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An Analysis of Metaphors Used by Students to Describe Energy in an Interdisciplinary General Science Course

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An Analysis of Metaphors Used by Students to Describe Energy in an Interdisciplinary General Science Course

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The meaning of the term *energy* varies widely in scientific and colloquial discourse. Teasing apart the different connotations of the term can be especially challenging for non-science majors. In this study, undergraduate students taking an interdisciplinary, general science course ($n = 49$) were asked to explain the role of energy in five contexts: radiation, transportation, generating electricity, earthquakes, and the big bang theory. The responses were qualitatively analyzed under the framework of conceptual metaphor theory. This study presents evidence that non-science major students spontaneously use metaphorical language that is consistent with the conceptual metaphors of energy previously identified in the discourse of students in introductory physics, biology, and chemistry courses. Furthermore, most students used multiple coherent metaphors to explain the role of energy in these complex topics. This demonstrates that these conceptual metaphors for energy have broader applicability than just traditional scientific contexts. Implications for this work as a formative assessment tool in instruction will also be discussed.

Keywords: *Student conceptions; Interdisciplinary science; Conceptual metaphor; Formative assessment*

Introduction

The exact meaning of the term energy depends on disciplinary context. Anecdotally, many teachers have noticed that students compartmentalize disciplinary ideas about energy; students think energy in biology is different from energy in physics. One way to understand these different conceptualizations of energy is through the lens of

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conceptual metaphor theory (Amin, 2009; Dreyfus et al., 2014; Lancor, 2014a; Scherr, Close, McKagan, & Vokos, 2012). Conceptual metaphor theory is a cognitive theory that argues that the way we understand the world is largely metaphoric in nature (Lakoff & Johnson, 1980, 1999). Metaphorical language is necessary to articulate and comprehend abstract ideas, and conceptual metaphor theory provides a way for researchers to gain insight into how students understand abstract concepts, such as energy. Introductory physics classes may primarily use energy as an accounting system to track changes in a system, while energy in an introductory biology class may primarily be presented as a substance that can be lost from a system. Although conscientious students may see connections between how energy is used in different contexts, most students are not required to confront and articulate these different conceptualizations of energy.

However, for students in multidisciplinary or interdisciplinary general science classes (such as middle-school science classes or those frequently taken by pre-service elementary education majors at universities), the concept of energy appears in multiple contexts throughout the course. The term is likely used in many different ways, and different metaphors for energy are employed by the teacher and/or the textbook depending on the particular topic being studied. To complicate matters further, the words *energy* and *conservation* also have very different meanings in everyday discourse. Students in these courses face a difficult task; they must not only reconcile different conceptions of energy from a scientific perspective, but also distinguish between scientific and colloquial uses of the term.

Purpose and Research Questions

This study uses an analytical framework based on conceptual metaphor theory (described in detail below) to uncover the conceptual metaphors students used to describe the role of energy in various scientific contexts. Previous publications have explored how this framework could be used to understand how energy is conceptualized in pedagogical discourse (Lancor, 2014a) and by students in introductory physics, chemistry, and biology courses (Lancor, 2014b). This study differs from the previous empirical study in that the students were not explicitly asked to use analogies in their responses, and the students were enrolled in an undergraduate, interdisciplinary science course for non-science majors. This course focused on current issues in the news rather than a traditional sequence of topics covered in introductory science courses (e.g. mechanical systems or chemical reactions). There were two goals of this study: (1) to evaluate the methodological framework and determine whether or not it could be applied outside of a traditional disciplinary science course; and (2) to gain some insight into how these students, who are more or less representative of the general public, understand energy. Thus the research questions addressed in this study are:

- What conceptual metaphors are used by students in an interdisciplinary science course to explain the role of energy in various systems?

- How do they compare to metaphors of energy that have been previously identified in traditional scientific courses? Do students use the same conceptual metaphors for energy spontaneously as when they are explicitly asked to use analogies on energy?

Literature Review

Models, Metaphors, and Analogies

Lemke (1997) argues that energy does not have one unambiguous definition that holds for all circumstances, but rather has a socially created meaning depending on the particular context of use. One way to make sense of these many interpretations of energy is through the lens of conceptual metaphor theory. Scholars of conceptual metaphor theory contend that many of our conceptual structures are built on metaphors, which help us to understand the world in terms of what is familiar (Lakoff & Johnson, 1980, 1999). Lakoff and Johnson (1999, p. 233) note that 'In the case of physics, there is certainly a mind-independent world. But in order to conceptualize and describe it, we must use embodied human concepts and human language.' When we encounter new ideas, we instinctively relate them back to what we already understand, which helps to make the new concepts intelligible.

As a part of our conceptual system, metaphors influence our perspective on the world. They do this by highlighting certain aspects of abstract concepts and obscuring others. When we conceptualize an experience or idea, we pick out the most important parts, find a way to categorize those parts in terms of what we already know about the world, and thus understand the experience. Within the field of science education, the theory of conceptual change recognizes metaphors (and analogies) as a key component of one's conceptual ecology (Posner, Strike, Hewson, & Gertzog, 1982). Metaphors and analogies 'help people explore their epistemological and ontological commitments' (Aubusson, Harrison, & Ritchie, 2006, p. 1). As researchers, we can work backwards; by analyzing the metaphors and analogies used by students to communicate their ideas, we gain insight into which ontological commitments they use to conceptualize energy in a given context.

Analogies and metaphors are often lumped together with models in the science education literature. Indeed, many times scientific models include analogies or metaphors (Aubusson et al., 2006) and mental models are often constructed through analogical reasoning (Collins & Gentner, 1987). Although they may not be aware of it, students harbor unique mental models that they use to explain the world around them. The difficult task for a researcher is to access these mental models. Hestenes (2006) describes three worlds: (1) the physical world where we interact with and observe phenomena, (2) the metal world where mental models are created to explain the phenomena, and (3) the conceptual world, the space in which mental models are communicated to others (often in the form of metaphors). The key to uncovering students' models is language—'Language does not refer directly to the world, but rather to mental models and components thereof!

Words serve to activate, elaborate or modify mental models, as in comprehension of a narrative' (Hestenes, 2006, p. 11). Thus understanding the language used to communicate the model allows us to understand the student's mental model and its relationship to the accepted scientific model.

Conceptual metaphor theory affords a systematic way to interpret this language. The idea of using metaphors as a tool to understand the world has much in common with scientific modeling. Generally speaking, scientific models predict and explain observed phenomena. They help us to make sense of new phenomena by making connections to, and expanding on, what we already know about how the world works. Similarly, metaphorical thinking is used to relate new ideas to prior experience. Additionally, scientific models simplify a system so that it may be described and quantified. Because of the simplifications required to create a scientific model, multiple scientific models are required to fully understand any given system. This is also true of the metaphors used to describe and explain a given system. Multiple coherent metaphors are necessary to gain a complete understanding of a system. This relationship between scientific models and metaphors had been noted by others (Duit, 1991; Hestenes, 2006). Viewing science as a set of coherent metaphors is not very different from thinking of science as a set of models; the way that we communicate scientific models is often metaphorical. Furthermore, multiple conceptual metaphors may be necessary to describe one scientific model, as is the case with energy, which will be explored in this paper.

Metaphorical construal of energy often involves what Lakoff and Johnson (1999) would call an 'Object Event Structure' metaphor (Amin, 2009). In particular, energy is an attribute of a system. A particular system may have a given amount of kinetic or potential energy. If we change the system somehow, the attributes of the system change. For example, if I drop a ball, the amount of kinetic energy increases while the amount of gravitational potential energy decreases. Typically, we say to students that the ball now *has* less gravitational potential energy at the bottom than it did at the top. In this way, we are conceptualizing energy as a possession of the ball. This is an example of what Lakoff and Johnson call the 'Changes are Movements of Possessions' metaphor, a subset of the Object Event Structure.

For the purposes of this analysis, we focus on substance metaphors as examples of the 'Changes are Movements of Possessions' mapping laid out by Lakoff and Johnson. Scientifically, we talk of energy being moved throughout a system or being transferred into or out of a system. However, it is difficult to speak intelligently about this movement of energy without connecting to an embodied experience of moving physical objects into or out of physical locations. The substance metaphors reflect the physical act of moving the energy substance from one system to another.

There is much discussion in the literature on how to define the terms metaphor and analogy. I use the term *analogy* to mean an explicit comparison of two ideas as expressed in written or verbal discourse. For example, a teacher may state 'The planetary model of the atom is like a solar system; the nucleus is like the sun and the electrons are like the planets orbiting the sun.'[1] *Metaphors* also compare two ideas, but do so implicitly. Additionally, I define *conceptual metaphor* to be the overarching ontological commitment that is supported by specific instances of metaphorical language and/or analogies. To summarize, the *conceptual metaphor* is how we interpret and apply scientific models, representing an underlying relationship between ideas; and *analogies* and *metaphors* are specific instances of discourse used to articulate those relationships (Table 1).

Defining Characteristics of Energy

Energy is an abstract concept; it is not directly observable and is impossible to measure directly, which makes it difficult to define. Most scientists have a working definition of energy that is useful in their particular field, but is not broadly applicable. Undergraduate science majors have the opposite experience; many take multiple science courses concurrently and sift through various definitions of energy. Often students are expected to use the concept of energy in biology and chemistry before they have taken physics, and yet the definition given is based on physics principles (i.e. energy is the ability to do work). Research shows that students taking biology simultaneously with physics and/or chemistry are particularly confused by the concept of energy (Gayford, 1986). Additionally, attempts to illustrate the interdisciplinary nature of energy require simplifications that lead to nonsensical results (Zurcher, 2008). In an analysis of physics and chemistry texts, Taber (1989) found over 50 discrete manifestations of energy, some of which were synonymous, ambiguous, or simply incorrect. Many educators avoid this quagmire by simply never giving a definition of what energy is. When energy is defined by scientists, educators, or textbook writers, the definition typically falls into one of three categories: (1) energy defined through the concept of work; (2) energy as something that 'makes things go'; or (3) energy as a measure of change in a system.

Hand in hand with the debate about how to define energy, there is an extensive, ongoing debate about how best to teach the concept of energy (Jewett, 2008a, 2008b, 2008c, 2008d). Scholars agree that teaching the law of energy conservation alone is not enough to facilitate understanding of the complex concept of energy. Teaching conservation in tandem with transformation, transfer, and degradation leads to a more complete understanding of energy (Duit & Haeussler, 1994; Hecht, 2007; Nordine, Krajcik, & Fortus, 2011; Trumper, 1990). This list of characteristics was expanded to include energy source, as it has been identified as an important feature of energy in other studies (Lee & Liu, 2010). Taking the literature on energy instruction as a whole, five characteristics of energy have been identified and will be used in analyzing the students' written work:

- *Energy conservation*—In an isolated system,[2] energy can neither be created nor destroyed. This is one of several conservation laws used in physics.
- *Energy degradation*—The total amount of usable energy[3] in a system may decrease over time. This may take the form of energy dissipation (energy lost from an open system) or energy transformation within the system to a less useful form.

Table 1. Definition and examples of models, metaphors, and analogy

Term	Definition	Example 1	Example 2
System	The system includes all elements necessary to understand a given phenomenon. Open systems can exchange energy with their surroundings. Closed systems are (theoretically) isolated and do not exchange energy with the environment	Mechanical system (e.g. a ball rolling down a ramp)	Ecosystem
Scientific model	The scientific (or conceptual) model is used to explain a given phenomenon or gain understanding of some aspect of the system. Examples of explanatory scientific models include energy, momentum conservation, and natural selection	Energy: Gravitational potential energy is converted to kinetic energy as the ball rolls down the ramp	Energy: The energy inputs and outputs of a system can be tracked and used to determine rates of production and consumption
Metaphor	Metaphorical language is used to explain the scientific model in more concrete terms, and implies a relationship between the target concept and some more familiar concept	Energy is the currency of the system. The ball has the same *total amount* of energy at the bottom of the ramp as it had at the top	Energy pours into an ecosystem as solar radiation and drains away as respiratory heat loss (Campbell & Reece 2002, p. 1206)
Analogy	An analogy is used to explain the scientific model in more concrete terms, and explicitly states a functional or structural relationship between the target concept and the analog	Energy is like money. The ball has a set amount of energy at the top; this is the potential energy. Imagine you have $10 in your pocket. If you go to the bank and deposit the 10-dollar bill, you still have $10, but it is in a different form—now it is in the bank account instead of your pocket. This is like the potential energy being converted to kinetic energy	Energy flows through an ecosystem like water flows through an irrigation pipe. Some makes water through to the next field, and some leaks out of the system

(*Continued*)

Table 1. Continued

Term	Definition	Example 1	Example 2
Conceptual metaphor	The conceptual metaphor represents the overarching relationships between components in the target concept and the source domain. The conceptual metaphors are based on specific instances of metaphorical language or explicit analogies identified in discourse	Energy is a substance that can be accounted for. This conceptual metaphor highlights the principle of energy conservation, and gives us a way to track changes in energy in a system	Energy is a substance that can flow. This conceptual metaphor emphasizes the idea of energy transfer through a system

- *Energy transformation*—Energy can be transformed from one form to another. For example, as a ball drops gravitational potential energy is transformed into kinetic energy.
- *Energy transfer*—Energy can be transferred between components in a system; in a collision, one billiard ball transfers its kinetic energy to another.
- *Energy source*—Energy can be added to a system. For example, in an ecosystem, an input of energy from the sun is needed to balance the loss of thermal energy from the ecosystem to the environment.

Metaphors for Energy

The framework for evaluating student ideas about energy was developed based on a survey of written materials from biology, chemistry, and physics, including textbooks[4] and the science education literature. Specific examples of metaphorical language and explicit analogies were identified following the method presented by Lakoff and Johnson (1980, 1999). These instances were then grouped into themes, representing variations on the Object Event Structure metaphor laid out by Lakoff and Johnson. Themes were identified that represented similar ways of understanding the role energy plays in a system (e.g. it can be stored, it can change forms, etc.). Generally the metaphors fall into the categories of either 'Attributes are Possessions' (i.e. the ball has kinetic energy; there is no change in the system) or 'Changes are Movements of Possessions' (i.e. Ball A transferred some of its energy to Ball B during the collision; there is a change in amount of energy possessed by each ball).

Note that no metaphor is exclusive to any one discipline. Each discipline may use one metaphor preferentially, but the other metaphors certainly make appearances. The goal here is not only to highlight the differences among disciplines, but also to recognize that common conceptual metaphors are being used across disciplines. The language may seem different on the surface, but the underlying relationships are similar. The conceptual metaphors are described in brief below, as well as some discussion of how they map onto the characteristics of energy defined above (Table 2). A more detailed account of the development of the framework can be found elsewhere (Lancor, 2014a).

Energy as a Substance that Can be Accounted for

References to energy as a substance that can reside in various 'accounts' or 'containers' are common in both physics and chemistry texts, such as toy blocks (Feynman, Leighton, & Sands, 2006) or money (Chang, 1998; Knight, 2007). The amount of energy in each 'account' changes as a result of some interaction with another system. These examples illustrate the conceptual metaphor that *energy is a substance that can be accounted for* within a given physical system. This metaphor is reinforced

Table 2. Conceptual metaphors identified in biology, chemistry, and physics discourse. The metaphor represents the overarching framework, supported by explicit analogies that highlight or obscure characteristics of energy

Conceptual metaphor	Examples of analogies from scientific contexts	Characteristics of energy	
		Highlights	Obscures
Energy as a substance that can be accounted for	Energy (or enthalpy) is like money	Conservation	Transformation
	Energy is like a child's blocks		Source
Energy as a substance that can change forms	Solar energy converted into chemical energy through photosynthesis	Transformation	Transfer
	Chemical energy converted into thermal energy in an exothermic reaction	Conservation	
Energy as a substance that can flow	Energy flows through an ecosystem	Transfer	Transformation
	Heat flows from hot to cold	Source	
	Electricity flows through a circuit		
Energy as a substance that can be carried	Organisms transport energy through an ecosystem	Transfer	Transformation
	Photons carry electromagnetic energy		
Energy as a substance that can be lost	Trophic pyramid	Degradation	Conservation
	Energy is lost in an exothermic reaction	Source	
Energy as a substance that can be added, produced, or stored	Energy is stored in chemical bonds (e.g. ATP) and can be released	Source	Conservation
	Energy is stored in a capacitor	Transfer	Degradation
	Energy is added to initiate a chemical reaction		

through graphical representations like bar charts (Scherr et al., 2012). The accounting system metaphor gives scientists a tool to apply energy conservation quantitatively, to track energy changes and interactions between systems. This accounting system is useful because it portrays energy as a substance that can be tracked. This conceptual metaphor emphasizes the conservation and transfer aspects of energy, but obscures the idea of energy transformation. The 'energy' in these examples is generally of the same form—it is a block or money—it never changes to another form of energy (e.g. a block does not change into a ball).

Energy as a Substance that Can Change Forms

The 'forms of energy' language is ubiquitous in science texts. It is generally accepted that these forms of energy fall into two broad classes: kinetic energy, which involves motion, and potential energy, which is stored in fields. Many scholars do not see a problem with the 'forms of energy' language, arguing that if used correctly this metaphor can represent a scientifically accurate understanding of energy (Kaper & Goedhart, 2010; Nordine et al., 2011; Trumper 1990). Obviously, this metaphor highlights the transformation of energy, particularly when used in tandem with the conservation principle. For example, 'If one form of energy in an isolated system decreases, then another form of energy in the system must increase' (Serway, Faughn, & Vuille, 2006, p. 118). In this way, the 'forms of energy' metaphor is a heuristic that helps to explain how energy is conserved in various situations. The 'forms of energy' metaphor can be used in conjunction with the accounting system metaphor; the forms of energy could be construed to be the various 'accounts' discussed above. According to the principle of energy conservation, we can never destroy or lose energy in an isolated system; if energy appears to be missing, scientists will search for another 'form of energy' that may account for the missing energy (as in the current search for dark energy). On the other hand, this metaphor obscures the transfer of energy; it provides no explanation for how energy can be passed from one object to another without changing forms.

Energy as a Substance that Can Flow

The metaphorical phrase 'energy flow' makes one imagine a pipe with water flowing through it. Energy flow language is used repeatedly in biology, chemistry, and physics textbooks. For example: 'Energy flows through ecosystems, while matter cycles within them' (Campbell & Reece, 2002 p. 1198); 'we often speak of "*heat flow*" from a hot object to a cold one' (Chang 1998, p. 205); and water flow analogies in the context of electrical circuits (Harrison & Coll, 2008). This language highlights energy transfer in a system. The 'water' (energy) substance stays the same in this metaphor, in contrast to the 'forms of energy' metaphor described above where energy takes on a different form as a result of an interaction in the system. Thus this metaphor highlights the transfer of energy while downplaying energy transformation. And if energy flows into a system, it has to come from somewhere outside the system, an external source of energy. The flow metaphor is a convenient way to discuss a continuous, uniform, energy transfer through a system.

Energy as a Substance that Can be Carried

Energy can also be conceptualized as a substance that can be contained and carried. For example, an electron 'carries' energy through an electrical circuit; organisms 'transport' energy through ecosystems. Both the electrons and the organisms could be considered to be energy carriers. Falk, Herrmann, and Schmid (1983) advocated for language of energy carriers, arguing that it is more scientifically accurate to view an energy transformation as energy being transferred from one carrier to another. For example, rather than saying the chemical energy in a battery is converted to electrical energy in a circuit, we would say a battery carries a given amount of energy, and then passes that energy along to an electron, which carries it through the circuit. Rather than thinking of the energy as changing form, the energy has a different carrier.

Energy as a Substance that Can be Lost from a System

The metaphor of energy as a substance that can be lost from a system is prevalent in biology textbooks, particularly in the discussion of ecosystems. In this context, the systems of interest are primarily open systems in which thermal energy is freely transferred to the surrounding environment. For example, 'on average, these primary consumers harvest 31 kcal/m^2 of energy each year. Of that total, 17.7 percent is unused and excreted and 80.7 percent is lost to respiration and other maintenance processes' (Freeman, 2007, p. 1230). This is more aligned with how students hear about energy in the media (e.g. turn off the lights because we are running out of energy) than it does the scientific notion of energy conservation. The 'energy loss' metaphor does a fantastic job highlighting energy degradation, but obscures energy conservation. For this reason, scholars have argued that degradation needs to be taught in parallel with energy conservation (Duit & Haeussler, 1994; Pinto et al., 2005).

Energy is a Substance that Can be Stored, Added, or Produced

In any chemical reaction, an input of energy is necessary to break bonds. Whether energy is absorbed or released overall depends on the particular reaction and the differences in binding energy between the ingredients and products. However, students often hold the misconception that energy is released when bonds break (Boo, 1998). Language indicating energy as an ingredient or a product is common among students (Trumper, 1990; Watts, 1983). Unfortunately, this can lead to confusion between matter and energy in chemical reactions (Anderson 1990) and ecosystems (Barak, Sheva, Gorodetsky, & Gurion, 1999; Leach, Driver, Scott, & Wood-Robinson, 1996; Lin & Hu, 2003). The language used to describe the role of energy in chemical reactions reinforces this idea and reflects a conceptual metaphor that energy is either an ingredient or a product of a reaction. However, this does provide the means to discuss the concepts of energy transfer and energy source in a meaningful way with students, provided it is emphasized as a heuristic metaphor for understanding the role of energy in facilitating chemical reactions.

A related idea is that energy can be stored. Both chemistry and biology texts describe how energy can be stored in bonds, even though this idea is commonly considered a misconception (Gayford, 1986; Novik, 1976). In many cases, a chemical bond is equated to a loaded spring (Campbell & Reece, 2002) or a battery (Harrison & Coll, 2008). The energy storage language is useful in discussions of potential energy in general (Swackhamer, 2005). Physics classes abound with language of energy stored in batteries, springs, even a block at the top of a ramp that 'stores' gravitational potential energy. The energy storage language is common among younger students as well (Watts, 1983).

Are Substance Metaphors Valid?

One finding from this analysis is that the vast majority of discourse about energy implies that it is a substance. Although widely accepted that energy is not actually a substance, it is virtually impossible to discuss energy without referring to it as a tangible quantity. These metaphors are not only common, but also provide a fruitful framework for helping students conceptualize the abstract notion of energy. Any ontological metaphor either highlights or obscures the various aspects of a given concept. In this case, the fact that energy is not a substance is obscured so that the other characteristics may be made clear. The downside is that this language implies that energy is a physical substance. Even so, many educators recognize that substance metaphors are not harmful to students' understanding of energy (American Association for the Advancement of Science, 2008; Duit 1987; Falk, Herrmann, & Schmid, 1983).

Although many of these conceptual metaphors are commonly cited as alternative conceptions (Watts, 1983) or fallacies (Sefton, 2004) students have about energy, it is probably more accurate to say that students holding these ideas have an incomplete understanding of energy. A complete definition of energy would recognize that energy is a conglomerate of the ideas listed above. Energy can flow through ecosystems; it can be the product of a reaction, and so on. None of these is entirely correct on its own, but each highlights different aspects of the broad concept of energy as they are used in a particular context. Taken as a whole, they form a set of *coherent* conceptual metaphors for energy. The value in each conceptual metaphor is that it helps to explain the role of energy in its application to a particular context; energy cannot be defined out of context or outside of a system.

It is important to recognize that there are limitations to using substance metaphors for energy (Amin, 2009; Scherr et al., 2012). The primary one being that it is difficult to conceptualize negative energy as a substance, as is the case for electrical or chemical potential energy in bound systems. For this example, some have pointed out that in this context it is more fruitful to use the Location Event Structure, as defined by

Lakoff and Johnson (1999), in which energy is described as a physical location (e.g. *up* or *down*) rather than a tangible substance (Dreyfus et al., 2014).

To summarize the literature, there is no consensus as to which definition (or metaphor) of energy is best. One consequence of this is that students receive mixed messages during instruction, and the definitions of energy are often at odds with each other. By documenting the different conceptual metaphors students use to describe energy, we can begin to understand the effect that these different conceptualizations have on student learning.

Methods

Participants and Setting

The participants in this study were enrolled in a university two-semester interdisciplinary general science course for non-science majors. Content was covered in an integrated manner using a Science, Technology & Society approach. A student who completed the course was expected to be able to read, understand, and intelligently discuss science-related stories in the media. Topical units included issues such as human energy use, transportation, radiation, natural disasters, and space exploration (in the first semester). The fact that energy appeared throughout the course gave students multiple points of entry for understanding this complex concept, and provided a unique environment for research because the students were exposed to the various scientific meanings of the term within one course.

The course was taught at a small liberal arts college in the Midwestern United States, and enrolls either 20 or 40 students depending on whether one or two sections are offered. The course met for two 75-minute lectures per week and one 3-hour laboratory session. Data presented in this paper were collected over two years in the first semester of the course sequence. All students taking the course were invited to participate in the study. A total of 49 students participated in the study over the two years. Students came from a range of majors (mostly business, early childhood education, or the humanities), and were generally juniors and seniors. These students typically had taken only two years of high school science, and no other college science course. Thus these students can give us some idea of how the general public understands energy.

Data

The data reported in this paper were drawn from an essay question on the final exam. This was a take-home exam; students were permitted to use notes, textbooks, and other resources. The question asked:

Energy and energy conservation (in the scientific sense) are key to understanding most topics in science. Look at the list of topics below and explain how energy and/or energy conservation are involved and why energy is important in understanding this topic.

(a) Radiation/radioactivity (e.g. taking an x-ray),
(b) Generating electricity using fossil fuels,

(c) Transportation (e.g. using gasoline to fuel a car),
(d) Earthquakes and tsunamis, and
(e) Creation of the universe (e.g. big bang).

Analysis

The data analysis draws on the methodology used by Lakoff and Johnson (1980, 1999). In their work, Lakoff and Johnson identified metaphorical phrases in language and grouped them together by theme. For example, the phrases 'Look how far we've come', 'I don't think this relationship is going anywhere', and 'We're at a crossroads.' reflect the conceptual metaphor LOVE IS A JOURNEY (Lakoff & Johnson, 1980, p. 44).

In the previous study (Lancor, 2014b), the students' analogies were grouped together based on a method of constant comparison, eventually converging on a list of six conceptual metaphors (described above). In this study, explicit analogies and instances of metaphorical language were identified and classified according to the following criteria:

- *Energy as a substance that can be accounted for*. Evidence included mention that the amount of energy in the system (changing or staying the same) could be counted. For example, 'X energy is here, Y energy is there, but the total amount of energy stays the same.'
- *Energy as a substance that can change forms*. Language indicating energy can change forms included 'X changes into Y', 'X is converted into Y', and 'X is transformed into Y'.
- *Energy as a substance that can flow.* Any language indicated a fluid movement of energy was coded as a flow metaphor. This included energy 'flowing' out of or through a system.
- *Energy as a substance that can be carried.* Anytime a student wrote that energy was moved from one location to another *by an object* was coded as an energy carrier metaphor. Verbs like carried, held, or transported were common. Also, if a student wrote an object 'has energy in it', it would be coded as an energy carrier metaphor.
- *Energy as a substance that can be lost*. Evidence of this metaphor included language such as 'energy is lost from the system' and 'energy is no longer useful or usable'.
- *Energy as a substance that can be added, produced, or stored.* Evidence of this metaphor included students writing that 'energy is needed for X to happen'. Other verbs included energy being created, produced, stored, added, or released.

In this study, many students used multiple metaphors to explain a given scientific topic. In these cases, the discourse was coded for both metaphors (sometimes even three metaphors).

For example:

> Also, the plate boundaries slide against each other, which will cause earthquakes, so the heat and gas energy will release in the environment. The heat and gas energy are not lost because it goes into the atmosphere.

The statement that energy will be released into the environment indicates an energy storage metaphor (if it was released, it had to be stored somewhere). The student also states that the energy is 'not lost', which is an indication of the accounting system metaphor and reflects an understanding of energy conservation.

A second round of coding determined which of the characteristics of energy were present in the students' responses. The criteria for each characteristic were:

- Energy conservation. Responses were considered to have evidence of energy conservation if they discussed a fixed amount of energy, or recognized that energy is never lost, destroyed, or created.
- Energy degradation. Evidence of energy degradation included recognition that energy can be lost from a system or that the total amount of (useable) energy in a system decreases.
- Energy transformations. Evidence of transformation was primarily that the analog to energy had the ability to change forms. Some students used the word 'transformation' but their analogy did not actually indicate that the substance changed forms in the analogy (e.g. water (energy) being poured from one bucket to another). These were not coded as transformation, but as energy transfer.
- Energy transfer. Evidence of energy transfer included the substance (energy) moving from place to place or being transported by an agent.
- Energy source. A clearly identifiable source of energy was included in the response (e.g. 'the ocean represents the sun, a source of energy').

The goal was to determine whether or not students used these characteristics in explaining the concept of energy. Note that student responses did contain many of the misconceptions cited in the literature (e.g. energy is causal, an anthropocentric view of energy). The focus of this analysis is on how students use metaphorical language to explain, and therefore conceptualize, energy. This is intentionally not an evaluation of the scientific accuracy of their claims. The goal of the study is to learn more about student cognition, not to evaluate mastery of the science content. Some of the examples cited below do contain scientific errors, but I have generally refrained from discussing these misconceptions in the analysis.

Results

The results presented below are grouped by conceptual metaphor to highlight the similarities and differences in the way that the metaphors were used in the various scientific contexts. Virtually all of the metaphors used by students could be placed into the previously identified categories. Table 3 compares this data to the results from the previous study which identified metaphors in traditional science courses. The overall results of coding for the characteristics of energy are shown after the metaphors are discussed.

Table 3. Prominent metaphors students commonly used to describe energy in this study and from the previous study on topics from traditional science courses (Lancor, 2014b)

	Metaphors for energy (% of student responses)					
Topics from interdisciplinary science course[a]	Energy as a substance that can be carried	Energy as a substance that can flow	Energy as an ingredient, product, or substance that can be stored	Energy as a substance that can change forms	Energy as a substance that can be lost	Energy as a substance that can be accounted for
Radioactivity	25	25	25	13	6	0
generating electricity	6	0	54	27	12	0
Transportation	3	3	25	47	22	0
big bang	23	15	31	8	0	23
Earthquakes and tsunamis	13	24	45	16	0	3
Topics from traditional science courses[b]	Energy as a substance that can be carried	Energy as a substance that can flow	Energy as an ingredient, product, or substance that can be stored	Energy as a substance that can change forms	Energy as a substance that can be lost	Energy as a substance that can be accounted for
Mechanical systems	11	10	9	22	0	48
Circuits	19	70	4	7	0	0
Ecosystems	15	38	12	5	25	5
Chemical reactions	6	4	58	8	0	14

[a]Totals may add up to more than 100% because some responses were coded for multiple metaphors.

[b]In the previous study, the analysis included a code for 'process metaphors' which was not included in the current study. For this reason, not all totals add to 100%.

Energy as a Substance that Can be Accounted for

The accounting system metaphor was practically nonexistent in the student responses, which indicates that students may not see this metaphor as useful in describing energy in these scenarios. It is interesting that this metaphor appears so rarely because it was used extensively in the discipline-based classes, particularly in the physical sciences (Table 3).

Energy as a Substance that Can Change Forms

Energy transformation is considered by some scholars to be a hallmark of understanding the concept of energy (Nordine et al., 2011; Trumper, 1990). In this study, many students identified forms of energy (e.g. kinetic energy and thermal energy), but did not show evidence of understanding that energy can be transformed from one form to another. Language describing various forms of energy and language describing energy transformation both fall under the umbrella of this metaphor, but the latter represents a more sophisticated understanding of the concept of energy. Examples of both forms of energy and transformation language are given in Table 4 to illustrate the difference in complexity of these responses.

The forms of energy language is common in the context of generating electricity and transportation because it emphasizes the many energy transformations that take place as energy propagates through these systems. The energy transformation metaphor is a useful framework for understanding complex systems with many interacting parts. On the other hand, the transformation metaphor appeared rarely in the context of either radiation or the big bang (only 2 and 1 responses, respectively). This is likely not a useful metaphor in those two contexts because it does not emphasize the characteristics of energy that are most important to explain these phenomena (i.e. energy transfer rather than energy transformation).

Energy as a Substance that Can Flow

The metaphor of energy as a substance that can flow (like water) occurred in the context of earthquakes and radiation, but was not used frequently compared to its prominence in the previous study (Table 3). For example:

> When these earthquakes occur in the ocean, the ground movement causes a wave that the energy flows through.

In this example, the energy flows through the wave; in other examples, energy is carried by a wave, making the wave an energy carrier. The metaphor of energy waves as a mode of energy transfer is an interesting case, and could be considered a subset of either the energy flow metaphor or the energy carrier metaphor, or perhaps a conceptual metaphor in its own right. Further investigation needs to be done to determine the extent to which this metaphor is useful in a range of contexts.

Table 4. Examples of student responses with evidence of the *Energy as a substance that can change form* metaphor

Context	Excerpts of student responses (emphasis added): Forms of energy	Energy transformation
Generating electricity	First off, electricity is a form of energy and can be generated by many sources such as hydro-electric energy	At power plants, coal is burned and its potential chemical energy heats up water in a boiler. When the water boils, it releases thermal energy in the form of steam. Then the steam powers a turbine engine by transforming the heat into kinetic energy that spins the turbine engine. After that, the turbine engine uses the kinetic energy to power a generator. The generator finally takes the kinetic energy and transforms it into electrical energy. Throughout this process, it can be understood that energy is primarily lost in the form of heat
Transportation	There are many types of energy involved in transportation. There is the most obvious which is seen in the movement of the car or Kinetic energy. The less obvious are those within the vehicle itself. There is electrical energy, light energy, thermal energy, chemical energy, gravitational energy, potential energy and friction. Chemical energy is in the burning of oil and the gas/fuel, and the battery. All of the forms of energy are needed to make a car run	The gasoline serves as the potential chemical energy that eventually turns into kinetic energy to place a vehicle in motion. During this energy transformation, the heat from the engine breaks down the chemical bonds in the gasoline. Then when these bonds break, their chemical energy is released and places the gears inside the vehicle into motion when a person pushes their foot down on the gas pedal to drive. However, not all of the gasoline's energy goes into powering the vehicle. A lot of it becomes lost in the form of heat and sound when the vehicle's engine and gears are working
Earthquakes and tsunamis	Energy involved with earthquakes and tsunamis include kinetic energy, friction, and geothermal energy	Earthquakes are caused by two tectonic plates rubbing against each other and creating potential which is waiting to be released. Once this energy is released it is transformed into kinetic energy

Energy as a Substance that Can be Carried

Under this metaphor, an energy transformation is explained as energy being transferred to a different carrier; the new carrier becomes the vehicle for what would be a different form of energy in the previous metaphor. This language is not frequently used in standard scientific discourse, but the students found this to be a useful metaphor. For example (emphasis added):

> Radiation itself is a type of energy that is packed into small units called Alpha and Beta particles.
>
> X-rays are basically the same thing as visible light rays as they are both forms of electromagnetic energy carried by particles called photons.
>
> The [tectonic] plates carry potential energy and when they shift, the energy they carry gets transferred into the ground creating a shaking from the kinetic energy which can and many times results in an earthquake.

Note in the earthquake example, the energy is transferred between multiple carriers, which would be a transformation under the previous metaphor.

Energy as a Substance that Can be Lost

The metaphor that energy is a substance that can be used up or lost was common in student responses, particularly in the two scenarios involving fossil fuels: generating electricity and transportation. Many students recognized fossil fuels (and also energy) as finite natural resources that must be conserved. Many students also recognized that the energy is not really lost, but is degraded into a less usable form or transferred to the environment. For example:

> The problem is that the input of energy from coal is almost equal to that of the energy which is transferred elsewhere or 'lost' during the conversion of this stored energy into electric. If the electricity production seems bad, then the energy usage of a car is worse. Energy that is lost to the system is no longer useful, resulting in degradation of the energy.

However, not all students recognized that energy was lost *from the system*. In these cases, it is not obvious that students recognize that the energy goes somewhere else; it could just be disappearing. For example, this student implies that the amount of useful energy (in the gasoline) in the system is decreasing, but does not recognize where that energy goes:

> . . . With normal gasoline this energy is lost, but with a biodiesels the energy from carbon dioxide goes back into the planets grown for the fuel, that why it's important to understand how this energy works so we can better our environment.

This makes it difficult to tell if the student has an understanding of the relationship between energy conservation and energy degradation. The distinction between these two variations on the energy loss metaphor is important because it draws a line between a student with a misconception (i.e. energy can be destroyed) and a student with a more complete understanding of how useful energy can dissipate from a system.

Energy as a Substance that Can be Added, Produced, or Stored

This is another metaphor that appeared frequently in each of the topics. It is interesting to see that this metaphor plays out in very different ways in this diverse group of scenarios (Table 5). Whether the energy is an ingredient or a product often depends on how the system is defined. Additionally, language of energy storage is often intertwined with language indicating energy is an ingredient or a product. For example, energy is *produced* from the combustion of gasoline (the system is the fuel), but is

Table 5. Example of student responses with evidence of the *Energy as a substance that can be added, produced, or stored* metaphor

	Example of Student Responses (emphasis added)		
Context	Ingredient	Product	Storage
Radiation	When taking an x-ray, high energy photons are needed to produce the x-ray. Inside of the x-ray vacuum, electrons are constantly jumping between energy levels, releasing an x-ray photon each time	These photons are produced by the movement of electrons in atoms. Atoms emit light by colliding with a moving particle which in turn causes an electron to climb to a higher energy level, and the fall back to its original level. This causes the extra energy to release in the form of a light photon	Your bones absorb this energy much better than the tissue in our bodies
Transportation	When gasoline is used to fuel a car it goes through a combustion engine and provides energy for the motor to move the wheels of the vehicle	Gasoline, and the energy it produces, is very important because it provides us with a way of transportation	Some motor vehicles are powered by gasoline, which holds potential energy
		When the car is moving forward, there is kinetic energy involved. Also, it produces thermal energy when it has friction with the tires and the road	Chemical energy is stored in gasoline which you use to power your vehicle
Earthquakes and tsunamis	That earthquake released a lot of (energy) that started to generate waves out at sea	As the plates slide along one another and collide, energy is created between the frictions and grinding of the two plates	Earthquakes are caused by the rapid release of stored energy (potential energy), turning into movement (kinetic energy) . . . This sudden release of energy then causes the ground to shake
	Geothermic energy is what creates earthquakes and tsunamis		

an *ingredient* needed for the car to run (where the system is the car). The energy is also *stored* in the gasoline in the tank, waiting to be combusted. Students write about energy production saying that energy is made, created, emitted, released, or produced. There are subtle differences; if energy was released that implies that it must have been stored in some way, if energy is created from some other type of energy that implies transformation. In general, this metaphor illustrates that energy can be transferred into or out of a system.

The fact that students used the energy storage metaphor repeatedly is interesting because it was not prevalent in the disciplinary contexts.[5] The idea of energy storage is commonly considered a misconception, and as a consequence the metaphor is not often used in the discourse of traditional disciplinary science courses. (And often it is explicitly addressed as an incorrect way of conceptualizing the energy in chemical bonds.) The fact that energy storage is commonly invoked here may reflect a lack of disciplinary expertise, and indicate that students are more likely to use intuitive metaphors for the more familiar, real-life scenarios. As was common in the course, students were constantly switching between the scientific and colloquial discourses and may not have made clear conceptual distinctions between them.

Characteristics of Energy

The purpose of identifying conceptual metaphors is to figure out which characteristics of energy the students understand. These results are shown in Figure 1. It is interesting to note that the profiles of each topic are quite different, but that energy transformation or energy transfer was the most evident in students' responses. Students may not be using energy conservation explicitly as a scientific model, but they are using the fact that energy changes (either form or location) in a system to explain these phenomena.

A final observation on the students' responses in this study is that there was generally less evidence for the characteristics of energy than in the responses from the students in traditional disciplinary science courses (Figure 1). This may indicate that a disciplinary structure helps students to have a more multifaceted understanding of the energy concept. The concept of energy is so abstract that it is difficult to conceptualize outside of a well-defined set of disciplinary norms. In an interdisciplinary science class, teachers need to be aware that the students' conceptions of energy are more fragile than those of students in a disciplinary course. They may have more difficulty piecing together the various characteristics of energy because they see the concept of energy used in so many different ways.

Discussion

This study demonstrates that students use metaphorical language spontaneously (without being prompted) to describe energy, and furthermore the metaphors in the students' responses are drawn from the same set of conceptual metaphors identified in traditional, disciplinary science courses. This shows that the methodological framework developed for the original study is useful for analyzing discourse in this

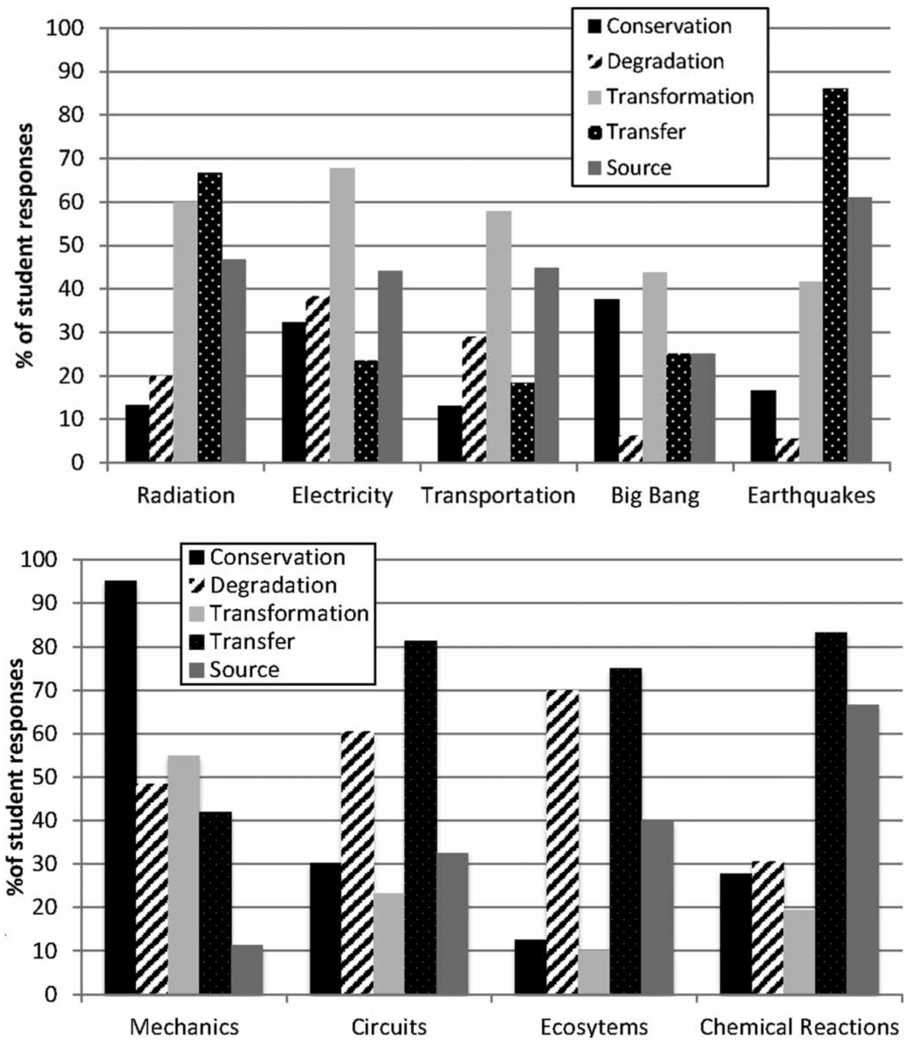

Figure 1. Percentage of student responses that indicated an understanding of each characteristic of energy in various scientific contexts from this study (a) and the previous study (b)

context. As a whole, these students were far from being steeped in the discourse of a particular discipline, but the language they used had many commonalities with disciplinary discourse about energy. This is significant because these students had not taken any other college-level science courses, and many only had two years of high school science (the state graduation requirement). The implication is that we, as teachers, can use this framework to identify conceptual metaphors for energy, and use these metaphors to assess how students understand the various characteristics of energy in a wide range of science courses.

Comparing these results to the previous study (Table 3), there are some interesting differences in which metaphors were used preferentially. The metaphors of energy as an accounting system and energy flow through a system are prevalent in traditional science contexts and uncommon here. Energy loss and energy as an ingredient/product/storage metaphors were much more common in the topics studied here, possibly because they are more common in everyday discourse about energy. Another observation to make about the data in Table 3 is that the students used a wider variety of metaphors to explain the topics in this study, as opposed to the findings from the earlier study that each scenario had one or two metaphors that were used predominantly.

Overall, applying the framework in this study was not as straightforward as when students were explicitly asked to write analogies. Student responses were often coded for multiple metaphors due to the complexity of their explanations. For example:

> Energy is also present when generating electricity. Much of the nation's electrical energy comes from coal. ... In order to get electrical energy from coal it must go through a process at a power plant to get the potential energy out.

This first part of the student's response indicates that energy is stored in the coal, and would be a product of the combustion reaction. The student is using the ingredient/product/storage metaphor. She goes on to say:

> The coal is combusted using a large amount of heat to form steam. A steam turbine then converts energy from the moving steam into mechanical energy. The electrons are captured instead of being used immediately so they can be sent to people around the nation to use for electricity. Electricity is a form of energy. This is why there is an importance to understanding energy when talking about and dealing with electricity. You can't have electricity without energy.

The second half of her explanation uses the energy transformation metaphor; energy is converted from thermal to kinetic energy. She also implies that the electrons are carries that will transport energy to people's homes. She has used three metaphors simultaneously to highlight different aspects of the process of generating electricity.

In the following example, the student used an explicit analogy to explain the role of energy in generating electricity:

> Energy is something like a soul; it cannot be destroyed and is always around. However, unlike our souls, energy can be transferred to different activities. Think in a way that makes [sense] such as when you eat your [*sic*] absorbing or transferring that energy that was contained in that apple or orange and is now in your body.

This particular student starts by comparing energy to a soul, but recognizes the limitation of this analogy—the soul cannot be transferred. He then goes on to compare energy to food, using the metaphor of an energy carrier. The fruit is the carrier, transporting the energy to the person. However, he also finds a limitation because he cannot explain what it is in the fruit that is the energy (what is the substance (energy) being carried by the food?). He goes on to write:

> When we conserve energy it is like putting water into a jug with a tap, like in your kitchen. We have a way of getting that energy easily but at times we need to refill it because we notice that the water is almost gone. This water jug is like fossil fuels, except when

> we're running low we cannot just go and refill the water jug from our close sink. We need to walk a tremendous distance to a water spring in the jungle. This trip would take us a year to make just to fill our jug back up, but in our world fossil fuels are the water and the spring we get it from is formed over millions of years, so we can't just make easy trips.

In this analogy, energy is a substance (water) that is contained by the water jug (the fossil fuels). In this response, we can see that his multiple analogies are creating a more complex picture of the energy concept than could be achieved by using only one metaphor.

As the examples above illustrate, students often used two or more metaphors simultaneously. It may be tempting to dismiss these mixed metaphors as incomplete or incorrect understandings. However, under conceptual metaphor theory, we expect complex ideas to be represented by a set of coherent metaphors, which are necessary to highlight the different characteristics of energy. Interestingly, multiple metaphors were used more extensively here than in the traditional science courses. This could be due to the fact that these were not simple systems, unlike the ones examined previously (e.g. mechanical systems or circuits) and multiple representations of energy are required to adequately describe the phenomena.

Asking students directly to define energy tells us little about how they actually understand the concept, and does not help us to gain insight into student ideas. This is why we do the metaphor analysis—when asked for a formal definition of energy, students can state the Law of Energy Conservation, but we do not actually have evidence that they are understanding this concept or find it fruitful to explain the role of energy in a system. The analysis of the students' writing using conceptual metaphor theory can help a teacher assess how well students actually understand the energy concept, as opposed to evaluating how well they can parrot back formal definitions.

Implications for Instruction

Qualitative discourse analysis has typically been relegated to the world of science education research, and not practiced systematically by classroom teachers. One goal of this project was to develop a framework that teachers could use to help them interpret student ideas about energy. As such, the substance metaphors for energy described above are designed to be accessible to classroom teachers as well as educational researchers. This qualitative metaphor analysis would not be a good summative assessment tool because there is no one right metaphor for energy that is scientifically accepted in any context. Rather, we can use this framework as a formative assessment tool to help teachers interpret classroom discourse (spoken and written).

One of the purposes of formative assessment is to monitor the progress of students' conceptual development. Research shows that formative assessment helps to improve learning, but only if teachers use the data gathered by formative assessments to influence their teaching (Black & Wiliam, 1998). Black and Wiliam (1998) note that discourse and questioning can be powerful tools for formative assessment, but the students' responses can be difficult to interpret, and therefore difficult to use in making instructional decisions. Additionally, Bell and Cowie (2001) note that one of the characteristics of good formative assessment is that it be an integral part of teaching and learning. There is a need for more authentic assessments, assessments that are integrated into the curriculum (Tamir, 1998).

As a formative assessment tool, the goal of the metaphor analysis described above would be to help the teacher identify which characteristics of energy are articulated in the students' metaphors. This allows teachers to better build on the students' existing ideas. Energy is a complex concept that can only be successfully applied if a learner has mastered all of it various characteristics (e.g. conservation and transformation). Information about which characteristics students understand, and which they do not, is valuable information to have as teachers plan future lessons. Using this method of discourse, analysis yields a more nuanced picture of student understanding than can be gained from traditional assessment questions such as 'What is the definition of energy?'

Limitations of the Study and Future Work

One limitation of this study was the exclusive focus on substance metaphors. It is quite possible that students used other metaphors for energy, but analyzing the responses for other metaphors was beyond the scope of this study. A future research project could re-analyze the data to look for evidence of the 'Location Event Structure' metaphors. Additionally, future studies could take a longitudinal approach, and examine how students' ideas about energy develop over time. It would be interesting to see if their metaphors remain consistent or evolve in some way.

Conclusions

This study found that students used metaphorical language extensively in written responses to exam questions. This is significant for two reasons. First, this validates the methodological framework that was previously developed to analyze explicitly solicited analogies. In this study, we see that students use the same conceptual metaphors spontaneously in their writing, and so the same framework can be used to help identify the characteristics of energy in student responses. Additionally, this study helped to further refine the classification of conceptual metaphors. The 'energy as a substance that can change forms' metaphor was split into two subcategories: 'forms of energy' and 'transformation of energy' that reflect the difference in complexity of responses. The complications of distinguishing energy as an ingredient, product, or a substance to be stored were also revealed in this analysis.

Second, the students were writing about the role of energy in different scientific contexts. In these particular contexts, students found it useful to employ multiple coherent metaphors to explain the role of energy in these systems. While the set of conceptual metaphors identified previously may not be complete, they do have broader applicability than just traditional science courses. This is interesting because these students did not have a strong disciplinary basis on which to draw;

they had little exposure to the metaphors used in traditional scientific discourse. This suggests that the conceptual metaphors represent a conceptualization of energy that goes beyond the disciplinary structures and into everyday understandings, and that the disciplinary structures are not divorced from everyday understandings.

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Notes

1. Note that some researchers use the term analogy to refer to the mapping between cognitive domains, but I am using it here in the literary sense to describe the actual language used by students.
2. An isolated system is one that is isolated from the surrounding environment. An open system is one in which energy can be transferred to and from the surrounding environment. By definition, energy is not conserved in open systems.
3. Usable energy refers to energy that can do work in a system, as opposed to energy dissipated to the environment (and therefore lost from the system).
4. It is worth noting that textbooks do not necessarily reflect the ideals of the disciplines. However, they are a primary source of information for students, and an important resource for teachers. At lower levels, teachers may learn the content from the text, and at higher levels the professors use the text to help them translate the content into language the students can understand. For these reasons they merit critical examination.
5. Table 3 lists this as a common metaphor for chemical reactions, but this was primarily due to students employing the ingredient/product aspect of the metaphor and *not* the energy storage metaphor. See Lancor (2014b) for details.

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