data** to an empirically verifiable **Claim** • **Supporting Backing** that use general principles of Matter/Energy	**Claim** consistent with conservation of matter and energy (e.g. Jin et. al., in preparation)
3	**Data** that consist of: • Specific **Matter and/or Energy Needs** but also: related Other and/or General observations; **Other Needs** with little connection to Mater and/or Energy • **Specific Matter and /or Energy Results** but also: related Other **and/or General observations**; **Other Result** with little connection to Matter and/or Energy	**Warrants** characterized by: • **Special Properties of Matte**r but also related Other properties to link **Data** to the **Claim** made • **Special Properties of Energy** but also related Other properties to link **Data** to the **Claim** made • **Suggestive Backing** that uses general principles of Matter/Energy but also **Some; Analogies, Tautological statements, and Citation of Evidence** to link **Data** to the **Claim** made	**Claim** that includes accounts of matter and energy but is not fully consistent with conservation laws
2	**Data** that consist of: • **Other/General observations** that may or may not relate to specific matter and/or energy • **A few Specific Matter** and/or **Energy Needs** mainly based on beliefs/guess work but also **Other Needs** that have little connection to specific Matter and/or Energy needs • **A few Specific Matter** and/or **Energy Results** mainly based on beliefs/guesswork but also **Other Results** that have little connection to Specific Matter and /or Energy results	**Warrants** characterized by: • **Analogies, Tautological statements, and Citation of Evidence** to link Data to the **Claim** made • **Other Properties of Enablers and/or Actors** to link **Data** to the **Claim** made • **A few Special Properties of Matter and/or Energy** mainly based on beliefs/guesswork	**Claim** that mentions matter and energy in context of force-dynamic accounts
1	Not considered	Not considered	Not considered

Data: Students provided data to support their accounts in the form of either, for instance, "obvious facts,"--- general observations which may or may not be empirically verifiable, specific observations which may be empirically verifiable or a combination of these two. For example, almost all students agreed with RKC's account of "what does a tree need in order to grow?" RKC (pre) responded, "it needs water for nutrients or nutrients in the soil, sunshine for photosynthesis and a space to grow and fresh air." These Data were used, however, to support different kinds of Claims by different students. For example, EKR (post) treated these needs as raw materials for transformations in matter and energy: "The mass comes from the food that the tree is producing during photosynthesis, which is mostly carbon and hydrogen pieces bonded together and that is then stored away and eventually enough of it is stored away so that it starts to grow and continues growing." In contrast, JAH (pre) said that "I think it just grows. Since it grows it has more mass and then it gets heavier."

Relatively few students provided "Data" in the scientific sense of empirically verifiable observations. This may be in part a result of the questions we asked; we rarely challenged students to justify their Claims in detail. For future studies, we will include requests for more detailed justifications of their Claims.

Warrants. Second, we found differences regarding warrants students provided to link the data to the claims they made, with lower level students generally assuming, for instance, that the Data themselves (tautological) were sufficient to justify their Claims. To illustrate, when RKC, in his pre-interview, was asked "how does a tree use water to make food for itself?" he said, "Water is very important and it has to be clean water too because if it's polluted then the tree could not survive." RKC's response indicates an understanding that water is important for the tree. Yet when he was asked for a Warrant that connects the tree's need for water with a Claim about matter and energy, he basically reasserts his original Data. Thus, he falls short of making the actual connection between water and photosynthesis.

In his post-interview, by comparison, RKC provides a more acceptable warrant about water and an explicit claim about matter saying, "It helps create glucose for the food that, not food, but sugar … that the tree grows on …. I believe it's $6H_2O$ and CO_2 turn into $C_6H_{12}O_6$ with is glucose and then $6O_2$ which is oxygen. So oxygen is like a byproduct …." Although he incorrectly mentions the term "create", his response is much improved because it correctly links and therefore shows his understanding that water is a reactant in the chemical process of photosynthesis. His Warrant makes the general principles underlying this process explicit through conserving matter by identifying its reactants and products.

Indeed, later on in the interview, when asked, "Do you think water is used up" in photosynthesis? he said, "No. It's not used. It's not like you use it and it's gone. It's just exists in another form and its' in the leaves." Thus, though implicitly, he shows use, and therefore understanding of the idea that the matter of water is neither created nor destroyed, and in effect, providing Backing for his Warrant about water.

Associations of elements to Claims: After identifying characteristics associated with Data, Warrants, (and sometimes Backing), we used the established Claims (see table 3) to identify the kinds of Data, Warrants, and/or Backing, for all the 16 participants, that align with those Claims. Our analysis show patterns of association between these elements and Claims. These patterns are summarized in Table 5 below. The nature of associations of Data, Warrants, and/or Backing is summarized after Table 5.

Table 5: Nature of Data, Warrant and/or Backing associated with levels of achievement

Level	**Data:**	**Example**	**Warrant/Backing**	**Example**	**Claim (from table 3)**
4	Appeal to scientific principles	I: …So, where does light energy go? EJR: Light energy… is…converted to a stored energy	Consistently bridge Data to Claim using scientific principles/scientifically verifiable way	I: …So, where does light energy go? EJR: …it's absorbed …then converted to a stored energy by combining…hydrogen and carbon atoms into various molecules.….That energy is stored in that bond for use later	Linking carbon-transforming processes at atomic-molecular, macroscopic, and global scales with matter and energy as constraints
3	Are inconsistent with scientific principles	I: …what does the car need in order to carry the family to Chicago? DRH: It needs the gas, that's the energy, *and somebody controlling the car.*	Inconsistently use scientific/general principles to bridge Data to Claim	I: …what does the car need in order to carry the family to Chicago? DRH: It needs the gas, that's the energy, and somebody controlling the car.	Link macro-processes with change of molecules and/or energy forms at atomic-molecular or global scale, but cannot successfully conserve matter/energy.
2	Appeal to individual and/or personal observations and beliefs	I:… So how about wax and a wood… What happens to them? JMJ: *It will disappear…*	Consistently use individual and/or personal curiosity, experiences, and/or interpretations to bridge Data to the **Claim** made	I:… So how about wax and a wood… What happens to them? JMJ: … *wax and wood are kind of like flames' food*. …	Link macro-processes with unobservable mechanisms or hidden actors (e.g., decomposer), but the focus is on enablers, actors, abilities, and results rather than transformation of matter and energy.
1	Not considered	Not considered	Not considered	Not considered	Not considered

Students used different kinds of data, warrants and sometimes baking to support the Claim they made and these fell into recognizable patterns. Less sophisticated (mostly younger) students provided elements that appeal to, for instance, individual beliefs, readily noticeable observations and interpretations based on personal experiences.

To illustrate, most students' data and Warrants were similar to those provided by JMJ (table 5 above): That the matter of wood/wax will not only "disappear" during Flame Burning but also that both of these "*… are kind of like flames' food*." Such *readily noticeable Data* and *analogical Warrant* that students provided seem to align with Level 2 Claims described as *"Force-dynamic accounts with hidden mechanisms."*

By contrast, more sophisticated students provided elements that appeal to scientific principles. These students' elements were similar to those provided by EJR: That light energy (input) is not only transformed into stored energy (output) but also that it is stored in the bonds of molecules (warrant). These elements seem to align with Level 4 Claims described as *"Linking processes with matter and energy as constraints."*

Other students, as exemplified by AHR (table 5), provided elements that both appealed to scientific principles and, for instance, individual beliefs and interpretation in relation to CTPs. These kinds of elements seem to align with Level 3 Claims described in part as "*…cannot successfully conserve matter/energy.* Thus our preliminary results suggest a proposed learning progression that includes most of Toulmin's elements of arguments.

Contribution to teaching and learning of Science

This study likely has to two-fold implications: The first regards teaching and student learning. For example, teachers, in an ever changing policy environment, face challenges (e.g. Barton et al., 2008) in their instructional practice and these may lead to difficulties in supporting student science learning. Second, it likely has implications regarding research in science teaching and learning. Given that instructional and learning challenges are not new, they call for renewed research efforts, including this study, as a means to providing students with more science learning possibilities. This would be in terms of helping them to more successfully learn to, for example, rather than rely on rhetoric, evaluate the validity of sources of information, and engage in data-driven arguments about socio-ecological issues (Covitt et al., 2009).

This study's main contribution to teaching and learning science is likely to be, therefore, a learning progression for arguments from evidence. The two examples from the data analysis above suggest that use of argumentation as an instructional tool in classrooms would help to support students in developing skills (e.g. Kuhn, 1991) for constructing inquiry-based arguments (Berland, & McNeil, 2009; Covitt et al., 2009; Gotwals et al., 2009) that are both based on empirically verifiable data and connected to the claims made. Moreover, argumentation could be used as a tool for both a more complete assessment of not only students' work but also that of pre-service teachers: That is, this study is likely to inform teacher professional development (PD) across disciplines with regard to designing instructional tools, using them in PD programs, instruction, and assessment.

Furthermore, this study attempts to make connections to our overall goal of the larger learning progression project of continued promotion of environmentally responsible citizenship. For example, do students who support their accounts of individual processes with true arguments from empirical evidence also support positions on environmental issues? (See e.g. Covitt et al., 2009): If they cite well-defined observational data and warrants in support of their accounts of tree growth, do they also favor arguments about environmental issues that are supported with well-defined observational data and warrants? These are questions for a possible future study.

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Appendix: Interview Protocol

Environmental Literacy Carbon Interview

FORM A

Please start by briefly introducing yourselves---include the idea that you are a member of Environmental Science Literacy Research Project from MSU. Then, briefly explain the purpose of the interview: In our work, we seek students' ideas about such processes as tree growth, girl growth, girl running, dead tree decaying, flame burning, car running, lamp lighting, and cross processes. Our goal is to use these ideas to design classroom tools/materials for use in teaching and learning science. The purpose of this interview, therefore, is to seek your help in terms of your ideas about some of these processes. Please feel free to ask questions at any time during the interview.

Next, please write down the student's names, grade (and age) here below---you may ask the student to help you spell his/her names. At this point, you may proceed to the interview items (Page 2).

Name ____________________ Grade ___________ Age ______________

The questions highlighted in green are for higher level students.
It is possible that you may not be able to finish all the interview questions.

--- PLANT GROWTH ---

Tree Growing	
	
A small tree was planted in a meadow	After 20 years it has grown into a big tree, weighing 500 lb more than when it was planted.

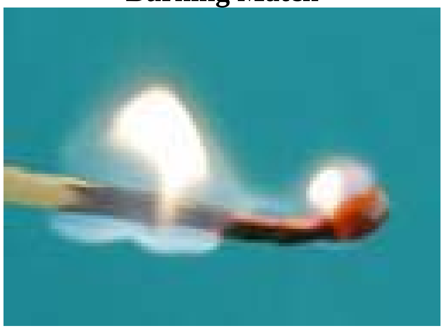
Actor: tree

Enablers: sunlight, water, soil, and air

1. What does the tree need in order to grow?
2. You said that the tree needs **[sunlight, water, soil, air]** in order to grow**.** Follow up probes about each enabler:
    a. How does [the enabler] help the tree to grow?
    b. What happens to [the enabler] inside the tree?
    c. Is [the enabler] used up to help the tree to grow? Does it change into other things inside the tree's body? Or, do you think it will not change inside the tree's body?
    d. Does the tree use [the enabler] for energy? How does that work?
3. Follow-up probes on enablers not mentioned
    a. Some other students have mentioned [other enabler]. Do you think [the other enabler] is necessary for the tree growth?
    b. [If yes, same probes as for other enablers.]
    c. [If no] Why not?
4. Scale
    a. Do you think that the tree is made of cells? Why?
    b. Do you also think that the tree is made of molecules? Why?
    c. You said that the tree is made of both cells and molecules. How are the cells and molecules related? What's the connection?
5. Matter
    a. Does the growing tree change the air? How does that happen?
    b. The tree gets heavier as it grows. How does that happen?
    c. Where do the increased materials come from?
    d. Do you think the tree's body can naturally create more and more materials? Why?
    e. Do you think the increased materials of the tree's body are changed from things outside of the tree? [If yes], how do these things change into the tree's body structure
    f. If the student mentions glucose/starch/cellulous/carbohydrates, ask: Do you think it contains carbon atoms? [If yes], where does the carbon atoms come from?
    g. [If the student talks about CO_2—O_2 exchange, ask]: You said that the tree needs Carbon dioxide and breath out oxygen. Where does the carbon atom of CO_2 go?
6. Energy
    a. Does the process of tree growth involve energy? [If yes], where does the energy come from?
    b. Why do you think the things you mentioned have energy?

c. [If the student associates energy with sunlight, ask]: Where does the energy of sunlight go? Is it used up? Does it change into other materials? Or, is it still energy? Where is it?
d. Do you think the tree stores energy inside its body? If yes, where does the tree store energy? In cells? In molecules? Where does that energy come from?
e. If students do not mention photosynthesis, ask: Is there any connections between the things you mentioned and photosynthesis?

--- FLAME BURNING ---

Burning Match	Burning Candle
	

Actor: flame
Enablers: fuels (wax, wick, wood), air

1. What does the flame need in order to keep burning?
2. You said that the flame needs [**wax, wick, air, wood …]**. Follow up probes about each enabler.
    a. How does [the enabler] help the flame to burn?
    b. What happens to [the enabler] inside the flame?
    c. Is [the enabler] used up? Does it change into other things? Or, do you think it does not change?
    d. Does the flame use [the enabler] for energy? How does that work?
3. Follow-up probes on enablers not mentioned
    a. Some other students have mentioned [other enabler]. Do you think [the other enabler] is necessary for the flame to burn?
    b. [If yes, same probes as for other enablers.]
    c. [If no] Why not?
4. Scale
    a. Do you think that the flame is made of materials?
    b. If yes, do you think the flame is made of molecules and atoms? Please explain.
5. Matter
    a. What change will happen to the match?
    b. Do you think the match will lose weight? [If yes], where does it go? Is it used up? Does it change into other things? Why?
    c. What change will happen to the wax of the candle?
    d. Do you think the candle will lose weight? [If yes], where does it go? Is it used up? Does it change into other things? Why?
    e. Does the event of flame burning change the air? How does that happen?
    f. Do you think wax/wood contain carbon atoms? [If yes], where do the carbon atoms go when the flame is burning?
6. Energy
    a. Does the process of flame running require energy?
    b. If yes, where does the energy come from?
    c. Why do you think the things you mentioned have energy?
    d. [If the student associates energy with wood or wax, ask]: Where does the energy of wood/wax go? Is it used up? Does it change into materials? Or, is it still energy? Where is it?

e. Why do you feel warmth when the flame is burning? Do you think heat is released from burning?
f. [If yes], how is heat released? Do you think heat is created in combustion, or do you think it is changed from other forms of energy in combustion? Please explain.
g. If students do not mention combustion, ask: Is there any connections between the things you mentioned and combustion?

--- CAR RUNNING ---

Car Running

Tom's family went to Chicago on vacation. When they came back, Tom's dad found that their car consumed 50 gallons of gasoline for the trip.

Actor: Car

Enablers: gasoline, air

1. What does the car need in order to carry the family to Chicago?
2. Why do people use gasoline instead of water to run their cars?
3. You said that the car needs [**gasoline, air**]. Follow up probes about each enabler:
    a. How does gasoline/air help the car to run?
    b. What happens to the gasoline/air inside the car when the car runs?
    c. Does the car use gasoline/air for energy? How does that work?
    d. Is gasoline/air always necessary for car running? Why or why not?
4. Follow-up probes on enablers not mentioned
    a. Some other students have mentioned gasoline/air. Do you think it is necessary for car running?
    b. [If yes, same probes as for other enablers.]
    c. [If no] Why not?
5. Matter
    a. When your family arrives at Chicago, the gas tank is almost empty? Where does the gasoline go?
    b. Do you think the gasoline is used up? Or, does it change into other things?
    c. Does the event of car running change the air? How does that happen?
    d. Do you think gasoline contains carbon atoms? If yes, where do the carbon atoms go when the gasoline is used by the car?
6. Energy
    a. Does the process of car running require energy? If yes, where does the energy come from?
    b. Why do you think the things you mentioned have energy?
    c. [If the student associates energy with gasoline, ask]: When the car stops, where does the energy of gasoline go? Is it used up? Does it change into materials? Or, is it still energy? Where is it?
    d. After the car runs for a while, the front part of the car will become very hot. Why?
    e. [If the student mentions heat, ask]: how is heat released?
    f. You said that the gasoline is burning inside the car. Do you think heat is created in burning, or do you think it is changed from something else? Please explain.
    g. If students do not mention combustion, ask: Is there any connections between the things you mentioned and combustion?