

**SUPPORTING MIDDLE SCHOOL STUDENTS' DEVELOPMENT OF AN  
ACCURATE AND APPLICABLE ENERGY CONCEPT**

**by**

**Jeffrey Carl Nordine**

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**Doctoral Committee:**

**Professor Joseph S. Krajcik, Chair**

**Professor Jean P. Krish**

**Associate Professor Elizabeth A. Davis**

**Assistant Professor David L. Fortus, Weizmann Institute of Science and  
Michigan State University**

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For Dad

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## **ABSTRACT**

### **SUPPORTING MIDDLE SCHOOL STUDENTS' DEVELOPMENT OF AN ACCURATE AND APPLICABLE ENERGY CONCEPT**

**by**

**Jeffrey Carl Nordine**

**Chair: Joseph S. Krajcik**

Energy is a fundamental unifying concept of science, yet common approaches to energy instruction in middle school have shown little success with helping students develop their naïve ideas about energy into more sophisticated understandings that are useful for making sense of their experiences. While traditional approaches to energy focus on performing calculations in idealized systems, our development team produced a new middle school energy unit that focuses qualitatively on the energy transformations that occur in everyday, non-idealized, systems. This approach uses project-based pedagogy to contextualize instruction with the driving question, “How can I use trash to power my stereo?” In this study, I investigate the effectiveness of our approach by tracking 8<sup>th</sup> grade students’ conceptual development during the unit, following up with students who participated in the unit a year previously, and comparing the energy conceptions and content knowledge between energy unit participants and older students in the same school who learned about energy in an approach that did not emphasize energy transformations in non-idealized systems.

Results indicate that during instruction, students' energy conceptions progress from a set of disconnected ideas toward a coherent understanding that is organized around the principle of transformation. After instruction, students who participated in the energy unit were generally more capable of using their understanding of energy to make sense of everyday scenarios than were older non-participants. Furthermore, 9<sup>th</sup> grade students who participated in the energy unit in their 8<sup>th</sup> grade year continued to develop more sophisticated understandings of energy during their 9<sup>th</sup> grade biology course. These 9<sup>th</sup> grade students seemed better prepared to learn about energy content in their biology course than 10<sup>th</sup> graders, who did not participate in the energy unit, but took the same biology course during their 9<sup>th</sup> grade year. Overall, my results suggest that middle school curricula can have a more meaningful and lasting impact on students' energy conceptions and content knowledge by focusing qualitatively on energy transformations that occur in familiar, non-idealized systems.



## **CHAPTER ONE**

### **INTRODUCTION**

Energy is one of the most fundamental and far reaching of all scientific concepts. Biologists use energy to describe the relationships between organisms in an ecosystem; chemists routinely interpret chemical reactions by tracking energy changes; geologists use the conservation of energy to build models that describe plate tectonics; astrophysicists rely on energy conservation when deducing the shape and structure of the universe. Regardless of its application, the law governing energy is strikingly simple – the total amount of energy in any closed system must be the same at any two points in time.

It is the simplicity of the law of conservation of energy and its wide applicability that make it a ubiquitous topic in school science, yet it is often addressed superficially in ways that are not likely to promote deep understanding in students. In a review of the most popular textbooks used in middle school science classrooms, Kesidou and Roseman (2002) found most to be inadequate in terms of their ability to promote students' development of coherent understandings of the major ideas in science, such as energy. Among their shortcomings, the most popular school science textbooks failed to model how science concepts and processes can be used in students' lives outside of school. Without making connections between science topics and between school science and

students' everyday lives explicit, students are highly unlikely to do it on their own (Brown, Collins, & Duguid, 1989; Lave, 1988).

In order to make such connections and to develop deep understandings of scientific concepts like energy, curricula must provide students with opportunities to refine and reorganize their prior understandings (National Research Council, 2000, 2007). When students enter the science classroom, they have already formed their own ideas related to energy (Driver, Squires, Rushworth, & Wood-Robinson, 1994a; Solomon, 1983; Watts, 1983), but traditional physical science instruction has proven largely ineffective for helping students refine these ideas into more accurate and sophisticated conceptions (Driver *et al.*, 1994a; Solomon, 1983).

Traditional middle school energy instruction often focuses on simple calculations of energy and work idealized systems, offers an operational definition for energy (e.g., “the ability to do work” or “the ability to cause a change”), and focuses on one form of energy at a time without emphasizing the importance of energy transformations in everyday phenomena. This common traditional approach may be a reaction to assertions that young children are not yet capable of dealing with energy as an abstract physical quantity (Piaget & Inhelder, 1971; Warren, 1986), yet recent studies indicate that such a stage-like conception of development is not entirely appropriate (Flavell, 1994). Further, instructional interventions seem to play a key role in developing understandings in young children that many adults never acquire (Klahr & Nigam, 2004; Linn, Lee, Tinker, Husic, & Chiu, 2006; Smith, Maclin, Houghton, & Hennessey, 2000; White & Frederiksen, 1998). When students develop understandings that are coherent rather than a collection of facts, they are more likely to be able to apply their knowledge to new situations and

continue to learn more efficiently even after instruction (Linn & Eylon, 2000; National Research Council, 2000, 2007). To help students develop coherent understandings, instruction must be organized around big ideas and involve learners in relevant contexts (National Research Council, 2007; Roseman & Linn, 2007).

A development team (of which I was a part) composed of collaborators from the Center for Highly Interactive Classrooms, Curricula, and Computing in Education at the University of Michigan and the Department of Teacher Education at Michigan State University developed a new curriculum (Fortus, Krajcik, Nordine, Plummer, Rogat, & Switzer, 2005) to introduce middle school students to the scientific concept of energy. The curriculum represents a substantial departure from typical middle school instruction on energy because it involves no calculations of work or energy, makes no attempt to operationally define energy, and focuses on energy transformations that occur in non-idealized phenomena that students are likely to see outside of the classroom. Because of its central focus on energy transformations in everyday phenomena, our approach gives students more of an opportunity to integrate their school science knowledge with their prior experiences into a coherent framework that is organized around the principle of energy transformation. When students are able to use their understanding of energy to interpret everyday phenomena, the explanatory power of their energy concept increases dramatically. By having a concept of energy that is more useful in more contexts, students are well-positioned to use their energy concept to learn and interpret new information. Because our unit is designed to help students develop a more accurate and applicable concept of energy, I believe our approach is a more effective way to introduce middle school students to energy than the traditional alternative of studying energy in a

piecemeal fashion using classical idealized phenomena that students are unlikely to experience directly.

In this study, I assessed the effectiveness of our instructional approach by investigating the following research questions:

- How do students' conceptions of energy evolve during the course of their involvement in the energy unit?
- To what extent do students' desirable conceptions of energy attained during their participation in the energy unit persist one year after instruction?
- How do the energy conceptions of students who have participated in the energy unit compare to the energy conceptions of students at the same school who have not participated in the unit?
- What effect does participation in the energy unit have on students' ability to perform on assessment items that are targeted at national standards and benchmarks?

To address these questions, I compared the 8<sup>th</sup> and 9<sup>th</sup> grade students who participated in the energy unit at a pilot site to 10<sup>th</sup> and 11<sup>th</sup> grade students at the same school who had the same 8<sup>th</sup> grade teachers but did not participate in the unit. Although the 10<sup>th</sup> and 11<sup>th</sup> grade students had also studied energy in 8<sup>th</sup> grade (the 8<sup>th</sup> grade science course at the pilot site has been organized around the theme of energy for many years), these students were exposed to an approach that did not emphasize the role of energy transformations in everyday, non-idealized systems. I compared students in terms of their energy conceptions and their ability to perform on assessment items that were developed by members of Project 2061 to assess middle school energy benchmarks from the

Benchmarks for Science Literacy (American Association for the Advancement of Science, 1993).

For each of my research questions, I hypothesized the effect of students' participation in the energy unit would be manifest in the following ways:

- I expected that 8<sup>th</sup> grade students would develop more coherent understandings of energy during instruction that are organized around the principle of transformation. This is the effect I observed in a pilot study (Nordine, Fortus, & Krajcik, 2006).
- Because our unit is likely to produce conceptions that are useful for interpreting everyday phenomena, I expected that students' coherent conceptions would be largely maintained. Therefore, I expected that 9<sup>th</sup> grade students would exhibit roughly the same quality of energy conception compared to that which they exhibited in a pilot study one year ago, with perhaps some small amount of deterioration.
- Because 10<sup>th</sup> and 11<sup>th</sup> grade students have not had energy instruction that is organized around transformations in everyday phenomena, I expected that 8<sup>th</sup> and 9<sup>th</sup> grade energy unit participants would be more likely to exhibit coherent energy conceptions organized around the principle of transformation and will be less likely to exhibit alternative conceptions than would 10<sup>th</sup> and 11<sup>th</sup> grade students who have not participated in the energy unit
- I expected that 8<sup>th</sup> and 9<sup>th</sup> grade students would significantly outperform 10<sup>th</sup> grade students on energy content assessments targeted at middle school energy benchmarks because energy unit participants would be more likely to have a

coherent cognitive framework that better supports energy content knowledge. I expected that 11<sup>th</sup> grade students, who are the group most highly self-selected for an interest in science and who have recently had energy instruction in physics, will perform at or above the level of 8<sup>th</sup> and 9<sup>th</sup> grade students on the energy content knowledge assessment.

The results of this study can inform educators' understanding of how students' conceptual development occurs, the design of *learning progressions* that describe how students' thinking about energy can become successively more sophisticated over an extended period of learning and investigation (National Research Council, 2007), and the development of new curricula that support students' understanding of the big ideas of science. Because over 90% of middle school physical science teachers do not hold a major and certification in their subject (Seastrom, Gruber, Henke, McGrath, & Cohen, 2004), and these teachers are highly likely to rely on curricular materials (Ball & Feiman-Nemser, 1988), putting proven high-quality instructional materials in the hands of teachers is perhaps the most promising way to improve science instruction in middle schools.

## CHAPTER TWO

### THEORETICAL FRAMEWORK

Although energy is one of the most central and richly connected ideas in all of science, students often have a great deal of difficulty understanding it (Driver, Squires, Rushworth, & Wood-Robinson, 1994a). While some have suggested that students' difficulty learning about energy is largely due to maturational factors (Warren, 1986), others contend that students' ability to learn about abstract concepts (such as energy) is not as centrally dependent on biological maturation as was once thought (Flavell, 1994), and that instruction can foster scientific understandings in young students that many adults never acquire (Klahr & Nigam, 2004; Linn, Lee, Tinker, Husic, & Chiu, 2006; Smith, Maclin, Houghton, & Hennessey, 2000; White & Frederiksen, 1998). In this chapter, I describe students' common ways of thinking about energy, how students develop and refine their ideas, and role of curriculum in supporting students' conceptual development.

#### **Common student ideas about energy**

Over the past several decades, a line of “misconceptions” research has been aimed at providing insight into the types of common alternative understandings that students bring to the classroom. Many of these researchers did not favor the term *misconception*,

because it implied some sort of inappropriate understanding among students, even though their ideas may be entirely consistent with their experiences. For this reason, some researchers use terms such as *preconceptions*, *children's science*, and *alternative frameworks* when describing students' thinking about science concepts that is not congruent with accepted scientific understandings (Confrey, 1990). Regardless of differences in terminology or beliefs about the origin of students' ideas, the body of misconceptions research has served the function of showing empirically that students do not enter the science classroom *tabula rasa*, rather, they bring in their own ideas that will influence the way they interpret new information.

Most students encounter the term energy in informal settings well before they enter the middle school science classroom. Before formal instruction, it is unlikely that they will have used their ideas about energy to reason about situations because, without a somewhat sophisticated understanding of transformation and conservation, they hold little explanatory power. It is likely that most of the energy-related thinking that students engage in before they enter the science classroom is related to everyday meanings of the term *energy*, e.g., a feeling of vitality or a resource that is consumed when powering devices. When they learn about energy in the science classroom, one of the first challenges facing students is to negotiate the difference between the everyday and scientific meanings of energy.

Solomon (1983) investigated students' ability to cross over from thinking about energy in everyday contexts to thinking about it in the science classroom. She found that students who were asked to think scientifically about energy problems posed in an everyday context had a great deal of trouble crossing over between their scientific and



everyday ways of thinking. This finding is consistent with previous studies that suggest knowledge is highly situated in the context in which it is learned (Brown, Collins, & Duguid, 1989; Lave, 1988; Lave & Wenger, 1992).

Although Solomon's findings indicate that students have trouble crossing over between scientific and everyday contexts, students' everyday and scientific ways of thinking are not entirely insulated from each other. Just as their prior experiences influence the way they interpret new information in the classroom, their classroom experiences will also tend to change the way students think and talk about energy (Solomon, 1983; Trumper, 1998). However, one should not assume that formal instruction or exposure to energy in scientific settings leads to more scientifically accurate conception of energy, particularly when one considers the way that scientists tend to talk about energy. Because scientists tend to use familiar language in unfamiliar ways, learners may have difficulty developing an accurate picture of scientific processes (Lemke, 1990). For example, while scientists may know that energy is not actually a fluid, it is often convenient to discuss energy in terms of its "flow" through a system. Upon encountering such language, a non-scientist may not see any problems with thinking of energy as some sort of physical fluid that is transferred between objects. This may promote the misconception that energy is, in fact, a physical fluid that can be put into or transferred out of an object or system.

Although the casual use of analogy and terminology may promote misconceptions in all areas of science, energy may be particularly problematic because so many words associated with it have both scientific and colloquial meanings. Aside from the word *energy* itself, terms such as *work*, *heat*, *conservation*, and *law* have multiple meanings

that do not tend to reliably translate between scientific and non-scientific contexts. Boyes and Stanisstreet (1990) studied students' tendency to confuse the scientific and everyday meanings of *law* and *conservation* by asking students to rate five statements of a "law of conservation of energy" according to their veracity. Each statement included a different interpretation of *law* and *conservation*, and one statement reflected an acceptable scientific meaning. They found that a low percentage of students identified a scientifically acceptable meaning of the law of conservation of energy as surely correct, ranging from 8% of 11 to 12-year old students to only 33% of 15 to 16-year old students. Although the percentage of students who illustrated an acceptable scientific understanding of energy is small for all ages, it is encouraging that students seem to be progressing toward a more scientifically compatible conception of energy with instruction. One limitation of the Boyes and Stanisstreet study is that students were only prompted to pick among ready-made sentences that exemplified particular ways of thinking; they were not given the freedom to apply (or not apply) and describe energy concepts using their own language.

In an effort to better understand how students tend to think about energy on their own, Solomon (1983) asked students who were in their first, second, and third year of a comprehensive high school to write 3 or 4 sentences that showed how they would use the word energy. She found that first year students who had not been exposed to formal instruction on energy showed a strong tendency to make living associations in their sentences compared to non-living associations. Furthermore, the ratio of living to non-living associations decreased with years of instruction. Solomon went on to identify four themes in students' responses: vitalism (we need energy to live), activity (energy is

associated with movement), fuel (energy is needed to run machines), and conservationism (global perspective concerning energy resources).

Solomon's themes were not intended to describe specific misconceptions, rather, to serve as a way of classifying responses typically given by students. The themes that Solomon described are similar to Driver and Easley's (1978) description of *alternative frameworks*, which were intended to describe patterns of thinking that are broader than individual misconceptions. Watts (1983) reported that students' responses could be categorized according to seven common alternative frameworks. He identified these frameworks by interviewing secondary science students using the "interview-about-instances" approach (Osborne & Gilbert, 1980), which is described more in-depth in chapter four. Table 2.1 identifies each of the seven frameworks, gives a brief description of them, and gives an example quotation from a student that is indicative of each framework. The quotations are from Watts' original student interviews.

**Table 2.1: Description of Watts' original alternative energy frameworks**

Framework	Description	Example Quotation
Anthropocentric	Energy is mainly associated with human beings.	(On a person pushing a box up a hill) The person's got a lot of energy in that one...I mean he can push it the whole way up to the top of the hill...but, er, once the box is there it can't do anything so the box definitely hasn't got any energy...whereas the person can walk away back down.
Depository	Some objects 'have' energy, and some 'need' it.	Well, the battery's got the energy...the bulb needs it and the wires...well they're just ordinary wires aren't they.
Ingredient	Energy is dormant within some objects, and can be released by some trigger.	Well, there is energy in things...it's there but it needs another form of energy to make it come out...it's like a seed, it's got energy inside it to grow but it needs the sun...well, one chemical needs another chemical to make it react.
Activity	Energy is identified by overt displays, and the display itself is actually called energy.	The [sledgehammer]...is creating energy by moving fast.
Product	Energy is a by-product of some situation and is relatively short-lived.	[The chemicals] might change...in which case they'll release some of their energy and produce heat...in this vapor here.
Functional	Energy is a very general kind of fuel, more or less restricted to technical devices and not essential to all processes.	[Energy is] something that can do something for us...say like gas or something...energy has got to make something else work...like if it was electrical it would make something like a tape recorder work.
Flow-transfer	Energy is some sort of physical fluid that is transferred in certain processes.	...the energy comes out from both leads...because you never get a circuit without the other one...it comes out of the negative end...flows round the circuit...encountering the light bulb on the way...where it can transfer some of the energy...and it goes back to the battery.

Watts' frameworks were later substantiated by Gilbert and Pope (1986) and Trumper (1990). After making some changes to Watt's original definitions, Trumper found that 96% of 14 to 16-year-old students' interview responses were classifiable according to these frameworks. Trumper split the depository framework into two parts: the original depository framework described by Watts (which is of a passive nature), and "the 'active' deposit or 'cause' framework. The energy as 'causes things to happen,' as 'being needed for certain processes to occur' ('The electric bulb needs energy in order to light')" (Trumper, 1990, p. 347). Furthermore, Trumper has defined a "transformation" framework that is intended to describe a desirable concept of energy: "When two systems interact (i.e., when a process takes place), something that we name energy, is transferred from one system to another" (Trumper, 1998, p. 313).

Solomon (1983) found that the most persistent alternative frameworks in young students include the anthropomorphic and activity frameworks, and there seems to be a progression away from these frameworks and towards a conservation-based conception with age. In a synthesis of research into children's ideas, Driver, *et al.*, (1994b) proposed that students' energy conceptions progressed through a fairly common sequence. In this sequence, students start from a conception that is largely defined by their own sense of feeling energetic, extend that sense of energy to other living and then non-living things, become aware of stored energy, and finally become aware of energy conservation and degradation. Because this sequence was constructed from a review of other studies that used a variety of methods in a variety of populations, this sequence was not empirically derived.

Seeking to empirically construct a typical progression through the energy concept, Liu and McKeough (2005) examined United States students' responses to selected items in the TIMSS database. They classified items according to the type of conception that they represented and developed the following categories: activity/work (energy is the cause for activities), source/form (energy is stored in a variety of sources and can exist in various forms), transfer (energy can be transferred), degradation (energy is "lost" during transformations), and conservation (the total energy in a closed system must be constant). After classifying items, they were able to calculate the frequency of correct responses for students in grades 3, 4, 7, 8, and in their final year of high school. Using a 50% correct response rate as a cutoff, they found that all grade levels reached the activity/work competence level, and the source/form level was reached by students in grade 4 and above. An understanding of energy transfer was marginally displayed by 7th, 8th, and high school students.

Liu and McKeough suggest that their results reinforce the neo-Piagetian assertion that maturational factors play a central role in students' ability to acquire the full energy concept, setting an upper limit on students' concept acquisition (Case, 1985, 1992). Recognizing variation within their sample, they acknowledge that students' aptitude and instructional experiences play a role in students' concept development, like the work of Driver, *et al.* (1994b), Liu and McKeough's study did not include an instructional component. Without an instructional component, these studies were unable to detect the effect that instruction can play in helping students develop a deep understanding of energy.

My study is predicated on the idea that instruction plays a crucial role in students' cognitive and conceptual development. Yet, not all instruction is bound to be equally productive in this regard; in fact, students' initial ideas seem quite resistant to change in many instructional contexts (Chi, 2005). The design of instructional interventions has a great deal to do with their success or failure in helping students develop sophisticated understandings. While some have advocated instructional approaches in which students' naïve conceptions should be confronted and overcome (Chinn & Brewer, 1993; Nussbaum & Novick, 1982; Stepan, 2003), others insist that instruction should not focus on highlighting deficiencies in students prior knowledge, rather, it should build upon students' prior knowledge to develop new understandings (Smith, diSessa, & Roschelle, 1993-1994). Differences in instructional approaches reflect different notions about the nature of students' conceptions and how they reason and learn about the physical world. In the next sections, I contrast the so-called "knowledge-in-pieces" and "naïve theories" perspectives on how students develop naïve conceptions and describe how these views fit into a practical theoretical framework that our development team used to develop the energy unit and that I used to analyze students' ideas about energy.

### **Knowledge in pieces**

diSessa argues that children make sense out of the physical world by constructing pieces of knowledge that are minimally abstracted from their experiences (diSessa, 1993). diSessa calls these pieces of knowledge *phenomenological primitives*, or *p-prims*. They are phenomenological because they are based on one's direct experiences, and they are primitive because they represent the type of knowledge that is so fundamental that it

is difficult for the knower to elaborate it with words. These p-prims are connected to each other into clusters and broader structures that result in, among other things, a sense of mechanism regarding the physical world.

Among the most common and richly connected p-prims identified by diSessa is what he calls “Ohm’s p-prim”. In this p-prim, some agent produces an impetus that acts to overcome some resistance to produce some result. In describing this p-prim, diSessa has described the common experience of pushing a wheelbarrow: if you push harder (impetus), you get move the load faster (result), and if the wheelbarrow has a heavier load (resistance), then you must push harder to overcome the resistance in order to achieve the same result. Ohm’s p-prim is common and richly connected because it is highly general and therefore applicable to a wide range of phenomena. The intuitive knowledge of the world encapsulated by this p-prim allows people to predict what they think should happen and to be surprised when their observations do not meet their expectations (diSessa, 2000). In most situations that people encounter on an everyday basis, Ohm’s p-prim works quite well to predict events and to provide an intuitively satisfying explanation for them.

Another p-prim that works very well on an everyday basis is called “Force as a mover”. In this p-prim, pushing on an object will reliably cause it to move in the direction of the force. Although not technically correct (force produces *acceleration* in the direction of the force – not necessarily *motion* – so an object already moving may not travel in the direction of the force), this p-prim tends to lead to accurate predictions because most objects that people push or pull during the course of the day are at rest.



When reasoning about a scenario in which they are exerting a force on an object, a physics novice is likely to invoke both Ohm's p-prim and "Force as a mover" to explain how hard they need to push and the direction in which the object moves. When they stop pushing, the physics novice is likely to invoke a third p-prim, "Dying away" to explain why the motion invoked by their force will eventually cease.

diSessa claims that individuals' cognitive schema are composed of hundreds or thousands of p-prims. These p-prims are clustered into groups that describe a particular range of phenomena. For example, the three p-prims I have already discussed are likely to be organized within the same cluster that applies to mechanical phenomena that involve force and motion. When people reason about phenomena, particular p-prims are activated, which in turn activate other p-prims to which they are connected. The likelihood that a particular p-prim will be activated by some antecedent is called its *cuing priority*. A p-prim with a high cuing priority requires a small number of antecedents. Furthermore, diSessa defined a p-prim's *reliability priority* to be the likelihood that a p-prim, once activated will remain activated through a reinforcing feedback loop. A p-prim with a high reliability priority is unlikely to be turned off with additional processing about an event or phenomena. The structure of one's cognitive framework is determined by the number and type of p-prims, their connections to each other, and their cuing and reliability priority. As novices develop expertise, they adjust the cuing and reliability priority of their existing p-prims, strengthen or diminish certain connections, and create new p-prims when necessary. While diSessa assumes that naïve knowledge of the physical world consists as a network of loosely connected pieces, others feel that novices

hold ideas that are more connected and therefore more appropriately described as naïve theories.

### **Naïve theories**

Hatano (2002) has argued that children's knowledge systems are best characterized as theory-like because they tend to involve causal principles, to be constrained by relevant theory-like principles, and to guide new learning. The assertions of Hatano and others (Carey, 1985; McCloskey, 1983; McCloskey, Caramazza, & Green, 1980; Vosniadou, 1994) are largely based on the consistency that is often seen among student responses to scenarios.

By asking college students to predict and explain the motion of objects, McCloskey (1983) noticed that many students' responses resembled the *impetus theory* that was accepted many centuries ago. In this theory, an object is set into motion when some external agent imparts some impetus to it, and this impetus then gradually dies away until the object in motion comes to rest. McCloskey reported remarkable similarities between students' responses and theorized that students had developed strikingly coherent ideas on their own that seemed to be constrained by their naïve impetus theory. Other researchers have conducted similar studies in young children. Ioannides and Vosniadou (2002) found that students from 4 to 16 years old largely adhered to one of four meanings of the term *force*, and that the meaning children assigned to the term varied with age. The major difference between these studies and diSessa's ideas is the degree to which students' knowledge is fundamentally coherent.

Some have argued that treating students' knowledge as theory-like inappropriately characterizes students' thinking according to expert classifications (Viennot, 1985). When researchers try to examine students' ideas about a particular concept (e.g. force) and interpret their responses by contrasting them with expert responses, this tends to impose a structure to students' thinking that may not be there on its own. Smith, diSessa and Roschelle (1993-1994) have challenged the notion of characterizing students' ideas as theory-like on constructivist grounds, arguing that if students possess coherent ideas that are at odds with expert understandings, then students' initial ideas must be replaced during instruction rather than built upon. In a criticism of the "Theory Theory" approach to characterizing students' knowledge and the methodology of the research supporting it, diSessa, Gillespie, and Esterly wrote:

The problem is not that there is pure incoherence in naïve thought, but that Theory Theories seem to grandly overestimate coherence and simplicity, running roughshod over contextual boundaries, and expecting that a few sentences can characterize a rich, complexly adapted knowledge system. (diSessa et al., 2004, p. 889)

### **Finding a practical common ground**

The temptation to characterize students' naïve knowledge as either entirely fragmented or entirely coherent most likely reflects a false dichotomy, as students' thinking is not well characterized by either extreme position. Within the knowledge-in-pieces perspective, diSessa and his colleagues have postulated existence of structures such as *clusters* (diSessa, 1993) and *coordination classes* (diSessa & Sherin, 1998;

diSessa & Wagner, 2005) in which knowledge pieces may be strongly connected and mutually reinforcing; from the naïve theory perspective, Vosniadou has argued for the existence of *specific theories* that are embedded within larger framework theories (Vosniadou, 1994). It seems clear that the advocates of both the coherent and fragmented knowledge perspectives recognize the need to account for students' understanding at different grain sizes.

In the classroom, teachers would be well-served to understand the implications of both perspectives, as they can offer valuable insight into students' thinking (Hammer, 1996; Minstrell, 2001). Minstrell is a teacher-researcher who has developed a system of *facets*, which assume a knowledge-in-pieces perspective, but are designed to describe students' understandings with a grain size that is somewhere between diSessa's p-prims and the naïve theories advocated by McCloskey. Largely influenced by existing research into students' ideas and by standards documents, the facets were designed to reflect what a teacher might actually hear students say in the classroom as they progress in their understanding (Minstrell, 2001, 2004; National Research Council, 2001). Minstrell has organized the facets into *facet clusters*. A sample facet cluster is shown in Figure 2.1.

Facet Cluster 470: Forces during interactions (developed).	
*470	All interactions involve equal magnitude and oppositely directed action and reaction forces that are on the separate interacting bodies.
474	Effects (such as damage or resulting motion) dictate relative magnitudes of forces during interaction.
474-1	At rest, therefore interaction forces balance.
474-2	"Moves," therefore interacting forces unbalanced.
475	Equal forces pairs are identified as action and reaction but are on the same object.
476	Stronger exerts more force.
477	One with more motion exerts more force.
478	More active/energetic exerts more force.
479	Bigger/heavier exerts more force.

Figure 2.1. Sample Facet cluster, reproduced from Minstrell (2001).

The facet cluster in Figure 2.1 is organized around the AAAS Benchmark, "When one thing exerts a force on another, an equal amount of force is exerted back on it."

(American Association for the Advancement of Science, 1993, p. 92) Facet 470 in Figure 2.1 is a restatement of the benchmark, and each facet is assigned a number that roughly places it in a sequence from least to most problematic. While facets are not intended to directly describe the small knowledge pieces (p-prims) that students possess, they are useful for grouping student responses, which are the manifestations of their underlying cognitive structure.

The categorization scheme provided by the facets makes it practical for teachers to understand common ways that students think about particular concepts and to roughly classify students' responses according to how close they are to the learning goal that is reflected by the content standard. In this study, I use Watts' frameworks as a sort of facet cluster for energy (Minstrell and his colleagues have not yet developed a facet cluster for

middle school students' understanding of energy), because the frameworks are useful for categorizing students' common ways of thinking. In doing so, I do not intend to assert that students' thinking is theory-like or constrained by an adherence particular alternative frameworks; I am simply using the frameworks as "bins" by which to categorize students' constructed responses in order that students' conceptual development can be efficiently categorized and evaluated.

### **Conceptual change**

When conceptual development occurs, students' understandings are not likely to progress in an ordered fashion from more problematic to less problematic ideas. Rather, their process of conceptual change will likely be a nonlinear process that reflects a complex interplay of both intuitive and instructed ideas of different grain sizes. From a knowledge-in-pieces perspective, students' knowledge networks consist of a large number of ideas, existing in different grain sizes, that are connected in various ways. These ideas may be intuitive or instructed and may include p-prims that are not easily articulated, facts, previous experiences, and scientific principles. When learning occurs, students' knowledge networks undergo a process of conceptual restructuring (Clark, 2006) and knowledge integration (Linn, Eylon, & Davis, 2004), during which students' ideas and the connections between them are redefined and reorganized. During this process of reorganization, the cuing priority of certain ideas is increased for certain contexts where they hold significant explanatory or decreased when they do not (Smith, diSessa, & Roschelle, 1994). Some ideas may gain a central position within the conceptual structure with high cuing and reliability priorities, while others may be

assigned such low cuing and/or reliability priorities that they are almost never used. Additionally, new ideas may be added to the network and existing ones may be changed by coalescing with other ideas or by becoming differentiated into multiple ideas (Clark, 2006).

During the process of conceptual restructuring, not all reorganizations are productive, and students' knowledge networks may not smoothly transition from that of a novice to that of an expert. As students encounter new situations, they modify their ideas and connections between them in order to account for new information. If, over time, the new structures prove themselves to be useful for predicting and explaining students' experiences, they will tend to be reinforced, if not, the structures will continue to be modified as students accumulate experiences. Well before students are exposed to formal science instruction, they have had many experiences with the physical world and have already begun the process of structuring and restructuring their knowledge networks. When they enter the science classroom, students hold many ideas about the physical world, and many of these ideas have been highly congruous with students' experiences, yet are not in line with expert understandings. The "force as a mover" p-prim is an excellent example of such an idea.

Regardless of how predictive students' understanding may be in their own experiences outside of school, there is no question that novices lack the broad explanatory and interpretive power of experts. Unlike experts, novices' understanding is not organized around the central unifying principles of science (Chi, Feltovich, & Glaser, 1981). Science curriculum, then, should be designed such that it supports students' understanding of the unifying principles of science that will allow them to connect

between topics and between contexts. In the next sections, I describe the design principles that guided our development of the energy unit to help students develop a deep and coherent understanding of energy.

### **Promoting coherent understanding with curriculum**

From a knowledge-in-pieces perspective, the goal is not to replace students' naïve ideas with more sophisticated ones, rather, it is to fit them into a broader cohesive framework in which the most explanatory and general ideas are assigned a high cuing priority in appropriate contexts. If students develop coherent understandings, they are able to "link their scientific ideas to make sense of experiences and observations and to explain new situations" (Roseman & Linn, 2007, p. 1). Students' coherent understandings may not only be manifest as short term learning, but also as the foundation for future learning (Bransford & Schwartz, 1999; Linn & Eylon, 2000; National Research Council, 1999). In order to support students' development of coherent understanding, curriculum materials must be designed with coherence in mind (Roseman & Linn, 2007).

Roseman and Linn (2007) have identified several characteristics of curriculum that promote coherence. Perhaps most importantly, curricula should focus on the big ideas in science and dispense with unnecessarily distracting ideas. Second, materials should be designed to connect with students' experiences. In order for students to tap into and reorganize their existing prior knowledge networks, they must think critically and analytically about familiar contexts, because it is in contexts familiar to the students where their initial ideas were formed and where they most conspicuously apply. By



using new ideas to reason about familiar contexts, students can better understand how the newer ideas learned in school have broader explanatory power than their initial ideas and adjust their thinking accordingly. A third key to promoting coherence with curriculum is to encourage student reflection and metacognition (Davis, 2003; White & Frederiksen, 1998). The process of refining and improving one's initial ideas should include scaffolded opportunities for students to reflect on what they know and why they know it, as well as to examine where to go next. From a social constructivist standpoint, students must also have an opportunity to develop new ideas and to refine existing ones through supported peer interactions such as presenting evidence, forming conclusions, and critiquing each other's ideas.

### **Energy unit design principles**

Our design efforts were predicated on the understanding that student success in science is most achievable when standards, instructional materials, and assessments are well-aligned (Bishop, 1998; Gamoran, Porter, Smithson, & White, 1997). To foster alignment, we used a learning-goals-driven design model (Krajcik, McNeill, & Reiser, in review) that is based upon the principles of backward design (Wiggins & McTighe, 1998). Learning-goals-driven design consists of three stages: interpreting standards and constructing learning goals from them, developing materials to support students' attainment of the learning goals, and eliciting feedback from teachers and other science educators. Figure 2.2 shows the learning-goals-driven design process in diagrammatic form.

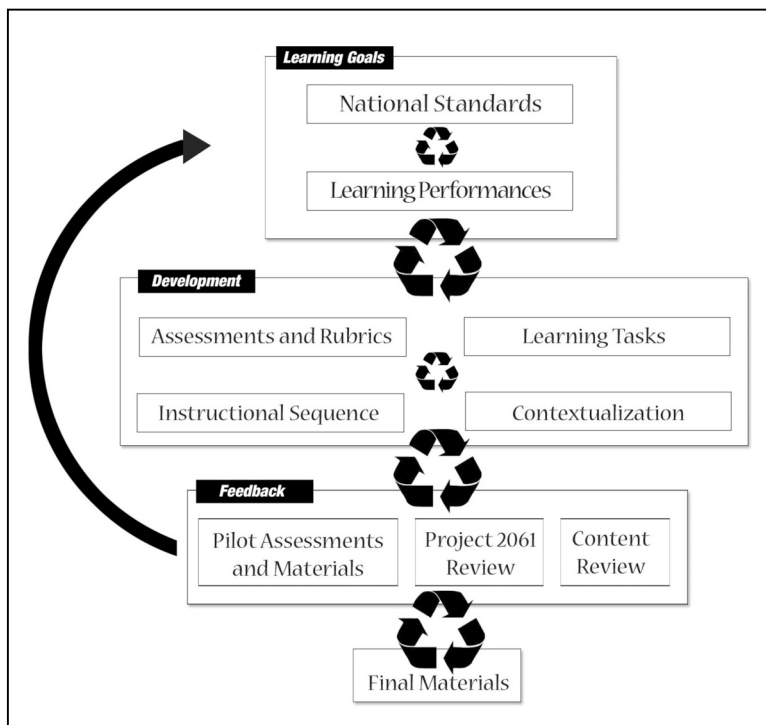


Figure 2.2. Learning-goals-driven design process

Our design of the energy unit was guided by the principles of project-based science. In this approach, units are contextualized by organizing instruction around real-world problems that connect with students' lives outside of the science classroom (Blumenfeld, Soloway, Marx, Krajcik, Guzdial, & Palincsar, 1991). Project-based pedagogy typically involves a *driving question* that frames the problem for students in such a way that students will ultimately need to achieve the learning goals of the unit in order to answer the driving question in a satisfactory way. Good driving questions are meaningful to students, capable of sustaining student interest and rich scientific investigations, feasible for investigation in the classroom, and worthwhile (Krajcik, Czerniak, & Berger, 2003) Project-based science has been extensively researched and has been shown to support students' learning of scientific inquiry processes (Fretz, Wu, Zhang, Davis, Krajcik, &

Soloway, 2002; Kolodner, Camp, Crismond, Fasse, Gray, & Holbrook, 2003), ability to construct scientific explanations of phenomena (Kuhn & Reiser, 2005; McNeill, Lizotte, Krajcik, & Marx, 2006), and science content knowledge (Geier, Blumenfeld, Marx, Krajcik, Fishman, & Soloway, in press; Marx, Blumenfeld, Krajcik, Fishman, Geier, & Tal, 2004).

In the next chapter, I describe the specific instructional choices the energy unit development team made as we interpreted national standards and benchmarks, created learning goals, and designed our instructional context and lesson sequence.

## CHAPTER THREE

### THE LEARNING ENVIRONMENT

We designed the energy unit according to the principles of learning-goals-driven design using project-based pedagogy (Krajcik *et al.*, in review). According to this design model, we first compiled, interpreted, and elaborated the middle school energy standards in the Benchmarks for Science Literacy (BSL) (American Association for the Advancement of Science, 1993) and National Science Education Standards (NSES) (National Research Council, 1995). The standards addressed by our unit are given in Appendix A. During the elaboration phase, our development team chose to change the wording of some standards to exclude some portion of certain standards statements. These changes included using the word “types” in place of “forms” of energy because we were aware that many students hold a misconception that energy has some definite physical form (Driver, Squires, Rushworth, Wood-Robinson, 1994a). Furthermore, we did not address some standards statements based upon a commitment to limiting the amount of prior knowledge required of students. Since the unit was designed for use in all grades of middle school, we could not assume that students would enter the classroom with a particulate view of matter; therefore, we excluded standards that would have required students to possess or develop a particulate nature of matter.

After interpreting and elaborating the standards, we produced seven learning goals, which are scientific ideas that are the focus of learning at some particular stage in the unit. Figure 3.1 shows these learning goals and the sequence in which they are addressed during the unit.

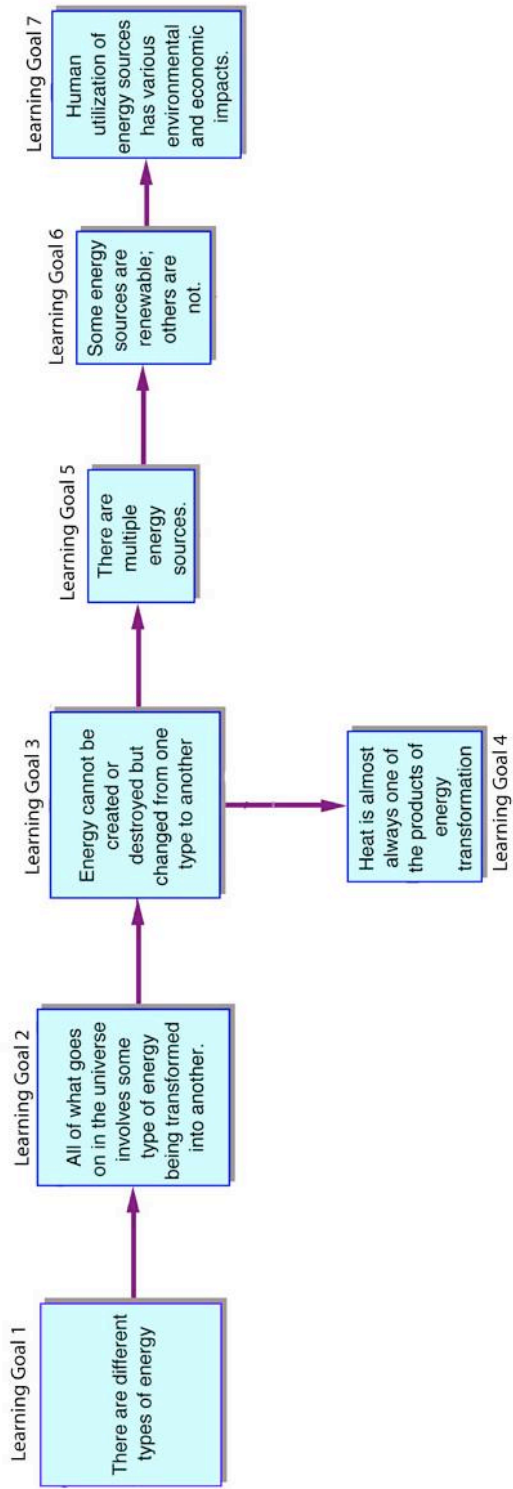


Figure 3.1. Learning goals of the energy unit and their sequencing.

## Instructional sequence

As noted in chapter two, we used a project-based model (Krajcik, Czerniak, & Berger, 2003) to organize the unit. In this model, instruction is organized, motivated, and contextualized by a driving question. After considering many options, we chose the driving question, “How can I use trash to power my stereo?” To address this question, students engaged in a series of activities that were organized into six lesson sets, which I describe briefly in Table 3.1.

**Table 3.1: Description of lesson sets and how learning goals are addressed.**

<b>Lesson set</b>	<b>Focal learning goals</b>	<b>Student activities</b>
LS 1	LG 1 – Energy types	Identify types of energy in various phenomena
LS 2	LG 2 – Transformation LG 3 – Conservation LG 4 – Degradation	Identify types of energy in phenomena at various times and track how they change
LS 3	LG 2 – Transformation LG 3 – Conservation LG 4 – Degradation	Formulate preliminary answer to driving question
LS 4	LG 2 – Transformation LG 3 – Conservation LG 4 – Degradation	Design and build an apparatus that exhibits many types of energy transformations en route to performing some task.
LS 5	LG 5 – Energy sources LG 6 – Renewability LG 7 – Human impact	Investigate various energy sources and resources, and develop an energy plan for some location
LS 6	LG 5 – Energy sources LG 6 – Renewability LG 7 – Human impact	Debate energy plans and develop a more sophisticated answer to the driving question

Lesson set one begins with an *anchoring activity* in which a pinwheel is set in motion by burning paper beneath it. This anchoring activity provides an opportunity for students to use their intuitive knowledge and preconceptions to make sense out of a relevant and conceptually rich phenomenon, and it serves as a common experience that can be linked to subsequent instructional activities (Clement, Brown, & Zietsman, 1989; Cognition and Technology Group at Vanderbilt, 1992). After watching the phenomenon once, students are asked to think about what makes the pinwheel turn and why burning more paper makes it turn longer and/or faster. If students do not introduce the term energy on their own, the teacher tells the students that energy in the paper was responsible for turning the pinwheel, and asks them to write down what they know about energy and/or where they have heard it in the past. No effort is made to offer some sort of operational definition for energy, and the teacher does not give students any information about how scientists think about energy. At this stage, the teacher emphasizes to the students that the goal of this unit is to find out more about energy and how it is involved in phenomena that we observe.

After the anchoring activity, lesson set one is devoted to introducing students to various types of energy. For each type of energy addressed in this unit, we have defined a set of associated *indicators* and *factors* to help students identify which types of energy are involved in phenomena and to make qualitative judgments about whether their magnitude is increasing or decreasing. An indicator is an observable physical feature of a phenomenon that indicates the involvement of a certain type of energy, while a factor is a characteristic that affects the amount of a particular type of energy. Indicators are a subset of factors, and both factors and indicators were extracted from the mathematical



expressions that allow one to calculate the magnitude of each energy type. For example, because kinetic energy is given by the formula  $\frac{1}{2}mv^2$ , we identify mass and speed as factors for kinetic energy. Because the speed of an object is the observable variable that determines whether an object can be considered to have kinetic energy, this variable is the indicator for kinetic energy. Since mass is necessary for determining the magnitude of kinetic energy, but not sufficient for an object to have kinetic energy, it is a factor. Similarly, the factors for elastic energy ( $\frac{1}{2}kx^2$ ) are rigidity and compression/elongation and the indicator is compression/elongation. The factors for gravitational energy ( $mgh$ ) are mass and height (the acceleration of gravity is assumed to be constant for all objects and is therefore neglected), and the indicator is height above some reference point. A complete list of energy types addressed in this unit and their associated factors and indicators is shown in Table 3.2.

**Table 3.2: List of energy types and their associated factors and indicators.**

<b>Energy Type</b>	<b>Factors</b>	<b>Indicators</b>
Kinetic energy	Mass Speed	Speed
Light energy	Brightness <sup>1</sup>	Emission of light
Sound energy	Loudness	Emission of sound
Thermal energy	Mass Temperature Type of substance	Temperature
Chemical energy	Type of substances Mass	Substances seeming to appear or disappear
Elastic energy	Compression/elongation Rigidity	Compression or elongation of an elastic substance
Gravitational energy	Mass, height <sup>2</sup>	Height
Electrical energy	Voltage <sup>3</sup>	Complete circuit and a voltage source

During lesson set one, students repeatedly interact with a variety of everyday phenomena in order to classify which energy types are involved in their operation. Such phenomena include toasters, glow sticks, tuning forks, portable music players, candles, and many others that the students were likely to see in their lives outside of school. By choosing everyday objects such as these, students are more likely to connect their school learning with their naïve ideas and intuitive knowledge (diSessa, 2000; Smith, *et al.*, 1993-1994).

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<sup>1</sup> Although the energy of a single photon is dependent upon its wavelength, we wished to describe the light energy emitted by a macroscopic apparatus, which is better described by intensity.

<sup>2</sup> Acceleration of gravity was not included because it is assumed constant for all objects.

<sup>3</sup> Although voltage is a measure of electrical energy per charge, we believed that voltage alone was an adequate factor for electrical energy because in virtually all devices that use electrical energy, the charge-carrying particle is the electron.

In lesson set two, students continue to work with everyday apparatuses, but begin to focus those that are easily delineated by some event, such as a jack-in-the-box, shooting a rubber band, inverted half racquetballs, instant heat packs, and others. The presence of a delineating event allows students to focus easily on types of energy that were present before the event, and those that were present afterwards. This primes students for the idea that any one apparatus or phenomena may exhibit different energy types at different points in time. In order to help students understand that these energy types are transforming into one another, they are asked interact with and classify phenomena that have straightforward “before”, “during”, and “after” times. For example, students classify the energy types present in a yo-yo before it is dropped, during its fall, and after it has reached the bottom of the string and is spinning. Then, they examine the energy types they listed in the “during” phase and, using their knowledge of the factors for each energy type, determine whether each type of energy was increasing or decreasing. By noticing that any time a type of energy increases, at least one other type of energy must decrease, students begin to see that these types of energy are actually transforming into each other. This activity also lays the groundwork for introducing energy conservation, which also occurs in lesson set two.

There is no feasible low-cost way to introduce middle school students to energy conservation by measuring it empirically, because energy in everyday devices is inevitably transferred to the surroundings as heat. Even if low-cost, specialized devices were available, it is likely that students would have difficulty understanding how their experiences with such an apparatus translates to their out-of-school experiences (Brown, *et al.*, 1989). Recognizing this, we chose to introduce energy conservation as a quality of

energy rather than a mathematical principle. If students accept the idea that an increase in one type of energy is always accompanied with a decrease in another type of energy, and vice versa, it is logical for them to understand that a decrease of all of the types energy in a system must be accompanied by an increase of some other types of energy. By investigating apparatuses in which energy is clearly not conserved (a bouncing ball and a marble rolling back and forth on a U-shaped track), students begin to recognize that they notice decreases in the amount of energy in the system, but are likely unable to account for the associated increasing energy types that must exist. To help students accept the idea that energy in a system can be transformed to thermal energy in the surroundings, teachers collide a pair of steel spheres (from Educational Innovations, Inc.) with a piece of paper in between them. Heat (we do not introduce this term to students as a noun, instead, we discuss “thermal energy”) released during the collision is sufficient to burn a hole in the paper where the spheres collided, and this serves as powerful evidence that thermal energy can be produced during this interaction. By recognizing that an increase in thermal energy must be accompanied by a decrease in another type of energy, students should realize that the thermal energy was transformed from the kinetic energy of the spheres. In lesson set two, the concepts of energy conservation and dissipation (Learning Goals 3 and 4) are developed in conjunction with each other and are built upon the idea of energy transformation.

After lesson set two, students have addressed all learning goals having to do with the energy concept itself: it can exist in different forms (or types), it can be transformed from one form (or type) to another, it cannot be created or destroyed (it is conserved), and it tends to be degraded in macroscopic transformations. Notice that the unit includes no

attempt to define for the students what energy *is* or to have students calculate energy in idealized situations, rather, we have attempted to develop students' energy concept by focusing on how energy can be used to describe and interpret the changes that occur during everyday phenomena. Regardless of our curricular design intentions, students are likely to ask what energy *is* – this is a natural question. In response, we suggested that teachers ask students to try to define *time*, which is an equally difficult challenge. By making an analogy to time, students are more likely to understand that it is possible for a concept to be useful even if we cannot satisfactorily define it.

Our approach to interpreting systems by qualitatively tracking energy transformations certainly does not directly prepare middle school students to quantify energy or to verify its conservation through calculations, but it is in line with energy learning progressions outlined by Project 2061 (American Association for the Advancement of Science, 2007) and it is more likely to promote students' ability to interpret complex everyday phenomena without losing their attention in the details of calculations – a common problem with many middle school curricula (Kesidou & Roseman, 2002).

After students have addressed the learning goals related to the energy concept, they are asked to use their understanding of energy to engage in a design project. During this project, students design a Rube-Goldberg-type contraption to accomplish some goal of their choice, such as breaking and frying an egg or peeling a banana. This project provides students with an important opportunity to refine their understanding of energy because it encourages them to reflect on what they know (Davis, 2003) and to iteratively develop and refine plans for a machine that exhibits many energy transformations

(Fortus, Dershimer, Krajcik, Marx, & Mamlok-Naaman, 2004). When completed, students' contraptions are judged based upon the number and variety of energy transformation that their machine accomplished and upon the quality of their *energy transformation diagram*. These diagrams are a graphical method by which students keep track of the energy transformations that occur in some device or system. Visual representations such as these are an important tool for students as they develop and refine their understanding of scientific concepts and processes (Ametller & Pintó, 2002; Wu, Krajcik, & Soloway, 2001). Energy transformation diagrams are similar to the energy flow diagrams used by scientists who study sustainable energy systems, but energy transformation diagrams pay specific attention to energy types and do not include quantitative information regarding efficiency or ratios of energy types. An example of an energy flow diagram is shown in Figure 3.2, and an example energy transformation diagram is shown in Figure 3.3.

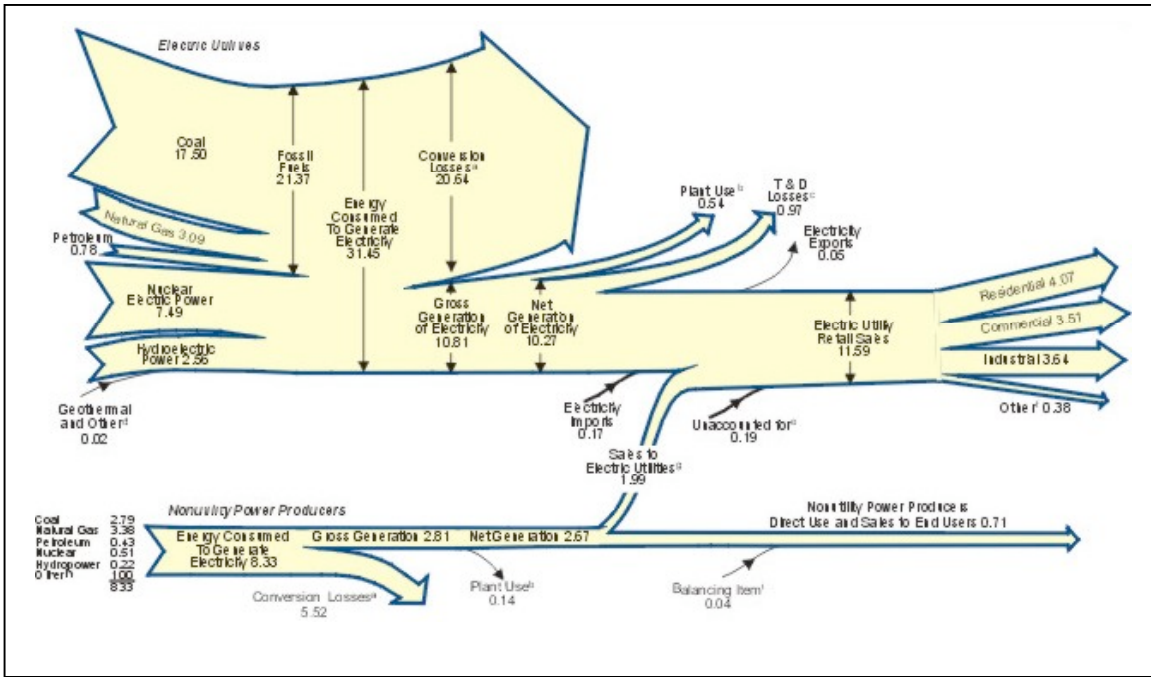


Figure 3.2. Energy flow diagram depicting US electricity production and uses in 2000.

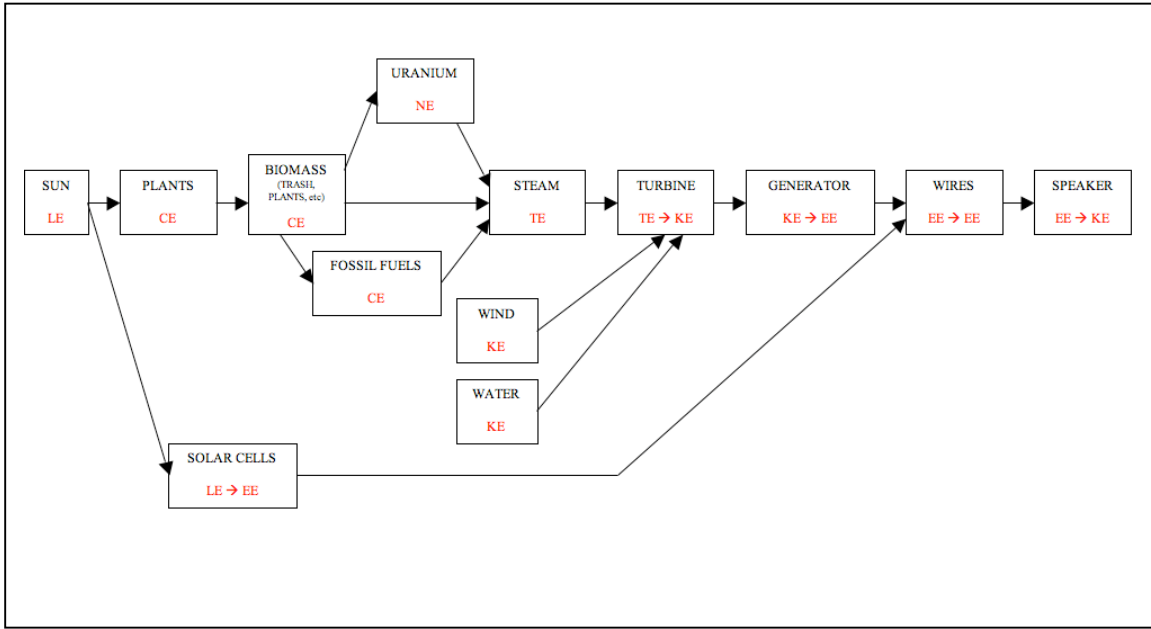


Figure 3.3. Energy transformation diagram depicting how energy may be delivered to stereo speakers via multiple sources

In the last two lesson sets, students turn their attention to the Earth's energy resources. Using what they have learned about energy during the preceding lesson sets, students research the availability of particular resources and the consequences of their use in order to develop an energy plan for a city of their choosing.

In the final lesson of the unit, students are given a fictitious newspaper article that proclaims, "Energy can be easily defined as the ability to run machines. We are in an 'energy crisis' because we have used so much energy that there is not enough in the world to last for much longer." Students are asked to respond to this article by providing a better explanation of what is meant by the term *energy* and what it means to be in an energy crisis. An ideal response to this prompt will demonstrate students' understanding that the value of energy more what it *does* than what it *is*, that energy is transformed in phenomena, that energy cannot be created or destroyed, and that energy transformations usually produce thermal energy that is difficult to reuse.

By the end of their participation in the energy unit, students will have learned how to identify when certain types of energy are involved in everyday phenomena, empirically investigated the process of energy transformation, used the idea of energy transformation to explain phenomena and iteratively design a Rube-Goldberg machine, and applied their knowledge of energy transformation and conservation to the Earth system as they produce with a plan to provide energy to a city. Throughout this instructional sequence, students' attention is constantly focused not on what energy *is* or on performing simple calculations, but on using the concept of energy transformation qualitatively to describe familiar systems. This approach represents a radical departure from traditional middle school energy curricula. In the following chapters, I describe



how I investigated the impact that our instructional approach has on students' conceptual development during the unit, the lasting effects of students' participation in the energy unit, and the difference in conceptual understanding and content knowledge between students who have participated in our energy unit and those who have learned about energy in other ways.

## **CHAPTER FOUR**

### **METHODS**

The purpose of this study is to investigate the effectiveness of a new approach to middle school energy instruction that focuses on energy transformations in everyday phenomena. I have hypothesized that such an approach will help students develop a more coherent conception of energy that is more useful for interpreting and explaining the behavior of systems. Of course, any educational intervention targeted at students' understanding of energy is likely to show some benefit when its effects are assessed using a standard pretest/posttest design. In this study, I go beyond a simple pretest/posttest design to a study that will enable me to examine the trajectory of conceptual change during the course of instruction, to assess students' conceptions one year after instruction, and to better assess the effects of participating in the energy unit by comparing participating students to non-participating students who have learned about energy in some other way.

While the gold standard of curriculum evaluations is the randomized experiment (Shadish, Cook, & Campbell, 2002), this design was not possible because the necessary random assignment and large sample size requires resources that are not available for this study. Another possible design for investigating the effects of the energy unit would be to include a matched control group of students drawn from nearby schools. Since the

enactment is at the classroom level and relies upon students' ability to talk with one another, such a matched group must have similar opportunities for interaction and should therefore be a group of students who share the same teachers at the same school. There is virtually no way to identify an adequately matched control group because student outcomes will depend substantially on contextual factors, such as teachers' instructional style, other learning activities during the year, and prior physical science instruction.

Although it was not feasible to use an experimental design, the school in which the energy unit was piloted presented an excellent opportunity to design a cross-sectional, quasi-experimental study. At this school, the energy unit was enacted as a part of the 8<sup>th</sup> grade science course during the 2004-2005 and 2005-2006 school years. Prior to this, students did not participate in the energy unit, but studied energy in different learning environments. Because the school has very low student and teacher mobility and contains both a middle and high school, I was able to find a sample of 10<sup>th</sup> and 11<sup>th</sup> grade students who were the most recent classes to participate in 8<sup>th</sup> grade science with the same teachers before the energy unit was introduced. Furthermore, a large contingent of students at this school follows the traditional biology, chemistry, physics progression through science courses, which limited the variation among students' learning experiences and made it possible for me to describe the in-school energy-related learning opportunities students had in 8<sup>th</sup>, 9<sup>th</sup>, 10<sup>th</sup>, and 11<sup>th</sup> grades.

My cross-sectional design allowed me to investigate the effects of the energy unit by comparing four different treatment conditions: 8<sup>th</sup> grade students who just completed the energy unit, 9<sup>th</sup> grade students who completed the energy unit one year previously and have taken a biology course, 10<sup>th</sup> grade students who did not participate in the energy unit

and have taken biology and chemistry, and 11<sup>th</sup> grade students who did not participate in the energy unit and have taken biology, chemistry, and physics. These four treatment conditions allowed me to go beyond a simple investigation of students' conceptual development during the energy unit to investigate how students' understanding of energy had changed one year after instruction and to compare energy unit participants to non-participants. Because the non-participants were older, had had more science instruction, and were increasingly self-selected for an interest in science, differences among treatment groups that suggest a benefit from energy unit participation are especially powerful.

### **Research Setting**

This study was conducted at an independent school located in a small Midwestern college town. The school, Fairmeadows<sup>†</sup>, serves about 200 students in a middle school and about 300 students in a high school, both of which are located on the same campus. The student population at this school is about 75% Caucasian, 6% African-American, 10% Asian, 1% Hispanic American, 3% Middle Eastern, and 5% multiracial. Students at the school come primarily from middle and upper-middle class families and have a relatively low mobility rate.

The faculty at Fairmeadows has a low turnover rate and teaching assignments tend not to change much over time. The teachers involved in this study are shown in Table 4.1, along with their relevant teaching assignments in recent years.

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<sup>†</sup> All proper names referring to the research setting, its faculty, and students are pseudonyms.

**Table 4.1. Participating teachers and relevant teaching assignments in relevant years.**

<b>Teacher</b>	<b>2002-2003</b>	<b>2003-2004</b>	<b>2004-2005</b>	<b>2005-2006</b>
Mrs. Nelson	8 <sup>th</sup> grade science	8 <sup>th</sup> grade science	8 <sup>th</sup> grade science	8 <sup>th</sup> grade science
Mrs. Geller	8 <sup>th</sup> grade science	8 <sup>th</sup> grade science	8 <sup>th</sup> grade science Chemistry	8 <sup>th</sup> grade science Chemistry Biology
Mrs. Forest	Biology	Biology	Biology	Biology
Mrs. Reynolds	Chemistry 8 <sup>th</sup> grade science	Chemistry 8 <sup>th</sup> grade science	Chemistry	Chemistry
Dr. Lightyear	Not at Fairmeadows	Not at Fairmeadows	Physics	Physics

The energy unit has been taught at Fairmeadows during the 2004-2005 and 2005-2006 school years by Mrs. Nelson and Mrs. Geller. Prior to this, both Mrs. Nelson and Mrs. Geller taught 8<sup>th</sup> grade science and were joined by Mrs. Reynolds, who taught a section of 8<sup>th</sup> grade science in the 2002-2003 and 2003-2004 school years. A junior physics student who has been at Fairmeadows since the 8<sup>th</sup> grade is most likely to have had either Mrs. Nelson or Mrs. Geller for 8<sup>th</sup> grade science, Mrs. Forest for biology in 9<sup>th</sup> grade, Mrs. Reynolds for chemistry in 10<sup>th</sup> grade, and Dr. Lightyear (doctorate in physics) for physics in 11<sup>th</sup> grade.

The intra-grade collaboration between teachers and the consistency of their teaching assignments made it possible to design a cross-sectional study to determine the effects of participation in the energy unit by comparing students who have participated in the energy unit to their older counterparts who have not. Furthermore, this setting

enabled me to follow up with 9<sup>th</sup> grade students who had participated in the energy unit during their 8<sup>th</sup> grade year.

While the low student mobility, consistency among faculty, and small school size make it possible for me to design a cross-sectional study to determine the effects of participating in an 8<sup>th</sup> grade unit, these factors also make it difficult to generalize my results to a larger population. In particular, it may not be appropriate to make predictions about the effects of the energy unit in urban settings where students generally come from lower-SES families, have higher mobility, and larger class sizes.

While it may not be possible to generalize to urban populations on the basis of my study alone, past research suggests that result in my research setting may be a good predictor of how successful the unit may be in urban settings. Curriculum developers at the University of Michigan have produced a number of units in the past according the project-based science model, and many of these units have been piloted in this study's research setting and later showed positive results when enacted in a large urban setting (Geier *et al.*, 2004; Marx *et al.*, 2004). Based upon past results, it is plausible that a unit that a curricular enactment that is effective in my research setting will also be effective in urban settings.

In the following sections, I explicate my research design in depth by describing the measures I administered to students, how these measures were administered, and how I analyzed the data from the measures to address each of my research questions. Table 4.2 provides an overview the research design.

**Table 4.2. Overview of research design**

	<b>RQ1: Conceptual development during the unit</b>	<b>RQ2: Conceptions one year after instruction</b>	<b>RQ3: Comparing conceptions across grade levels</b>	<b>RQ4: Comparing content knowledge across grade levels</b>
<b>Data sample</b>	8 <sup>th</sup>	8 <sup>th</sup> , 9 <sup>th</sup>	8 <sup>th</sup> , 9 <sup>th</sup> , 10 <sup>th</sup> , 11 <sup>th</sup>	8 <sup>th</sup> , 9 <sup>th</sup> , 10 <sup>th</sup> , 11 <sup>th</sup>
<b>Relevant measures</b>	A. Student interviews B. Learning goals test C. Energy concept questionnaire D. Energy content questionnaire	A. Student interviews B. Learning goals test C. Energy concept questionnaire D. Energy content questionnaire	A. Student interviews B. Energy concept questionnaire C. Energy content questionnaire	A. Energy content questionnaire
<b>Data collection times</b> (letters correspond to letters of measures above)	A. Before unit/after LS1/ after LS2/end of '05-'06 B. Pretest/posttest C. Pretest/end of '05-06 D. Pretest/end of '05-06	A. '04-05 enactment/end of '05-06 B. Previous enactment pretest/posttest C. End of '05-2006 D. End of '05-2006	A. End of '05-06 B. End of '05-06	A. End of '05-06
<b>Data analysis</b> (letters in parentheses correspond to the measures used in analysis)	Code interview responses according to energy frameworks (A) One-way ANOVA comparing interviewed and non-interviewed students (ABC) OLS regression to assess effect of prior knowledge, gender, and teacher on student outcomes (BCD)	Code interview responses according to energy frameworks (A) One-way ANOVA comparing interviewed and non-interviewed students (ABC) One-way ANOVA comparing 8 <sup>th</sup> & 9 <sup>th</sup> grade students before and after energy unit (B)	Code interview responses according to energy frameworks (A) One-way ANOVA comparing interviewed and non-interviewed students (BC) One-way ANOVA with orthogonal contrasts between grade levels (B)	One-way ANOVA with orthogonal contrasts between grade levels (A) One-way ANOVA with subscores for physical and life science items (A)

## **Measures**

This study is designed to investigate four research questions targeted at understanding the effects of students' participation in the energy unit during their 8<sup>th</sup> grade year. To address these questions, I administered a number of measures designed to describe students' energy conceptions, assess their attainment of the unit learning goals, and assess their preparedness to perform on external measures targeted at the national standards and benchmarks. In the following sections, I describe each of these measures.

### *Learning goals test*

The seven learning goals for this unit were based upon the National Science Education Standards and Benchmarks for Science Literacy. The learning goals and relationships between them are illustrated in Figure 3.1, and the learning goals test is included in Appendix B. Administered as a pretest and posttest, this measure is designed to assess students' understanding of the unit learning goals.

The learning goals test (shown in Appendix B) and its scoring rubric (shown in Appendix F) remained identical between the 2004-2005 and 2005-2006 school years. Using this rubric, I scored the pretests and posttests from both years. To establish inter-rater reliability, I recruited a research associate with several years of experience coding interviews and written responses from middle school students who were participating in project-based curricula. After reviewing the rubric together, we randomly selected 10% of the tests and the research associate scored the open-ended questions independently. This process yielded an inter-rater reliability of 97%.



### *Teacher Interviews*

In order to make more accurate comparisons between groups and to properly attribute differences I observed among students in different grades, I conducted interviews with each of the teachers whose students participated in my study. During these interviews, I asked teachers to describe how they include the energy concept in their courses, and the extent to which their energy-related instruction has changed during relevant years.

I interviewed Mrs. Geller and Mrs. Nelson to determine what kind of energy-related instruction existed before the energy unit was introduced at Fairmeadows, and I interviewed Mrs. Forest, Mrs. Reynolds, and Dr. Lightyear to investigate the types of energy-related learning opportunities students have in their biology, chemistry, and physics courses. Although Mrs. Geller taught one section of biology and one section of chemistry during the 2005-2006 school year, I did not ask her to take additional time to participate in the biology and chemistry interviews. Mrs. Geller was not the primary teacher for those courses, and she collaborated extensively with Mrs. Forest and Mrs. Reynolds to ensure that her students had the same learning experiences as students in the other classes.

### *Student Interviews*

The student interviews were designed using the interview-about-instances approach, which was developed to better understand children's ideas about a particular concept without emphasizing whether these ideas conform to the accepted scientific view (Osborne & Gilbert, 1980). In this approach, students are shown a number of pictures

that illustrate various everyday situations and asked whether that picture illustrated *their* idea of the concept under investigation. The pictures are chosen around a single concept and illustrate instances, non-instances, and borderline cases (from a physicist's point of view) of the concept. Once a student identifies whether the picture is an illustration of their idea of the concept, the researcher ask the student to describe his or her reasoning. Student responses are then probed by the researcher, using the students' language when possible.

Because the interview-about-instances approach was designed to follow students' responses rather than prompt them to think about specific content-related questions, the researcher can get a clearer picture of how the student thinks about the concept on their own. Furthermore, this approach allows students to connect ideas as they prefer rather than grouping concepts according to the researcher's perspective. Because of its grounding in everyday experiences and flexibility for students to describe scenarios as they see fit, this approach is particularly well suited to investigating students' conceptions of energy. Energy is a scientific concept that is pervasive among everyday situations and is a commonly used term in non-scientific settings, so it is natural for students to describe how energy may be involved in everyday situations because they have likely thought about such situations in energy terms before.

The interview-about-instances approach has been used by many researchers to investigate students' conceptions of energy, force, and light (Gilbert, Watts, & Osborne, 1982; Kruger, 1990; Osborne & Gilbert, 1980; Trumper, 1993, 1998; Watts, 1983, 1985). Watts (1983) used this approach to develop his alternative frameworks for energy and Trumper (1993, 1998) used this approach to verify and extend Watt's frameworks.

The scenarios I used in the interviews have been drawn from past studies that used the same approach to investigate students' energy conceptions and are shown in Appendix C. Because the 8<sup>th</sup> grade students were interviewed four times, there are three different sets of scenarios. The scenarios that comprise the first and last round of interviews administered to 8<sup>th</sup> grade students are identical to each other, and these same scenarios were used to interview students in the 9<sup>th</sup>, 10<sup>th</sup>, and 11<sup>th</sup> grades. The scenarios in the second and third round of interviews administered to 8<sup>th</sup> graders were unique in order to reduce interview fatigue and to ensure that students continue to think carefully about their responses throughout all four interviews. The order and content of the scenarios used in this study are identical to those I used in a pilot study (Nordine, Fortus, & Krajcik, 2006) that I conducted during the 2004-2005 school year.

### *Energy Concept Questionnaire*

Authors of past studies investigating students' energy conceptions have used a questionnaire to assess student thinking and to categorize students' responses according to Watts' alternative frameworks (Bliss & Ogborn, 1985; Kruger, Palacio, & Summers, 1992; Trumper, 1993, 1998). I have produced an energy concept questionnaire by adapting items from the instruments used in these studies and from items that appear on the Energy Concept Inventory, which was produced by the developers of the widely-used Force Concept Inventory (Swackhamer & Hestenes, 2003). The full energy concept questionnaire appears in Appendix D.

The energy concept questionnaire is intended to address a shortcoming of the student interviews. While the interviews are an excellent tool to discover which

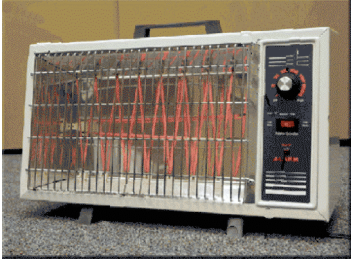
alternative energy frameworks that the students seem to hold, they are relatively poorly-suited to determining whether a particular conception is not held by a student. For example, if a student were responding to a scenario in which a man is pushing a barrel up a ramp, she may respond in a way that is indicative of the activity framework. While she may simultaneously hold an anthropocentric framework, her response may not have indicated it and this framework will not be attributed to her.

The energy concept questionnaire was intended to serve three purposes. First, it was designed to go beyond determining which frameworks are held by students to investigate which frameworks are not held. Second, it allowed me to gather information about energy conceptions from a larger group of students. Finally, the questionnaire and interviews constitute two different methods of assessing the quality of students' energy conceptions and can be used to corroborate each other.

In the energy concept questionnaire, students are presented with a variety of everyday situations and asked to respond to a variety of statements about those situations. In the first part of the questionnaire, students respond to the statements by checking whether they agree, disagree, are not sure, or don't understand. In the second part of the questionnaire, students respond by checking statements that they feel apply to a particular scenario. Like the interview-about-instances approach, the questionnaire is designed to avoid a situation in which students feel pressure to make an on-the-spot decision regarding an idea that they had not previously considered. By asking students whether they agree or disagree with statements rather than asking them which statements are correct, and by allowing them the freedom to be unsure, the questionnaire is less likely to

diagnose conceptions that students do not hold. An example item from the energy concept questionnaire is shown in Figure 4.1.

The picture below shows an electric heater that is plugged into the wall. The heater is switched on and the bars are glowing.



**For the following statements, check the appropriate box.**

1. The energy from the power station which supplies this heater did not exist before it was generated at the station.  
 Agree       Disagree       Not sure       Don't understand
2. Only some of the energy from the heater goes into heating up the room  
 Agree       Disagree       Not sure       Don't understand
3. The energy from the heater goes into the room and disappears.  
 Agree       Disagree       Not sure       Don't understand

Figure 4.1. Sample item from energy concept questionnaire

Statements in the energy concept questionnaire were chosen to be aligned with particular energy frameworks, thereby producing information regarding whether particular frameworks are held (or not held) by students. For example, a student who agrees with statement #3 in Figure 4.1 is likely to hold the product framework, whereas a student who disagrees is unlikely to hold such a framework.

### *Energy Content Questionnaire*

With the implementation of No Child Left Behind legislation and related directives, the dominant trend in education today is toward measurement-driven instruction. In this environment, it is important for curriculum to assist students in developing measurable knowledge and skills. Students' abilities are measured through the administration of assessments, and these assessments can vary widely in their scope and purpose. Ruiz-Primo, Shavelson, Hamilton, and Klein (2002) developed a classification scheme to describe the proximity between enacted curriculum and assessments. In this scheme, *immediate* assessments are artifacts produced by students such as science journals and classroom tests, *close* assessments are parallel to the slightly more advanced activities in the unit, *proximal* assessments address the same concept or principle but with topics not seen in the curriculum, and *distal* assessments reflect state or national standards in a particular knowledge domain. In their study of two curricular units, Ruiz-Primo, et al, found a greater effect size for close pre/post assessments than for proximal pre/post assessments (Ruiz-Primo *et al.*, 2002).

As a development team, we produced a learning goals test (described above) that would be best described as a proximal assessment. This test was designed to measure students' achievement of our learning goals by asking students to apply the knowledge and skills they learned in class to new phenomena. While the learning goals test is an important measure of the unit's effectiveness, it is not a particularly good indication of whether this unit will help students perform on the type of distal items they would see on a large-scale assessment used to determine school accountability.

It is important to evaluate whether the energy unit improves student performance on distal assessment items because they are intended to assess students' mastery of the national standards and benchmarks the unit was designed to address. Fortunately, members of Project 2061 at the AAAS have been developing assessment items intended to measure students' achievement of particular benchmarks and were willing to share relevant energy items with me for use in my study. With these items, I was able to investigate whether participating in the energy unit enhances students' ability to perform on the type of distal items they are likely to see on large-scale assessments that are targeted toward content standards and benchmarks. A sample item is shown in Figure 4.2, and the full content questionnaire is given in Appendix E.

1. A student began a swimming workout by diving straight down into the pool from a 5-meter-high board. At which point in the dive did the student have the most kinetic energy?
  - A. At the top of the ladder prior to the dive.
  - B. Just after the dive began.
  - C. In the middle of the dive
  - D. Just prior to entering the water.

Figure 4.2. Sample item from the energy content questionnaire

While items on the energy concept questionnaire are intended to assess whether students hold certain common conceptions about the nature and behavior of energy, items on the energy content questionnaire are intended to assess whether students have specific knowledge related to how scientists use the energy concept. For example, the sample item from the energy concept questionnaire assesses whether students believe that power stations actually create energy, but this type of question does not assess whether students have the type of technical knowledge required for students to do science. On the other

hand, the sample item from the energy content questionnaire assesses whether students have specific knowledge about kinetic energy and how objects fall. Theoretically, a student could believe that energy was created during the diver's fall, but the content questionnaire would be unable to diagnose this particular misconception. Conversely, the energy concept questionnaire is not designed whether a student knows the factors for kinetic energy or how the speed of objects changes as they fall. Together, the energy concept and content questionnaires provide tools to assess the overall quality of students' understanding of energy.

### **Data collection**

To answer my research questions, I gathered student data from four sources: learning goals tests, one-on-one student interviews, energy conceptions questionnaires, energy content questionnaires. The research questions in this study are intended to address two major themes: describing how students' understanding of energy tends to change during the course of instruction and evaluating the effect of the energy unit compared to the energy instruction that occurred at Fairmeadows prior to the enactment of the energy unit. Thus, data collection occurred in two phases, first focusing on students currently in the energy unit and then on students enrolled in all grade levels.

#### *Phase one: in-depth examination of current energy unit participants*

Phase one of data collection occurred during the 2005-2006 enactment of the energy unit and was focused on providing a description of students' learning related to



energy while they are enrolled in the energy unit. The data collected during phase one were intended to address research questions 1 and 4. These are:

- How do students' conceptions of energy evolve during the course of their involvement in the energy unit?
- What effect does participation in the energy unit have on students' ability to perform on assessment items that are targeted at national standards and benchmarks?

This phase is a continuation of previous research that I have completed on the energy unit and is intended to reinforce (if appropriate) and extend conclusions from that research.

Immediately prior to instruction, Mrs. Nelson and Mrs. Geller administered the learning goals test, the energy concept questionnaire, and the energy content questionnaire to all of the students in their classes. I also asked them to identify 16 of their students whom they felt were representative of their classes and who would be comfortable participating in an interview. These 16 students comprised the sample that I interviewed throughout the course of the unit. To examine how students' energy conceptions changed during the course of the unit, I interviewed them immediately prior to instruction, after lesson set one (which focuses on identifying energy types), and after lesson set four (which focuses on energy transformations). The final interview took place roughly two months after the end of instruction. While this timing does not strictly enable me to describe students' conceptions at the end of the unit and reduces the extent to which I can compare these results to those of my pilot study, it ensures a more fair comparison between students in 8<sup>th</sup> grade who have recently participated in the energy

unit and older students who may not have had explicit energy instruction for months or years.

Energy concept questionnaires, energy content questionnaires, and the learning goals test were administered to every student after the conclusion of the unit. The learning goals test was administered immediately after instruction, because it was intended for comparison with the learning goals pretest and with the previous year's posttest results. Because they are primarily intended for comparison with students in other grades, the energy concept and content questionnaires were administered roughly two months after the conclusion of the unit.

*Phase two: comparison of students across grade levels*

Phase two of data collection occurred at the end of the 2005-2006 school year and was focused on comparing students who have recently participated in the energy unit to those who participated a year ago and to students who have never taken the unit. The data collected during phase two were intended to address research questions 2, 3, and 4, which are:

- To what extent do students' desirable conceptions of energy attained during their participation in the energy unit instruction persist one year after instruction?
- How do the energy conceptions of students who have participated in the energy unit compare to the energy conceptions of students who have not participated in the unit?

- What effect does participation in the energy unit have on students' ability to perform on assessment items that are targeted at national standards and benchmarks?

Mrs. Geller, Mrs. Forest, Mrs. Reynolds, and Dr. Lightyear administered the energy concept and energy content questionnaires to all of their students at roughly the same time as they were administered in the 8<sup>th</sup> grade classrooms. These teachers also identified 16 students per grade level whom they felt were representative of their students and whom had attended Fairmeadows continuously since their 8<sup>th</sup> grade year. I asked the teachers to include students in the interview sample who participated in my pilot study the previous year; six of the eight students in my pilot sample were still enrolled at Fairmeadows and were included in the interview sample. I conducted interviews with each of the selected students using the same scenarios that I presented to 8<sup>th</sup> grade students in their initial and final interviews.

The purpose of the student interviews was to diagnose students according to which energy frameworks they seem to hold. The energy concept questionnaire was also intended to identify the presence of alternative frameworks, but does not have as much power to explore individual student conceptions. While its ability to diagnose individuals' conceptions is not as strong, the energy concept questionnaire is useful because it can be administered to all students in a class to get a sense of the overall quality of the class members' conception of energy. The questionnaire enabled me to assign an overall numerical score to students' responses based upon how closely their responses agreed with expert responses.

I recruited physics experts from a variety of specialties to independently complete the energy concept questionnaire, and seventeen of the experts I solicited returned their questionnaire. This group included seven physicists, astronomers, and energy scientists with PhDs in physics, eight science educators with physics bachelor's and/or master's degrees, an aerospace engineer, and a biophysicist. After the questionnaires were returned, I searched for questionnaire items on which experts seemed to have consensus. I defined consensus to be when more than 80% of the experts (14 out of 17) answered a question the same way. Five questions achieved 100% consensus, four questions achieved 90-100% consensus, and six questions achieved consensus of 80-90%. All questions that did not achieve consensus were excluded from all future analyses. I generated quantitative scores for students' questionnaires by giving a point whenever students' responses to items aligned with experts' consensus response. The quantitative scores on the energy concept questionnaire enabled me to assess the extent to which students in different grade levels conceptions of energy aligned with those of physics experts.

### **Data analysis**

In this section, I describe how the data collected during each phase of data collection is relevant to each research question, and I describe the methods by which the data was coded and analyzed in order to construct answers to each question.

*Research question 1: Development of students' conceptions during instruction*

This question focuses on how students' knowledge and conception of energy changes over the course of the unit. To address it, I used the student interviews, learning goals test, and energy conceptions questionnaires.

Before addressing this question, I assessed the extent to the students selected to be interviewed were accurate representations of their classmates. I used a one-way ANOVA to compare the quantitative scores of interviewed and non-interviewed students on the learning goals pretest (for 8<sup>th</sup> and 9<sup>th</sup> grade students), energy concept questionnaire, and energy content questionnaire. For each grade level, I produced a scatter plot in which I plotted students' energy concept questionnaire score on the x-axis and their energy content questionnaire score on the y-axis. By using different markers for students who were interviewed or non-interviewed, I was able to do a visual inspection to look for outliers and to examine how well the interview samples represented their classmates' scores on the concept and content questionnaires.

While conducting the interviews, I used a digital audio recorder to record each student interview. Using these recordings, I fully transcribed students' initial responses to the interview scenarios, as well as relevant sections of their probed responses. After all interviews were completed, I developed a coding rubric based upon Watts' original descriptions of the energy frameworks, Trumper's revisions and extensions, and my own interpretations. The full coding rubric is shown in Appendix G. Using the transcriptions and the audio recordings, I classified students' responses according to the coding rubric to attribute particular frameworks to each of the students' interviews. Each time I attributed a framework to a particular student, I recorded at least one supporting

quotation. To assess the reliability of my classifications, I recruited a research associate with several years of experience coding interviews and written responses from middle school students who were participating in project-based curricula. The research associate was not a part of the development team that produced the energy unit. After reviewing the rubric and discussing several sample interviews to come to a common understanding of the energy frameworks, we randomly selected 12 interviews (>10% of the data set) and the research associate scored these independently. This resulted in an inter-rater reliability of 93%. Once the interview coding was complete, I was able to look at the class as a whole to see which frameworks were prevalent at particular points in time and to look at individual students to see how their conceptions of energy changed during instruction. Using these data, I constructed case examples for students with less conceptual development, moderate conceptual development, and high conceptual development during the course of the unit.

While the interviews allowed me to look in depth at how individual students developed during the unit, the interview sample consisted of only about 20% of all students in the class. On the other hand, the energy concept questionnaire was administered to all students participating in the unit. While not designed to provide an accurate picture of individual students' conceptions, the energy concept questionnaire allowed me to look at the class as a whole to determine the extent to which their conceptions seemed to change with respect to experts' conceptions. To assess the amount that the class seemed to move toward an expert conception of energy, I conducted a paired t-test with students' scores on the energy concept questionnaire before and after instruction.

Additionally, I examined whether the energy unit has a different effect for different types of students. I used data gathered from 8<sup>th</sup> grade students and built three simultaneous regression models with the same set of independent variables: their 8<sup>th</sup> grade teacher, gender, initial energy concept questionnaire score, initial energy content questionnaire score, and learning goals pretest score. One model included students' learning goals posttest score as the outcome variable, another used the students' numerical score on the concept questionnaire as an outcome, and the third model used the energy content questionnaire as the outcome.

*Research question 2: Energy conceptions one year after instruction*

My second research question addresses how well students' energy conceptions persisted one year after instruction. To investigate this, I used the frameworks classifications obtained from student interviews during this study and my pilot study to investigate the extent to which conceptual development that I observed during the pilot study has persisted. Eight students participated in interviews during my pilot study, and six of these students remained at Fairmeadows for their 9<sup>th</sup> grade year. I compiled the frameworks these students exhibited during their final 8<sup>th</sup> grade interview and their 9<sup>th</sup> grade interview into a chart and conducted a holistic evaluation to look for changes. Additionally, I compared individual students' 8<sup>th</sup> grade and 9<sup>th</sup> grade responses to the same interview scenarios to gauge whether students' responded differently from one year to the next. Finally, I compared students who participated in interviews both years to those who were only interviewed in their 9<sup>th</sup> grade year to investigate the likelihood that changes I observed were due to repeated participation in the interview.

### *Research question 3: Energy conceptions across grade levels*

This research question focuses on whether students who have participated in the energy unit tend to think differently about energy than students who have not participated in the unit. To address this question, I used the conceptions data that I gathered during the student interviews and students' responses on the energy conceptions questionnaire.

I compiled the interview data into a table and computed used a chi-square test to determine whether there is a significant difference between grade levels in terms of the energy frameworks that students exhibited during the interview. Because the chi-square test is only designed to reveal non-random variation and does not isolate the nature of that variation, I also conducted a holistic examination to determine how the distribution of energy frameworks compares between these groups. I conducted this holistic evaluation by creating a chart showing percentage of each interview sample that exhibited a particular energy framework and looking for differences between grade levels.

The student interview data also allowed me to identify case examples and construct somewhat detailed descriptions of students in each grade whose conceptions were less developed, moderately developed, and well developed relative to their peers. These case examples allowed me to do a qualitative comparison across grades between students who are in the same group relative to their peers.

I also used students' scores on the energy concept questionnaire to look for differences in students' conceptions across grade levels. While this questionnaire was not designed to diagnose individual frameworks as successfully as the student interviews, it yields useful data in assessing how closely students' conceptions in each grade



resemble that of an expert. To look for differences across grade levels, I computed a one-way ANOVA by grade level with the energy concept questionnaire as the outcome. I used orthogonal contrasts to compare individual grade levels to each other.

#### *Research question 4: Performance on energy benchmark assessments*

This question focuses on whether students perform differently on energy content assessment items based upon whether they participated in the energy unit. To address this question, I computed a one-way ANOVA by grade level with the energy content questionnaire as the outcome. I used orthogonal contrasts to compare individual grade levels to each other. After isolating the differences on the energy content questionnaire between grade levels, I created sub-scores on the energy content questionnaire for physical science items and life science items. I repeated my ANOVA analysis with these sub-scores to better understand the nature of the variation that I detected between classes.

#### *Validity and reliability*

Because this study was completed wholly within one school, my results are not generalizable to the broader population of students in the United States. A focus on this type of external validity would be premature, however, because the unit is still very new and intended to be just one part of a comprehensive middle school curriculum. External validity will be much more important during future summative studies in which schools who adopt the full curriculum are compared to schools who have not, because such studies will be intended to inform the decisions of policy-makers. This study, which is more formative in nature, is intended to investigate the mechanism of action for the

energy unit and to evaluate how students who have participated in the energy unit compare to similar students who have not. This study's design is intended to maximize internal validity so that conclusions about the development of students' energy conceptions and knowledge can be considered valid.

An important component to establishing validity is to assess the validity and reliability of the instruments I used. To investigate the reliability of my instruments, I conducted a factor analysis to determine whether items within each instrument that were intended to measure particular understandings could be grouped as a factor. I calculated Cronbach's alpha for each group of items and judged whether these items could be reasonably assumed to measure the same latent construct. I performed this analysis on the energy concept questionnaire and energy content questionnaire because there were several items on each test that were targeted toward the same standard or understanding. I did not conduct such a factor analysis on the learning goals test because it did not include multiple items targeted to the same understanding. When developing the learning goals test, we chose to include items of higher cognitive complexity and items that were based on in-class demonstrations, which did not leave adequate time to assess individual learning goals with multiple items.

The student interviews and energy concept questionnaires were both intended to investigate the quality and characteristics of students' energy conceptions. To determine whether these were reliable measures of students' conceptions, I looked for correlations between the frameworks students exhibited during their interviews and their responses to interview scenarios.

### *Summary of methods*

Because this study uses a cross-sectional design that builds on previous pilot work (Nordine *et al.*, 2006), it simultaneously has features of a longitudinal study and a quasi-experiment. It therefore allows an investigation of changes that occur in individual students' understanding of energy over time (research questions 1 and 2) and a description of the effects of participating in the energy unit by comparing across treatment groups (research questions 3 and 4). In the next chapter, I use the data collected from my measures to describe how energy unit participants' conceptions change over time and how participants' understanding of energy is different from non-participants understanding of energy.

## **CHAPTER FIVE**

### **RESULTS**

I designed this study with three major goals in mind: to examine the trajectory of conceptual change during the unit, to assess students' conceptions one year after instruction, and to better assess the effects of participating in the energy unit by comparing participating students to non-participating students who have learned about energy in some other way. In order to achieve these goals and to make valid conclusions from the data, a number of underlying assumptions must be met. First, since my study relies on samples of interviewed students, I must determine whether the group of interviewed students is indeed representative of their peers. Second, I must investigate the validity of the measures that I am using to collect data from students. Finally, I must be able to describe the energy-related learning opportunities that students at Fairmeadows had in 8<sup>th</sup> grade before the energy unit was introduced, in 9<sup>th</sup> grade biology, 10<sup>th</sup> grade chemistry, and 11<sup>th</sup> grade physics. Before I describe my findings, I will address the representativeness of my interview samples, the validity of my measures, and the energy-related learning opportunities at Fairmeadows.

## Representativeness of interview samples

To determine whether students were representative of their classmates, I used a one-way ANOVA to compare interviewed students to non-interviewed students on all available measures. Tables 5.1 thru 5.4 show the results of the ANOVA for 8<sup>th</sup>, 9<sup>th</sup>, 10<sup>th</sup>, and 11<sup>th</sup> grade students.

**Table 5.1. ANOVA results comparing interviewed 8<sup>th</sup> grade students and their classmates**

Measure	Mean (SD)		df	t-statistic
	Interviewed students	Non-interviewed students		
Learning goals test				
pretest	15.0 (3.1)	15.2 (4.3)	77	-.033
posttest	26.5 (4.3)	27.1 (5.1)	77	-.265
gain	11.6 (4.7)	11.6 (4.9)	74	.000
Concept questionnaire				
pretest	8.5 (2.6)	8.1 (2.8)	75	.299
posttest	11.3 (2.3)	11.3 (1.8)	77	.001
gain	2.8 (2.4)	3.2 (2.7)	72	-.023
Content questionnaire				
pretest	6.5 (2.0)	6.7 (2.1)	74	-.097
posttest	9.0 (3.0)	9.5 (2.4)	74	-.375
gain	2.5 (2.0)	2.8 (2.7)	68	-.150

\*\*\*  $p \leq .001$

\*\*  $p \leq .01$

\*  $p \leq .05$

~  $p \leq .1$

**Table 5.2. ANOVA results comparing interviewed 9<sup>th</sup> grade students and their classmates who have attended Fairmeadows since their 8<sup>th</sup> grade year.**

Measure	Mean (SD)		df	t-statistic
	Interviewed students	Non-interviewed students		
Learning goals test <sup>a</sup>				
pretest	15.6 (5.2)	13.1 (4.8)	50	2.86~
posttest	27.7 (4.0)	27.9 (5.2)	51	-.012
gain	12.1 (5.7)	14.9 (5.7)	49	-2.47
Concept questionnaire	11.5 (1.4)	10.5 (2.4)	53	2.95~
Content questionnaire	10.3 (2.0)	10.3 (2.1)	53	.009

<sup>a</sup> Test was taken during the previous school year

\*\*\*  $p \leq .001$

\*\*  $p \leq .01$

\*  $p \leq .05$

~  $p \leq .1$

**Table 5.3. ANOVA results comparing interviewed 10<sup>th</sup> grade students and their classmates who have attended Fairmeadows since their 8<sup>th</sup> grade year.**

Measure	Mean (SD)		df	t-statistic
	Interviewed students	Non-interviewed students		
Concept questionnaire	7.5 (2.5)	8.7 (2.4)	33	-2.62
Content questionnaire	8.4 (1.7)	8.8 (1.9)	33	-.424

\*\*\*  $p \leq .001$

\*\*  $p \leq .01$

\*  $p \leq .05$

~  $p \leq .1$

**Table 5.4. ANOVA results comparing interviewed 11<sup>th</sup> grade students and their classmates who have attended Fairmeadows since their 8<sup>th</sup> grade year.**

Measure	Mean (SD)		df	t-statistic
	Interviewed students	Non-interviewed students		
Concept questionnaire	10.4 (3.2)	10.5 (2.8)	19	-.037
Content questionnaire	11.3 (2.4)	11.2 (2.3)	27	.010

\*\*\*  $p \leq .001$

\*\*  $p \leq .01$

\*  $p \leq .05$

~  $p \leq .1$

The ANOVA results provide a quantitative measure of the likelihood that the difference between the mean scores of interviewed students and non-interviewed students is due to a systematic difference between the groups. While the results provide good information about the representativeness of the sample, they mask individual data points and are potentially influenced by outliers. To examine all data points and look for outliers, I produced a scatter plot for each grade level with students' energy concept questionnaire score on one axis and their energy content questionnaire score on the other. By using different markers for interviewed and non-interviewed students, I was able to graphically assess whether the interview populations were different from the classes from which they were drawn. These scatter plots are shown in Figures 5.1 thru 5.4.

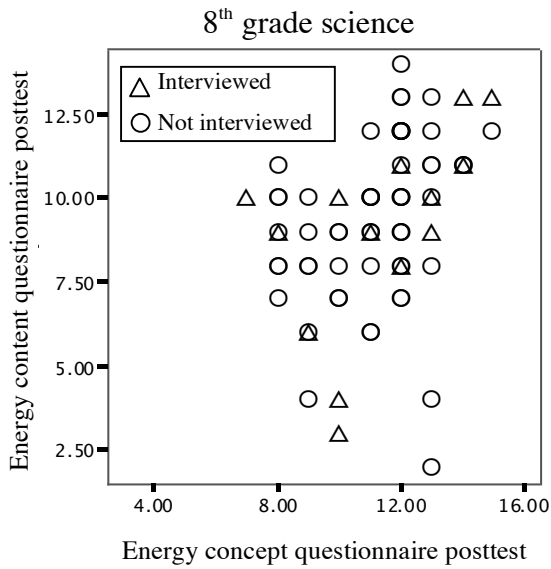


Figure 5.1. Scatter plot comparing interviewed and non-interviewed 8<sup>th</sup> grade students on the energy concept and content questionnaires.

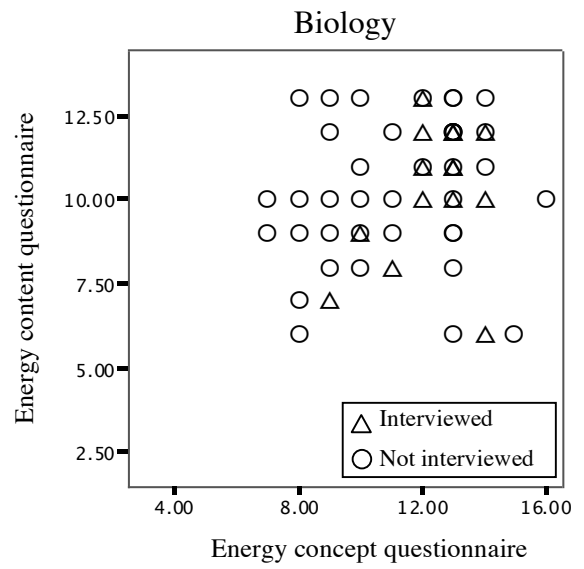


Figure 5.2. Scatter plot comparing interviewed and non-interviewed biology students on the energy concept and content questionnaires.

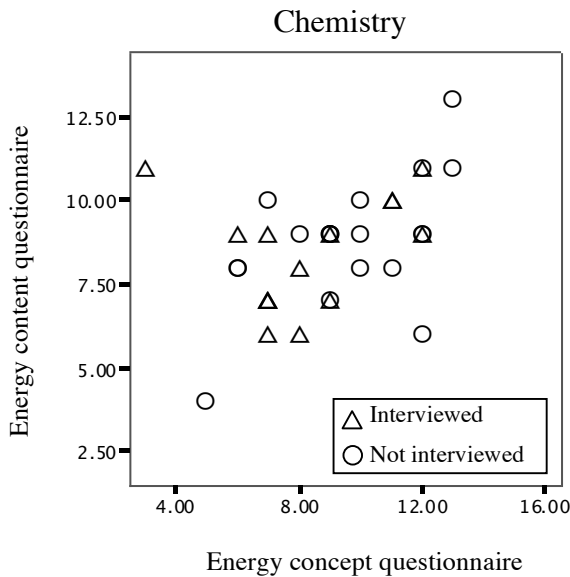


Figure 5.3. Scatter plot comparing interviewed and non-interviewed chemistry students on the energy concept and content questionnaires.

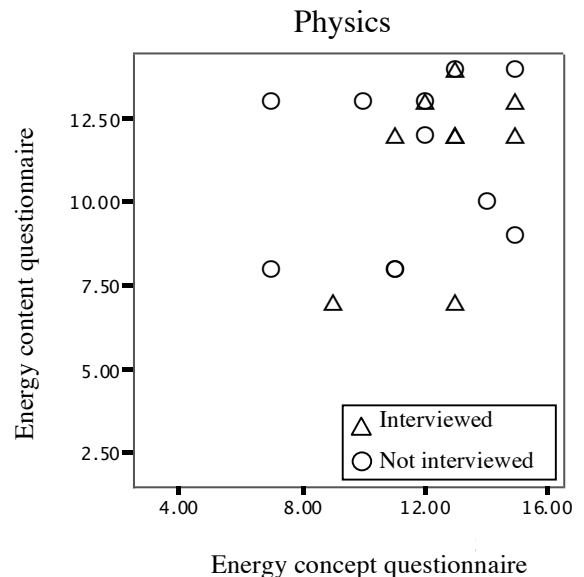


Figure 5.4. Scatter plot comparing interviewed and non-interviewed physics students on the energy concept and content questionnaires.



Figures 5.1 thru 5.4 and the ANOVA results in Tables 5.1 thru 5.4 show that the interview samples are generally well-distributed among all students, but that some further discussion is warranted for the chemistry and biology samples.

In the chemistry sample, the ANOVA results reveal a non-trivial, yet non-significant difference in the mean score on the energy concept questionnaire, with the interview sample scoring lower than their classmates. The scatter plot reveals the presence of an outlier in my interview sample, whose score of 3 on the energy concept questionnaire was the lowest of all chemistry students and well below the mean. After inspecting this student's questionnaire, I found that the student scored unusually low because he checked "not sure" for the majority of the items on the questionnaire. Because the student's low score was likely due to a feeling of uncertainty rather than an incorrect set of beliefs about energy, and because his score on the content questionnaire was above the class mean, I did not exclude the student from my interview sample.

In the biology sample, the ANOVA results show a difference between interviewed students and their classmates approached significance on the learning goals pretest and on the energy concept questionnaire. The marginal difference on the learning goals pretest is not alarming because neither the learning goals posttest nor the energy content questionnaire were significantly different between groups.

Also in the biology sample, there was marginal difference on the energy concept questionnaire that may be due to some real difference between the interviewed and non-interviewed students. The graph in Figure 5.2 shows that there were no clear outliers among the biology students, yet there seems to be a region in the graph that is populated only by non-interviewed students. This region consists of students who scored well on

the energy content questionnaire, but lower on the energy concept questionnaire.

Therefore, it seems that the interview sample may slightly over represent students who scored highly on the energy concept questionnaire.

I hypothesized that this difference may be due to some instructive effect of participating in the interview. However, energy concept questionnaires were administered to 9<sup>th</sup> grade students before they were interviewed, so any difference between interviewed students and the rest of the class cannot be due to an interview effect. While interviewed students' higher scores on the questionnaire could not have been a result of participating in the interview, the 9<sup>th</sup> grade interview sample contained six students who had been interviewed four times as a part of my study last year, and it is possible that these students received some benefit from participating in the interviews last year. To check for an effect of participating in interviews the previous year, I used a one-way ANOVA to compare the scores on the energy concept questionnaire between biology students who were interviewed last year and those who were only interviewed this year. This analysis revealed that biology students who were interviewed last year actually had a lower mean on the concept questionnaire than students who were only interviewed this year, and that this small difference was not significant ( $F(1,13)=2.32$ ,  $p=NS$ ).

The difference in means between interviewed and non-interviewed 9<sup>th</sup> grade students is 1 point out of a possible 16 points. An item analysis revealed that the interviewed students in 9<sup>th</sup> grade significantly outscored their counterparts (at the  $p \leq .1$  level) on items 5, 9, and 11. These items do not represent a particular energy concept, nor do they address a certain piece of content. While the difference in concept

questionnaire scores between interviewed and non-interviewed 9<sup>th</sup> graders may be real, it is small and does not seem represent any consistent differences in the character of their understanding about energy. I will therefore proceed with the assumption that all interview groups are an acceptable representation of students in the classes from which they were drawn.

### **Validity of measures**

#### *Energy content questionnaire*

I performed a factor analysis on the energy content questionnaire by grouping items according the benchmarks statements to which they were targeted. No factors with Cronbach's alpha greater than 0.7 emerged from this analysis. This result does not mean that the energy content questionnaire is invalid, but it does mean that the items on the content questionnaire that were targeted to the same benchmark are not likely measuring the same latent construct. As a consequence, I cannot use the energy content questionnaire to claim whether students have met particular benchmarks. In my analysis, the only sub-scores I created were based upon whether the items were targeted to a physical science benchmark or to a life science benchmark.

#### *Energy concept questionnaire*

I performed a factor analysis on the energy concept questionnaire by grouping answer choices according to the energy framework they represented. Using only the questionnaire items that achieved greater than 80% consensus among expert respondents, I attempted to create factors for the activity, deposit, flow-transfer, and product

frameworks. No factors with Cronbach's alpha greater than 0.7 emerged from this analysis. While this analysis does not invalidate the instrument, it means that I am unable to use the energy concept questionnaire to make claims about which frameworks are (or are not) held by a particular student. Because I could not use the concept questionnaire to assert whether students held a particular energy framework, I was not able to use the energy concept questionnaire to triangulate the interview classifications that I assigned to students' interview responses.

Although the energy concept questionnaire was not able to diagnose particular frameworks for individual students, I investigated whether the students' score on the energy concept questionnaire was likely a good measure of the overall quality of students' conceptions, as defined by the presence of the transformation framework and the absence of undesirable alternative frameworks. To do this, I assigned each student a dichotomous score (zero or one) for each framework based on whether they exhibited that framework during their interview and calculated Pearson correlations between interviewed students' score on the energy concept questionnaire and their dichotomous scores for each framework. These correlations are shown in Table 5.5.

**Table 5.5. Correlations between interviewed students' energy frameworks and their energy concept questionnaire score (N=57).**

Energy Framework	Pearson correlation with energy concept questionnaire score
Anthropocentric	-.249~
Deposit	-.169
Cause	-.083
Ingredient	-.102
Activity	-.079
Product	-.300*
Functional	-.331*
Flow-transfer	.072
Transformation	.558***

\*\*\*  $p \leq .001$

\*\*  $p \leq .01$

\*  $p \leq .05$

~  $p \leq .1$

All undesirable (alternative) frameworks, with the exception of the flow-transfer framework, are negatively correlated with students' score on the energy concept questionnaire. Although the flow-transfer has a positive correlation coefficient, it is small and non-significant. The transformation framework has a strongly positive and highly significant correlation with students' energy concept questionnaire score. Although the energy concept questionnaire cannot be used to diagnose individual frameworks, these correlations suggest that it is a valuable measure of conceptual coherence because it assesses the extent to which students' ideas are organized around the principle of transformation. Also the energy concept questionnaire measures how well students' responses align with those of experts, who tend to have more coherent understandings of concepts (Chi *et al.*, 1981).

The final underlying assumption of my study is that differences between 8<sup>th</sup>, 9<sup>th</sup>, 10<sup>th</sup>, and 11<sup>th</sup> grade students can reasonably be attributed to their participation in the

energy unit. To check this, I interviewed teachers about how they address energy in their classes.

### **Energy learning opportunities in science courses**

I gathered information from teachers about their classes by asking them to describe how they address the concept of energy in their courses and probing their responses. I initially contacted all teachers via email and followed up with them in face-to-face interviews. The information and quotations contained in this section were obtained both audio recordings of from face-to-face interviews, from email correspondence, and from course descriptions and syllabi provided by the teachers.

#### *Eighth grade science*

Over the years relevant to this study, the theme of the 8<sup>th</sup> grade science course at Fairmeadows has been energy. Prior to the introduction of the energy unit, students participated in five units throughout the course of the year, all of which were focused on energy and designed using the project-based science model of instruction. In the first unit of the year, students investigated weather concepts and energy systems in various weather patterns during a unit with the driving question, “Why is it so difficult to predict Michigan’s weather?”. The second unit used the driving question, “Where do plants get their energy?”. In this unit, students investigated photosynthesis and the importance of green plants for life. The third unit of the year was the logical extension of the second; it turned students’ attention to the human system and focused on the driving question, “Where do you get all of your energy?”. In this unit, students study the processes of

digestion and respiration. The fourth unit focused students' attention on sound energy and instruction is organized around the driving question, "How can you hear what I'm saying?". Finally, 8<sup>th</sup> grade students learned about electrical current and its applications during a unit organized around the question, "Why do the lights turn on when I flip the switch?"

Since the introduction of the energy unit, the central theme of the 8<sup>th</sup> grade science course has remain unchanged, but some modifications have been made in order to allow room for the energy unit. In the 2004-2005 and 2005-2006 school years, the 8<sup>th</sup> grade curriculum consisted of four units, three of which were carried over from the old curriculum. As with previous years, students began the year with the unit titled, "Why is it so difficult to predict Michigan's weather?". The unit entitled "Where do plants get their energy?" was removed from the curriculum and key elements, such as photosynthesis, were rolled into what became the second unit of the year, "Where do you get all of your energy?". The energy unit was the third unit of the year and was followed by the unit on electricity entitled, "Why do the lights turn on when I flip the switch?".

Overall, the focus of the 8<sup>th</sup> grade curriculum changed very little, yet the type of energy instruction that students received changed significantly. When I asked how they dealt with energy in their course before they taught the energy unit, Mrs. Geller recounted:

Well instead of having energy transformation and having to think about all the um, all the energy transformations at the same time, you know, in any unit, we broke it apart and there was not a connection of one energy transformation to another. It was learning about each energy separately.

Mrs. Nelson echoed her colleague when describing 8<sup>th</sup> grade energy instruction in the years preceding the energy unit:

So they were, in some sense, looked at separately, but with some ties across the curriculum, so you know, the idea of energy, but as [Mrs. Geller] said, much less focus in terms of the identifying all the different types of energy and then the energy transformation...

In another exchange, Mrs. Nelson and Mrs. Geller explained how they tended to talk about energy in their course before the introduction of the energy unit:

Mrs. Nelson: We did talk about the law of conservation of matter in terms of the photosynthesis equation with, you know, eating and respiration. Did we so blatantly say energy transformation?

Mrs. Geller: No.

Mrs. Nelson: No, we didn't. And I think it was more than implied, but it wasn't presented so directly or implicitly as energy transformation...

The key difference in energy instruction during 8<sup>th</sup> grade science before the inclusion of the energy unit and afterwards is a focus on the importance of energy transformations in phenomena. While the 8<sup>th</sup> grade science course routinely focused on phenomena that are essential mechanisms of energy transformation, they did not incorporate a unified energy transformation framework in which students tracked the energy transformations that occur in these phenomena in order to explain their observations. This represents a crucial difference between how energy was taught in 8<sup>th</sup> grade science before the energy unit was introduced and how it has been taught since.

### *Biology*

The first day of the 9<sup>th</sup> grade biology course at Fairmeadows has been the same for about ten years. On this day, Mrs. Forest conducts an activity that is designed to get students thinking about the role of energy in life processes and in enabling living systems to maintain order. Because they have learned about photosynthesis and cellular



respiration during 8<sup>th</sup> grade, Mrs. Forest reviews these processes and describes them as mechanisms for energy transformation. In a written description of this activity Mrs.

Forest noted,

I introduce for them the idea of energy transformations and that in each of these processes, what is really going on is an energy transformation. We then work together to figure out what the transformation is in each case.

During the interview, I asked if her focus on energy transformations was new:

Jeff Nordine: And so [in previous years], had you emphasized, uh, this idea of energy transformations as much?

Mrs. Forest: I don't know if I used that word before, because the Rube Goldberg thing was new, you know, so that was fresh in my mind and so that's why I picked – I talked about them being a way to change energy from one form to another, but I don't know if I used 'transformation' or not.

There are many other opportunities in biology for students to learn about the role of energy in living systems. They discuss the existence of various types of energy, including “potential, kinetic, electrical, light, sound, motion, chemical, etcetera, etcetera” and focus on chemical energy as a type of potential energy that comes from the force holding atoms together when they form molecules. Building on this idea, they revisit the photosynthesis and cellular respiration as balanced chemical equations and as energy transformations. Also, they use a money analogy – that a \$100 bill is typically harder to use than a \$1 bill – to explain why ATP is more useful to cells even though glucose has more energy per molecule.

Next, the class studies the difference between energy and nutrients in food and analyze the flow of each through food webs. During their discussion of food webs, students participate in an activity where they pass handfuls of water down a line to demonstrate energy transfer between trophic levels. The activity is designed to draw an

analogy between water and energy: as students pass the water, less and less is transferred between students hands, but it has not vanished, it has merely been given off to the surroundings where it is difficult to retrieve.

During a unit on biomolecules, the class returns to the idea of chemical energy. They discuss covalent bonds and the energy inputs required to form these bonds and the subsequent energy release when the bonds are broken. They go on to compare lipids, proteins, and carbohydrates in terms of their “energy per gram”. Finally, they discuss energy in terms of enzymatic activity. Mrs. Forest burns a peanut in front of the class and stresses that covalent bonds are “providing the energy that we are seeing as light and heat”.

The 9<sup>th</sup> grade biology course at Fairmeadows is rife with opportunities for students to learn about the role of energy in living systems, and the curriculum for this course has not changed significantly over the years relevant to my study. During the interview, I asked Mrs. Forest to describe the extent to which her course had changed with respect to what students learn about energy and how they talk about it:

- Jeff Nordine: You used that particular term, transformation, last year. But, did you emphasize, did you use that term throughout the year?
- Mrs. Forest: I might have more last year. And, it comes in most years, but I may have brought it out more last year, just because I knew they had done the transformation thing in the 8th grade.
- Jeff Nordine: The emphasis that you might have added there, do you think it would have been more, sort of the language you used on an everyday class basis?
- Mrs. Forest: Yeah, I don't think I changed what we were talking about, but maybe how I talked about it a little bit.

While Mrs. Forest recalls that she may have used the term “transformation” more frequently during the 2005-2006 school year, she emphasized that the curriculum itself had not changed in recent years.

### *Chemistry*

Students’ first exposure to energy concepts in chemistry comes when they investigate heating and cooling in the context of the classic coffee cup calorimeter experiment, in which students observe ice melting in an insulated coffee cup and measure temperature and calculate energy transfer between the ice and water as the ice melts.

When I asked Mrs. Reynolds what energy related she intended students would take from this activity, she responded:

That we have to add energy to the ice cube for it to melt, and that the energy’s coming from the surrounding water. Um, that if we have it too hot, we’re releasing a lot of heat energy to the surroundings. That heat energy itself is hard to control to make it do stuff for us, but so it’s lost.

When they begin activities in which students heat materials, they engage in a brief, yet somewhat superficial discussion of how energy is involved with the Bunsen burner:

We looked at the Bunsen burner and what’s going on with the Bunsen burner, and we looked at combustion, but um nothing detailed – this is energy, this is energy transformation. Nothing in depth with them yet.

As the year progresses, students learn to classify chemical reactions in terms of their spontaneity and whether they are exothermic or endothermic. The last major content area in which energy is a focus comes with bond energy, although Mrs. Reynolds recounted that students do not go into much depth here:

We don’t get into a ton of detail with bond energies with the [10<sup>th</sup> grade] group. They’re just not ready for it in some cases and it’s one of those details I don’t always have time for, in terms of specifics.

As she described what she expects 10<sup>th</sup> grade students to learn about bond energies, she said:

I think they'd get into how tightly they're held together, you know, how many electron groups are being shared...if they can understand the idea that anything, when you're breaking and reforming bonds, you're going to need energy transfer.

Energy transfer is a running theme in the 10<sup>th</sup> grade chemistry course at Fairmeadows.

Nearly every energy-related learning opportunity focuses on the importance of energy transfer between systems during chemical phenomena. Although she does not spend time focusing on the character and behavior of energy itself, Mrs. Reynolds uses two analogies to describe energy and its role in phenomena. The first analogy illustrates that energy transfer between systems is more important than the total energy in either system:

We've gone into it in terms of bond energy and that we can't measure the total energy of a system, but we can measure how it changes, and there will always be some that we can't observe, so it's like going through a door. We don't know how many people are back there, but we know how many come out or how many go in. So that's our basis for energy, and that things have energy, but we can only monitor changes. And that when a substance is giving off energy, an exothermic reaction, heat will go into the surroundings, we often determine the heat energy.

The second analogy also illustrates energy transfer, but focuses on the conservation of energy during this process:

If your parents give you 20 bucks, you've got 20. They have 20 dollars less, but it's still money. If you then go and buy something else, someone else has got that money, it's still money, you're just transferring it. And what it is, it's a reference to that starting point...it's like energy. Has it gone into you or has it left you? It's still energy.

Throughout the course, there is very little emphasis on energy transformation. Mrs. Reynolds explained that the energy-related questions she is interested in having students investigate require an understanding of energy transfer more than energy transformation.

I think I do more energy transfer, and not so much transformation, just because we don't get a lot of – we've mentioned potential energy and kinetic energy, and going from one to the other, but it's very limited...it's getting it started and what it ends up as at the end, versus all the steps in lighting a match going from chemical to light and heat. So we don't get into [transformation] as much.

Students who have completed the chemistry course at Fairmeadows will have had many opportunities to relate the behavior of systems to the idea of energy transfer. Yet, they will have encountered relatively few occasions when they are expected to use the idea of energy transformation to predict and explain phenomena.

### *Physics*

Unlike the biology and chemistry courses at Fairmeadows, the physics course includes a unit in which the primary objective is to learn about energy. Dr. Lightyear described the sequence of events when students are first exposed to the energy concept in physics:

That's actually what I do first, I introduce kinetic energy, and I give them the work-energy theorem at that point, without mentioning uh, potential energy...then we start working on gravitational work. Then we say, so if you lift an apple up to the table, gravitational work is minus ' $mgh$ ', that's the work done by the gravitational field...then I say that this thing is special, it's a conservative field, and I go through several examples explaining how – what that means.

During the interview, I asked Dr. Lightyear about the types of systems students deal with when they learn about energy:

- Dr. Lightyear: Well, they do the inclined plane. They do projectile motion in terms of energy. They do, um, let's see.
- Jeff Nordine: Do they do roller coasters?
- Dr. Lightyear: Yeah, they do roller coasters. They do non-inclined plane hills, so they do non-ideal hills. They do the Atwood's machine and they do the pendulums and they do the car going across the table with the mass hanging down...I guess I would call those coupled force systems, and their

energy conservation ideas. And rotational systems. And the very last system at the end of the year this year was the electrical system, so the electrical field...

The systems that students study in Dr. Lightyear's course are quite common among high school physics courses. To solve problems associated with these systems, students are typically asked to use the law of conservation of energy and assume that the frictional and other losses are zero. I asked Dr. Lightyear about teaching the law of conservation of energy in his class:

Jeff Nordine: And do you specifically teach them the law of conservation of energy?

Dr. Lightyear: Uh, I tell them that if the work non-conservative is zero, then mechanical energy is conserved, and I teach them that. I don't explicitly say energy is conserved in all cases ... I sort of avoid saying it specifically to emphasize, okay, in physics we can worry about mechanical energy, but we can't really track the other forms so easily.

As students predict and explain the behavior of the systems they study, they assume that energy neither enters nor leaves the system and that energy is transformed from one type (e.g., kinetic energy) to another type (e.g. gravitational potential energy) as the system changes. This is a convenient idealization that allows beginning physics students to make numerical calculations to predict and explain the behavior of the systems they encounter. Yet, real systems will slow down and eventually stop as frictional forces transform mechanical energy into thermal energy that is transferred the environment. I asked Dr. Lightyear what he expects his students to know about why the systems they study will slow down and stop:

Jeff Nordine: So if you take a pendulum or a spring system and the kids notice that the energy – the oscillation stops after a time, do you expect them to be able to tell you what happened to the energy that was there?

Dr. Lightyear: No, because I don't really go into the non-conservative

forces, I'll tell them that's – I mean generally in my honors physics class, I would say that's a more advanced problem that we're not quite ready for yet. So I don't really deal with where the energy goes.

I continued by asking Dr. Lightyear whether he deals with thermal energy in his course:

Jeff Nordine: And do you do anything with, like, thermal energy?

Dr. Lightyear: No. Carefully avoided.

There is a notable contrast between how 11<sup>th</sup> grade physics students and 10<sup>th</sup> grade chemistry students are asked to use energy concepts at Fairmeadows. While chemistry students focus on the importance of energy transfer between systems and largely leave out energy transformation, physics students focus on energy transformations that occur within a system and largely leave out energy transfer between systems.

#### *Overview of energy-related learning opportunities at Fairmeadows*

While there are many energy-related learning opportunities in the science courses at Fairmeadows, the majority of explicit energy-focused instruction seems to occur in 8<sup>th</sup> grade science and in the physics course. Based upon the teacher interviews, a science student following the traditional science progression at Fairmeadows will experience the following energy related instruction: an 8<sup>th</sup> grade curriculum organized around the theme of energy, a biology course in which they have opportunities to learn about energy transfer and transformation through ecological and biomolecular phenomena, a chemistry course in which they tend to focus on energy transfer in chemical phenomena, and a physics course in which they focus on the quantitative conservation of mechanical energy. Students in 10<sup>th</sup> and 11<sup>th</sup> grade have had more energy-related learning

opportunities than students in 8<sup>th</sup> and 9<sup>th</sup> grade, but those opportunities did not include a unit focusing on energy transformations during their 8<sup>th</sup> grade year.

Because the major difference in students' energy-related learning opportunities was the 8<sup>th</sup> grade energy unit, I was able to compare across grade levels and attribute differences among treatment groups to their participation in the energy unit. In the following sections, I address each of my research questions in turn as I describe students' conceptual development during the unit, their conceptions one year after instruction, and compare students in different grade levels based on their energy conceptions and content knowledge.

### **Conceptual development during the unit (Research question 1)**

The student interview data allowed me to look in-depth at individual student conceptions and to assess the amount and type of conceptual development that took place in these students during their participation in the energy unit. In previous work, I examined the development of students' energy conceptions over the course of the pilot enactment of the energy unit at Fairmeadows. In this study, I repeated my pilot work with double the interview sample size, and I gathered information about all students by incorporating the energy concept questionnaire.

By repeating my pilot study with a larger sample size, I was to determine the extent to which the conceptual movement that I observed during the pilot enactment would be repeated with a second group of students. Figures 5.5 and 5.6 shows graphs that illustrates the frameworks identified per round in my pilot study (2004-2005 school year) and in this study (2005-2006 school year).



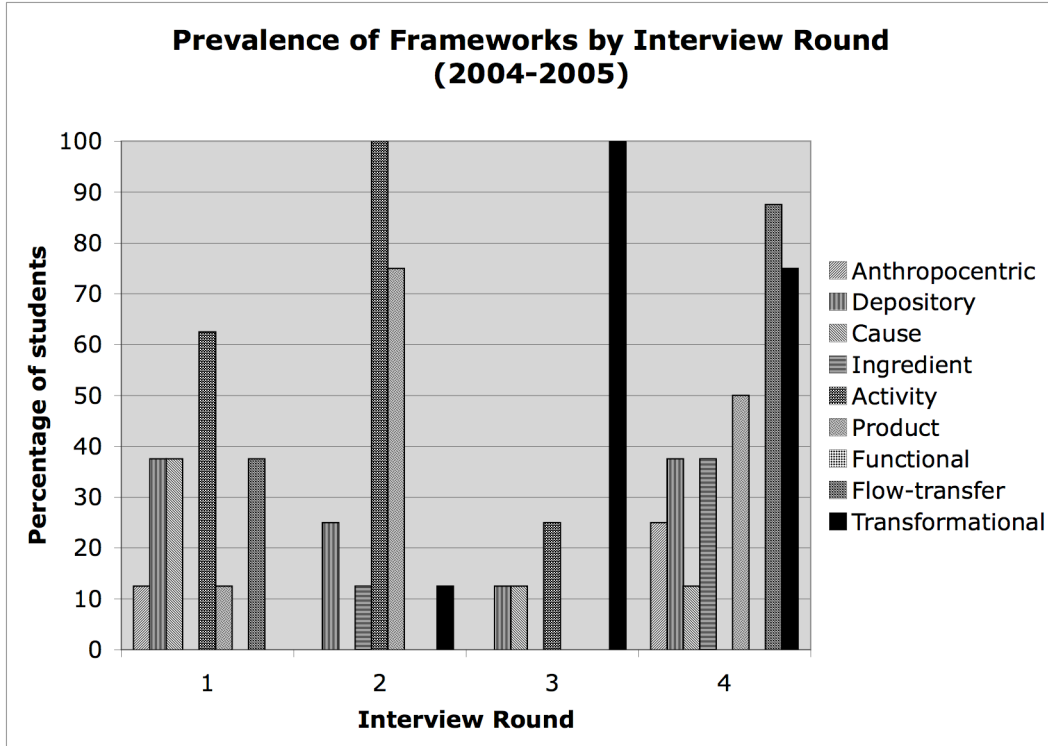


Figure 5.5. Percentage of students in the interview sample who exhibited particular frameworks, by round, during the first enactment of the energy unit.

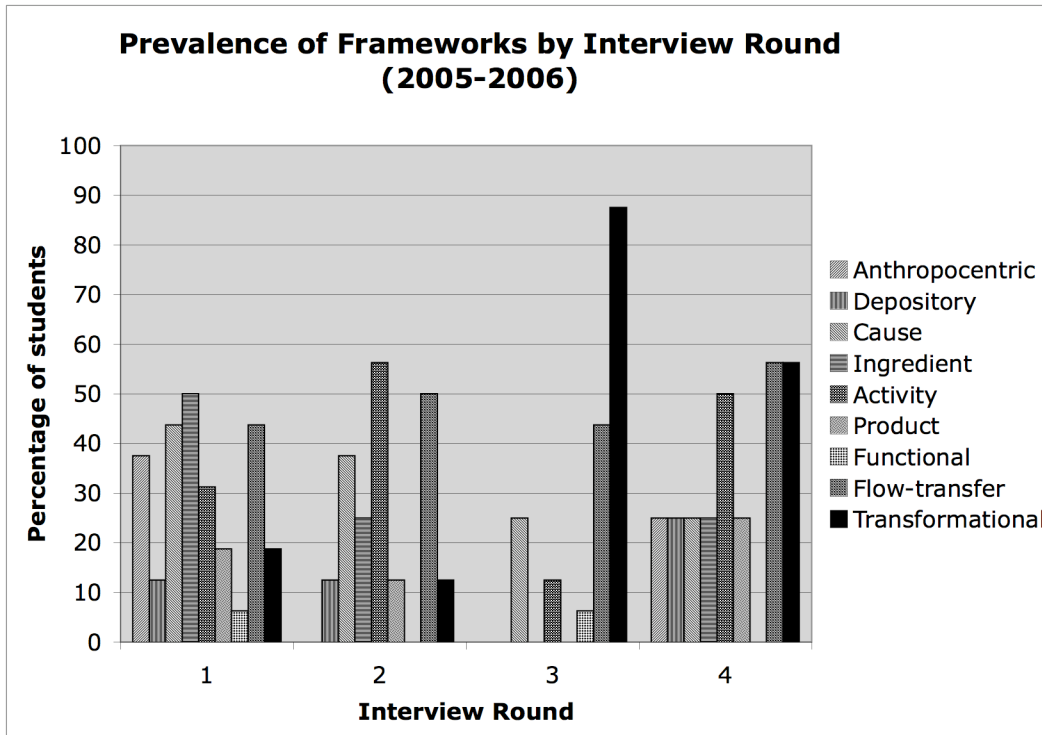


Figure 5.6. Percentage of students in the interview sample who exhibited particular frameworks, by round, during the second enactment of the energy unit.

Figures 5.5 and 5.6 show that there were many similarities between the 2004-2005 and 2005-2006 enactments in terms of how students' energy conceptions developed during the course of instruction, but, there are two notable differences between the graphs. First, the transformation framework appeared during the first round of interviews for the 2005-2006 students, while it did not appear during this round in the previous year. While this may simply be due to random variation among students, it is more likely due to efforts by the 8<sup>th</sup> grade teachers to deal with energy consistently throughout the year. After teaching the energy unit once, Mrs. Nelson and Mrs. Geller began to incorporate some of the ideas from the energy unit into the weather and life science units that came earlier in the curriculum. During my interview with the 8<sup>th</sup> grade science teachers, Mrs. Geller verified that she begins to lay the groundwork for the energy unit earlier in the year:

Now after teaching the energy transformation unit, I've gone back to a little bit of the weather, but I've done photosynthesis and now the digestion, and being very conscious of energies, you know, transforming, you know, what changes into what...

The second notable difference between the successive years is that the activity framework seemed to vanish in the last round of interviews during the pilot enactment, but not during the second enactment. While this may indicate a real difference in the way students' conceptions developed, there are several other possible explanations for this difference. First, students in the pilot study were interviewed immediately after the conclusion of the unit, but in this study, students were interviewed roughly two months after the conclusion of the unit. During these two months, students may have had learning experiences that pushed them toward an activity framework. A close temporal proximity to the unit may have also tended to constrain students' responses more in the first year than in the second year. Another possible explanation is that there is a

somewhat narrow difference between the activity and product frameworks. In the activity framework, students indicate that an action or process *is* energy. In the product framework, students indicate that an action or process *creates* energy while it is happening. In both frameworks, the energy can pop into and out of existence based upon whether a process is happening, therefore, it can be difficult to distinguish which framework a student is really exhibiting in the course of an interview. While no students in the final round of the 2004-2005 interviews seemed to exhibit the activity framework, four students (50% of the sample) exhibited the product framework. In the 2005-2006 sample, nine students (56% of the sample) exhibited the activity framework, product framework, or both.

While there were caveats, the major themes of students' conceptual movement seemed to hold true from one year to the next. In the remainder of this section, I describe each of these themes and illustrate three case examples to exemplify students who went through varying degrees of conceptual development during the unit.

*Theme 1: Student conceptions tend toward the transformation framework*

In both years, interviewed students began the unit demonstrating little or no evidence that they understood the role of energy transformations in phenomena. At the end of the unit, most interviewed students exhibited the transformation framework during their interview. This change is almost certainly due to the emphasis the unit places on using the idea of energy transformations to explain and predict the behavior of everyday phenomena.

While many more students exhibited the transformation framework at the end than at the beginning, the number of students exhibiting the transformation framework peaked at round three in both years. The third round of interviews took place immediately after the lesson set in which energy transformations were explicitly introduced and during the lesson set in which students build and explicate their “Rube Goldberg” contraptions. Therefore, the high number of students exhibiting the transformation framework during round three may be a reflection of the activities the students were doing concurrently in class. As students are asked repeatedly to describe the energy transformations that take place during phenomena, it is possible that the idea of energy transformation was temporarily assigned a higher cuing priority when students described the interview scenarios. By round four, the number of students exhibiting the transformation framework had subsided.

It is important to note that the interviews were designed to identify frameworks that seem to hold, and are not a good tool for identifying whether a student does not seem to hold a particular framework. In other words, if a student does not mention the idea of energy transformation in conjunction with some scenario, the student may nonetheless think of energy as something that is transformed during phenomena, but this idea may not have a high cuing priority. This is true for all frameworks – if a student does not exhibit a particular framework, they may still hold that idea, but invoke it less frequently when explaining phenomena. The energy concept questionnaire was intended to address this shortcoming of the interviews by asking students whether they agreed with particular statements that were chosen to align with particular frameworks. However, the concept

questionnaire proved to be an unreliable way to assess particular frameworks and I could not use it to qualitatively compare students' conceptions at different points in time.

Although it seems that the idea of energy transformation became less prominent in students' cognitive structures between the third and fourth interview rounds, there is nonetheless unmistakable movement toward the transformation framework over the course of the unit.

*Theme 2: Progression toward the transformation framework was not smooth*

Although students tended to progress toward the transformation framework, this movement with neither monotonic nor smooth. Simply examining the prevalence of the transformation framework itself reveals that students do not gradually acquire the framework over the course of the unit, rather, it appears suddenly and then fades somewhat. There is little doubt that this occurs because of the instructional sequence of the unit.

In lesson set one, students learn a series of *indicators* and *factors* that they use to determine whether a type of energy is involved in a situation and the amount of that type of energy that is present. After the first lesson set, a student would be expected to know that movement indicates that kinetic energy is present, while the mass and speed of an object determine the amount of kinetic energy it has. Students learn the factors and indicators for kinetic, light, sound, thermal, and chemical energy in the first lesson set (a complete list of the factors and indicators presented in the unit is given in Table 3.2). The idea of transformation is not introduced until lesson set two, and the second round of interviews was situated after the conclusion of lesson set one and prior to the beginning

of lesson set two. It is not surprising, therefore, that students tended not to display the transformation framework in this round. On the other hand, the first lesson set did seem to have some effect on students' energy conceptions by pushing them toward an activity and/or product framework. During both enactments, the most commonly displayed framework in round two was the activity framework, in which energy is viewed as an obvious activity that is not distinct from the action itself. As students learn about the indicators for each energy type, it seems that they can easily adopt the idea that the energy *is* the indicator. For example, Katherine displayed the activity framework during round two when presented with a scenario depicting a lit firecracker.

Katherine: It's because, well, first, if it's lit, the fire is kind of moving down. And it explodes, which is like, light, sound, kinetic, electric. Well, not really, but a lot of different energies.

Jeff Nordine: What happens to those types of energy you mentioned [after the explosion]?

Katherine: Um, they're kind of over. It just kind of stops.

Responding to the same scenario, another student displayed the closely-related product framework.

Lisa: Well, it has like, fire at the end. So that's thermal energy, and it makes a really loud noise, so that's sound energy. And light energy, and kinetic energy. Okay.

Jeff Nordine: What about after the firecracker is exploded, what happens to those types of energy that you mentioned?

Lisa: Um, they're not there anymore.

Jeff Nordine: And where have they gone?

Lisa: No where, I mean, I don't know. They just leave. They aren't being made, so they aren't there.

Neither Katherine nor Lisa seem to be bound by the ideas of energy conservation or transformation, as they indicate that energy types simply pop into and out of existence based upon whether their indicators are present. While Katherine seems to think that

there is no difference between the energy and its indicator, Lisa suggests that the energy types are being made by their indicators.

Prior to interview round two, Katherine and Lisa learned how to identify energy types, but they did not learn what happens to energy once its indicator is no longer present. By concentrating on the indicators and factors for each type of energy in the and excluding the idea of energy transformation, the energy unit seems to promote the activity and product frameworks during the first lesson set.

While students moved toward the activity and product frameworks in round two, they moved sharply away from them and toward the transformation framework in round three. Between interview rounds two and three, the students begin to use their indicator and factor framework to trace the types of energy present at different points in phenomena and track whether those types of energy are increasing or decreasing. Students are introduced to the idea of transformation by noticing that any time one type of energy increases, at least one other type must decrease. Then, they are asked to track the energy transformations as they occur in various phenomena. In round three, students tended to talk very readily about the energy transformations that occurred in the interview scenarios, and they tended to account for the “disappearance” of certain energy types by claiming that they had been transformed into other types. It seems possible that the activity and product frameworks serve as a useful intermediate abstraction as students move toward the transformation framework. Although these frameworks did not disappear as the unit progressed, their prevalence relative to the transformation framework decreased. This suggests that students were moving away from the intermediate abstraction, but that some students were more successful than others when it

came to moving past the activity and product frameworks and toward a transformation framework exclusively.

*Theme 3: Students prefer to reason from a mechanistic perspective*

Although nearly all interviewed students exhibited the transformation framework at some point during the energy unit, students' initial responses seldom reflected the transformation framework. Of the nine students in the 2005-2006 sample who exhibited the transformation framework during the fourth round of interviews, only three students invoked the idea transformation in their responses prior to probing. After the second lesson set, the majority of students' initial responses included a list of the types of energy that were present based upon the indicators that they identified in the scenarios. Most of the students who exhibited the transformation framework did so in response to probing. Typical probes included asking students whether the types of energy were related to each other, to describe what happens to the energy types as time goes on, or to clarify language that the student used. The following exchange, which was given as a round three response to a scenario depicting a melting icicle, illustrates how a student might invoke the transformation framework in response to probing:

Angelina: Well, like the drop of water like, obviously there's thermal, there's heat that's causing the ice to melt and so there's thermal energy, but there's like kinetic energy of the raindrops falling, and probably sound when they hit the ground.

Jeff Nordine: Are those energies related to each other in any way?

Angelina: Um, well once the thermal energy like heats the, like makes the icicle, like be heated, and like melt, then maybe some of it, not all of it, cause like (unintelligible) part of it, it's converted into kinetic energy.



In this scenario, Angelina did not initially use the idea of transformation to explain the melting of the icicle, rather, she seemed to organize her response around three major actions: heating of the frozen water, falling toward the ground, and hitting the ground. For each of these three steps, she assigned the appropriate energy (although she did not include the role of gravitational energy as the “raindrops” fall). Although sound energy is nearly irrelevant to core phenomenon of ice melting, Angelina included it in her initial response. This suggests that her initial thinking centers on the scenario as a series of events, to which energy types can be assigned based upon the presence of indicators. Although she demonstrated an understanding that energy transformations are important to the phenomenon, the idea of transformation seemed to be a way to explaining how different energy types can be involved at different times and not a central organizing theme of her thinking.

When students’ thinking is primarily focused on the mechanism of action in a scenario rather than the idea of energy transformations, they are prone to suggest energy changes that would violate the law of conservation, even though they may adhere to the idea of energy transformation.

*Theme 4: A deep understanding of conservation was elusive for many students*

The energy unit does not include a learning goal that deals with energy conservation, and the Benchmarks for Science Literacy recommend that this idea should not be introduced until high school. Still, many students are familiar with the phrase “energy can never be created nor destroyed” even before they begin the energy unit. Yet, this statement seemed far from straightforward to many students. In fact, it seems that

some students combined this idea with the indicator and factor framework to construct an understanding of energy that was a hybrid of the activity framework, the ingredient framework, and the idea that energy is never created nor destroyed. In responding to a second round scenario depicting a lit firecracker, Wes explained:

Jeff Nordine: After the firecracker has exploded, what happens to the types of energy that you mentioned?

Wes: They, well, they don't disappear, but they're not used anymore, like, the heat created by the fuse dies down, and you can touch the firecracker again and throw it away.

Jeff Nordine: When you said that they don't disappear, why did you say that?

Wes: Kinetic energy doesn't just, poof, it's there. It's always going to be there, like, even though that's sitting there, if I kick it, it would move, and that's kinetic energy, but before, it's not in use, but it's there.

Wes seems to believe that the maxim “energy cannot be created nor destroyed” applies to each type of energy individually. That is, when the kinetic energy from the firecracker exploding is no longer there, it simply becomes dormant until it has been activated later by some event that involves motion. This was perhaps the most common misunderstanding of energy conservation among students during both the 2004-2005 and 2005-2006 enactments, and it was not present in students' initial round of interviews. It is possible that learning a fairly in-depth indicator and factor framework prior to learning about energy transformation leaves students to make their own conclusions about where energy comes from or where it goes when they do not observe the indicator for a particular energy type. Students continued to show this type of misunderstanding of energy conservation during the fourth round of interviews, which suggests that transitioning away from an activity/product framework and toward a transformation/conservation framework is challenging for some students.

Although the quantitative conservation of energy was not a learning goal, it is certainly implied. During the unit, students are introduced to the idea of transformation through an activity where they notice that any time an energy type increases or decreases during some phenomenon, at least one other energy type must do the opposite. This activity, as well as the ensuing instruction, is targeted toward learning goals that state, “All of what goes on in the universe involves some type of energy being transformed into another”, and, “Energy cannot be created or destroyed but changed from one type to another”. Implicit in these learning goals is that the total amount of energy in the universe must not change. Furthermore, this means that the total amount of energy put into a system must equal the energy increase of the system plus the amount that leaves the system in other forms. Angelina is an example of a student who was successful in understanding this idea, who gave the following responses as we discussed the solar car scenario in round three:

- Jeff Nordine: When it slows down and stops, what happens to the energy that was originally there?
- Angelina: ...all the energy that it had previously transformed, it still there, it's just in a different form.
- Jeff Nordine: Can you compare the amount of solar energy hitting the car to the amount of kinetic energy it has when it's moving, is it more, less, equal?
- Angelina: It's probably like, equal, because like none of it is like, lost. Well, it may not be the same amount, because there's other types of energy that light is being transformed into like sound...like it's the same amount of energy, just different types, I guess.

Angelina demonstrates not only a sense of quantitative conservation, but also a nascent understanding of energy degradation. Using these ideas, a student would be able to predict the behavior of the car as certain constraints are changed. For example, she would likely be able to assess the impact of adding an air conditioner in the car, because

she would know that the energy required to run the air conditioner would have to come from the sunlight, and this would leave less energy available to be transformed into kinetic energy. It is important to note that a student could make these predictions without knowing the inner workings of a solar car – in fact, Angelina requested that I explain what a solar car was before she responded to the scenario. Many students asked for this explanation, and I responded by analogizing a solar car to a solar-powered calculator and explaining that you could drive a solar car around when the sun shines on it. Based on her response to this scenario, Angelina is well positioned to encounter energy-related biological concepts such as energy flow through ecosystems and within organisms.

Moving toward a sense of the quantitative conservation of energy certainly seemed to be the exception rather than the rule, but it seems that most students are moving in the direction of a deep understanding of energy conservation even though they are not there yet.

### **Case examples of eighth grade students' conceptual development**

The four themes I identified provide an overview of how students' conceptions tend to evolve during their time in the energy unit, but they by no means apply to every student in the class. In this section, I provide an in-depth description of the conceptual changes that I observed in three students who represent lower, moderate, and higher levels of conceptual development during the course of their time in the unit.

*Case example of less conceptual development: Taylor*

Taylor is a student who clearly likes science and who seems to be exceptionally bright, yet his scores on the energy concept questionnaire and the learning goals test were on par with his classmates (he was missing his content questionnaire posttest). His energy concept questionnaire score began as a 9 and ended an 11, and he scored 14 on the learning goals pretest and 27 on the learning goals posttest. All of these scores are quite close to the class average.

Despite his average scores on the concept questionnaire and learning goals test, Taylor demonstrated an unusual knowledge of how things work. He explained that batteries rely upon chemical reactions, that a table and gravity exert equal and oppositely directed pushes on a book, and that villi in the large intestine absorb monosaccharides during digestion.

His initial ideas about energy seem to have been shaped by his obvious prior experience with science, and while he seemed familiar with the notion that energy can transform, he did not seem to understand that energy exists in various types, and that energy transformations occur between different types of energy. Instead, Taylor claimed that a battery works because there are “chemical compounds in the battery which are transferred to energy”, and that in a heater, “the rods heat up because of a transformation of energy into heat”. While he seems to have some initial appreciation for the importance of some kind of transformation or transfer involving energy, he seems to view energy as a product of some processes and a driving mechanism for others. Prior to instruction, Taylor most strongly exhibited the product, ingredient, and flow-transfer frameworks as he explained the role of energy in the interview scenarios.

After learning the indicator and factor framework in lesson set one, Taylor began to display an activity framework that did not seem present prior to instruction. His second round response to the firecracker scenario is a classic example of a student who exhibited the activity framework as he reasoned from a primarily mechanistic perspective:

Taylor: Definitely chemical energy, and thermal energy, and also light energy. And sound energy. Because, okay, one chemical energy is because the flame with the wick, and also once it explodes, there's chemical energy with whatever chemical's in that...sound energy because it will make a crackling noise when it goes through the wick...

Jeff Nordine: After the firecracker explodes, and it's a pile of debris, what happens to all those types of energy that you mentioned?

Taylor: Um, they do not exist anymore because, like if I were to take a sparkler and not light it, there's no chemical energy, but when I light it, there is, and when that chemical reaction stops, there's no more fire, so there's no more chemical energy with it. So it will just disappear.

Rather than viewing energy as something that is transformed or transferred when it seems to disappear, Taylor seems to believe that energy comes and goes depending on which indicators are present.

In a scenario depicting a power station, Taylor indicated that energy from the station could be used to power a light bulb. I attempted to explore what he meant by the term "used":

Jeff Nordine: Is it changed in some way when it's used?

Taylor: Ah, yes, it's changed a little bit because once it moves through the light bulb, ah, the energy is too weak, let's say to power another light bulb...

This response indicated a belief that the mere presence of energy can cause things to happen, and that no transformation need occur. His responses during round two suggest that, rather than building upon nascent transformation ideas that may have been present prior to instruction, Taylor's thinking about energy is dominated by the product and cause frameworks.

After learning about transformation in lesson set three, Taylor continues to reason strongly from a mechanistic perspective. When he claimed that a melting icicle involves a thermal energy increase, I asked him to explain how such an increase happened:

Jeff Nordine: How does that [thermal energy] increase happen?

Taylor: Um, from the temperature increase...

His response indicates that he thinks of the presence of energy types to be a reaction to the presence of their indicators. When an indicator is not present, Taylor seems to think that the associated energy type still exists, but in some sort of reduced form. He explained this concept in round three:

When [an energy type] decreases, it just goes into a lower state. It can never like, it's kind of like function graphing, you can never reach zero...it will be at a really, really, really low state, but there's still some.

It seems that Taylor misinterprets the maxim "energy can never be created or destroyed" to apply to individual energy types. His idea of conservation does not involve summing over all energy types, nor does it require that the amount of an energy type remain the same – only that it never disappears completely.

Unlike most students, Taylor did not successfully demonstrate a transformation framework during the third round of interviews. After the conclusion of the unit, his thinking seemed to have changed very little. For each scenario, he initially gave an extensive list of energy types that were involved, but did not invoke the concept of

transformation. Furthermore, he seemed to cling to the idea that energy types are conserved individually, as in this exchange:

- Jeff Nordine: When you say [gravitational energy] ‘goes down’, can you describe what you mean by that?
- Taylor: It goes down and then, like, stores. It’s there, but not working at that moment. So, energy is like never created or depleted, or destroyed. So, it just goes into a low form of energy, I guess.

From the first round of interviews, Taylor’s talk about energy closely resembled a transformation framework, but he did not indicate that he understood the role of energy transformations in phenomena. In his final interview, he explained that energy types have some relationship to each other, but stopped short of claiming that one type of energy actually becomes another: In the battery, light bulb, and switch scenario, I prompted him to explain whether the energy types he identified were related to each other:

- Jeff Nordine: Are those types of energy related to each other in some way?
- Taylor: Ah, yeah, because you need the chemical to charge the electrons...the light needs the electrons so the light can light...so everything like needs each thing.

In his thinking, a chain of energy-related events is certainly important in driving phenomena, but he does not seem to believe that one type of energy actually becomes another as phenomena occur. Although he believes that energy types can produce each other, each type “retreats back” when another takes over. Despite starting with a conception that seemed to resemble the transformation framework, it seems that Taylor has made little progress toward understanding the role of transformations in phenomena.



*Case example of moderate conceptual development: Kyle*

Kyle did not seem to enter the energy unit with as much science content knowledge as Taylor, but he demonstrated substantial gains on the learning goals test. His pretest score of 8 was somewhat below the class mean, and his posttest score of 27 was on par with his classmates. He did not demonstrate such dramatic improvement on the energy content questionnaire, as his score remained unchanged at 6. On the energy concept questionnaire, he improved from a score of 5 to a score of 9, but remained below the class average both before and after instruction.

It seems that prior to instruction, Kyle had devoted little, if any, thought to energy as a unified scientific concept; his ideas seemed to be an amalgamation of the many ways that the term “energy” is used outside of a scientific setting. In his initial interview, Kyle exhibited the functional framework by saying that “energy was like – turned on my lamp, it comes through the outlet and stuff. It’s like, uh, parts, helps run electronic things, kind of.” His first round interview responses were also indicative of the activity framework as he mentioned that “If the book were to fall, [it has energy], but not if its just sitting on the table.” In his responses during the interview and on the energy concept questionnaire, Kyle indicated that energy was used up in some processes, created in others, that people can gain energy by “warming up”, and that it is generally useful for running things. It is unlikely that, prior to instruction, Kyle had given much thought about energy as a single unified concept.

During interview round two, Kyle demonstrated some movement toward an activity framework, although he continued to hold several ways of thinking about energy. In response to a scenario in which a weightlifter was holding a weight, he demonstrated

that he was moving away from an idea of energy associated with a person's liveliness or exertion. After being asked whether the scenario illustrated his idea of energy, he said:

Kyle: Yes, because, no not really.  
Jeff Nordine: Why did you change your mind?  
Kyle: Because of what we learned, like in, like nothing's really moving if he's just standing there.

Without seeing any of the indicators he learned illustrated in the scenario, Kyle decided to go against his initial intuition that the scenario illustrated energy. Later in the interview, he gave further evidence that he thought of energy as something that was present or not based solely upon the presence of its indicator:

Jeff Nordine: After the firecracker is exploded, what happens to those types of energy that you mentioned?  
Kyle: It goes into the air? Or, it just disappears. Like, there's no more of it.

He went on to contend that when a piece of ice had melted completely, it no longer illustrated energy, and that coal has no energy before it is burned. Kyle did not move exclusively to an activity framework, as he continued to indicate that energy had some physical location and that it was generally useful for doing things. While he did not move toward a transformation framework, Kyle's thinking about energy already seemed to have become more coherent during lesson set one.

In the third round of interviews, Kyle had begun to refine his intuition that energy is generally useful for doing things to be more precise about what it means to say that energy is used when processes occur. In response to the solar car scenario, Kyle said:

Kyle: [It illustrates energy] because it uses solar energy to run.  
To go.  
Jeff Nordine: What happens to that energy once it gets used?  
Kyle: It turns into kinetic energy for the car to move, the thermal – or, the solar energy.

While he indicates that energy transformation is an important part of the process, he also seems to cling to his previous ideas that energy types can “stop” when their indicators are no longer present. In this exchange, he seems to be in transition between an activity and transformation framework, and he demonstrates that he does not understand what is meant by the law of conservation of energy:

Jeff Nordine: [When the car stops], what happens to that kinetic energy?  
Kyle: It stops because it stops moving.  
Jeff Nordine: And when it stops, what do you mean?  
Kyle: Well, it (long pause). It gets – restored?  
Jeff Nordine: What gets restored?  
Kyle: Well the energy transforms into another energy.  
Jeff Nordine: So are you talking about the light –  
Kyle: Conservation.  
Jeff Nordine: Conservation, what’s conservation?  
Kyle: To conserve energy.  
Jeff Nordine: What does that mean?  
Kyle: Uh, the same amount of energy is in the same place, ah, before and after something happens, but it’s in different energies. It’s been transformed, but it’s still the same.  
Jeff Nordine: How much solar energy is there compared to kinetic energy for this car?  
Kyle: A lot.  
Jeff Nordine: Would it be more or less, or the same?  
Kyle: At the beginning, there’s more solar, at the end there’s more kinetic.

As Kyle has learned about transformation in lesson set three, he seems to have begun to replace his idea that energy types disappear when their indicators are gone with the idea that energy types that seem to disappear have been transformed into other energy types. He goes on to invoke the idea of conservation, but fails to account for energy flowing into and out of the solar car system, implying instead that the car receives a certain amount of solar energy that is gradually converted into kinetic until kinetic energy dominates.

In round three, Kyle demonstrated a transformation framework that was somewhat weakly-held and not well-developed. When the fourth round of interviews were administered two months after instruction, Kyle seemed to move away from the transformation framework again. During the barrel scenario, I probed Kyle to account for kinetic energy that had decreased:

Jeff Nordine: Suppose he pushes it all the way up to the top here where it's flat, and then he just, like, stops. What happens to that kinetic energy?

Kyle: It stops. There's no more for that time.

In this response, he indicated that while the kinetic energy stopped, there was no more for that time. I probed Kyle again during the chemical reaction scenario to determine what he thought happened to energy types when their indicators were no longer present:

Jeff Nordine: If the reaction goes for a while and fizzles out, what happens to the types of energy that you mentioned?

Kyle: They're still there, but they're not active.

Jeff Nordine: So when you say they're still there, where's 'there'?

Kyle: They're still around, but I guess they're not able to be used.

Jeff Nordine: Could they be used again later?

Kyle: Yeah.

In his response, Kyle demonstrated the misunderstanding of energy conservation that energy types are conserved individually, e.g., that they exist in some inactive form when their indicators are not present and spring up again when their indicators are present.

Although he did not sustain the transformation framework that he exhibited in the third round of interviews and developed a misunderstanding of energy conservation, Kyle demonstrated good conceptual change. From beginning the unit with no apparent ideas about energy as a unified concept, he seems to have moved considerably in the right direction.

*Case example of more conceptual development: Mabel*

Mabel entered the unit with a learning goals pretest score of 16, which was one point higher than the mean. Yet, her learning goals posttest score was 22, which was well below the mean. At the same time, her performance on the energy content questionnaire started and ended above the mean, going from a score of 9 to a score of 13. Mabel also showed good improvement on the energy concept questionnaire, where she moved from a score of 11 to a score of 15. On both her content and concept questionnaires, Mabel's pretest score was roughly equal to the posttest mean of her classmates. Although her initial performance on these measures was high relative to her peers, her initial thinking about energy left much room for improvement.

Prior to instruction, Mabel was one of only a few students who seemed to confuse the idea of energy and force. In response to the scenario depicting a book sitting on a table, Mabel explained that:

The gravitational energy, um yeah, the gravity pulls the ground, and the table so the table is on the ground and the book is on the table. So the gravitational energy like pulls down...

Perhaps related to her confusion of energy and force, Mabel seemed to regard energy as a causal entity that was used up in the course of phenomena. In the light bulb scenario, her initial response was, "The battery, like, um, gives the light bulb energy to turn on, and the switch, it turns on the um, battery so that it is able to give the energy to the light bulb."

When I prompted her to explain what happens to the energy as time goes on, she claimed that, "It gets all used up by the bulb." She also felt that the melting ice, chemical reaction, and heater scenarios demonstrated energy being used up during the phenomena. In her thinking, energy was transferred to objects like a light bulb, a melting ice cube, or

heater in order to make things happen, and this energy was used up in the process. The deposit and cause frameworks dominated her pre-instruction interview.

After lesson set one, Mabel had shifted toward the activity framework while retaining an adherence to the cause framework. Her response to the weightlifter scenario indicated that she was moving away from a deposit framework in which energy is used up and toward an activity framework where energy pops into and out of existence based upon the presence of its indicator:

- Mabel: The person lifting the weight makes the weight move, which is kinetic energy, and yea, that's it.
- Jeff Nordine: Suppose he's holding it really, really still at the top, um, what happens to that kinetic energy that you mentioned before?
- Mabel: It's like used up. Well, not used up, it's not present.

Like most of her peers, Mabel's initial responses to second round interview scenarios were lists of energy types that she identified based upon the presence of their indicators.

I probed her initial response to the firecracker scenario to explore what she thought happened to energy types when their indicators were no longer present:

- Mabel: It has kinetic energy because it moves. It has light energy, because light is produced by the fire, the spark, and whatever, and it has sound energy because it makes a crackling noise. And it has thermal energy because it's hot...chemical energy...something inside of it causes a chemical reaction to occur.
- Jeff Nordine: What happens after the explosion?
- Mabel: They're no longer there. They're not there. I don't know.

In both the weightlifter and firecracker scenarios, Mabel indicated that energy simply disappears when its indicator is no longer there. She did not move exclusively to an activity framework, as she continued to maintain that energy was a causal entity that is

required for things to happen. In the power station scenario, she indicated that, "...the chemical energy that was created at the power station is like, making the light bulb turn on." This statement indicates that she believes energy can be created and subsequently transported somewhere to make something happen.

After learning about transformation in lesson set three, Mabel moved dramatically toward the transformation framework. She invoked transformation ideas in her unprobed initial responses and she seemed to begin to reason about scenarios from a transformation-based perspective rather than a mechanistic perspective. Although she was not previously familiar with the idea of a solar car, she was able to apply her knowledge of energy transformation to its function. After I explained that a solar car could move when light shines on it, she responded:

Well, then solar energy is transforming into, um, I don't know, eventually to kinetic energy because it makes the car move. And I'm guessing there's thermal energy because the sun heats up the metal stuff on the car. And, um, maybe there's chemical, no because there's no batteries in it.

Although Mabel was unfamiliar with the inner workings of a solar car, she demonstrated an understanding of how the rules of energy transformation place constraints on its performance:

- Jeff Nordine: Can you compare the amount of light energy that's there originally to the kinetic energy?
- Mabel: They should be pretty, like, match-upable, because of the law of conservation of energy.
- Jeff Nordine: Is it possible to have more kinetic energy than light energy?
- Mabel: Only if there's more types of energy transforming into kinetic energy.

In this exchange, Mabel went beyond a simple understanding of transformation to demonstrate a sense of quantitative conservation. Using these ideas, she could make

accurate predictions about how changes such as adding a radio inside the car would affect the speed at which the car could travel – all without knowing the mechanism by which a solar car operates.

Mabel also demonstrated in round three that she had developed an understanding that energy cannot pop into and out of existence based on the presence of energy type indicators. In a scenario depicting a stationary bridge, Mabel showed that she no longer believes that energy can be used up:

Mabel: There has to be something. (pause) There's gravitational energy because the bridge is like, above the Earth, and that's like the gravitational pull. And, it's not moving in any way. There's no sound, no thermal energy being given off, electrical energy, and no chemical energy. So, yeah, just gravitational energy.

Jeff Nordine: In the beginning, you said there has to be something, why did you say that?

Mabel: Because all things have energy, like energy's present everywhere, it can't, like, be used up. It just transforms into other things, so there's always energy everywhere.

In the final round of interviews, Mabel adhered to the transformation framework and continued to exhibit it in her initial responses to scenarios. Yet, she demonstrated some regression into the deposit and activity frameworks. In her response to the battery, light bulb, and switch scenario, she indicated that the battery has the energy that the light bulb needs to light, but unlike her response in round one, she indicated that when the light bulb uses this energy, it is transformed into light and thermal energy. She demonstrated the activity framework in the scenario depicting a girl eating a meal:

Jeff Nordine: Does the food have energy when it's just sitting there in the bowl?

Mabel: Yeah, well like, no. No. It has to chemically react with something inside of your body, in order for like – then there's chemical energy once the chemical reaction occurs, then there's a new substance.



Although she indicated that chemical energy was not present until a chemical reaction occurred, she explained that after the reaction, this energy was not gone:

Jeff Nordine: Once that chemical reaction is complete, then what happens?

Mabel: The energy is like, some kind of energy is transformed into chemical energy, from the reaction, and then that, like, transforms into another kind of energy, like if you're moving, then kinetic energy.

Although Mabel demonstrated the deposit and activity frameworks in her final interview, these ways of thinking about energy seem to have taken a back seat to a more firm commitment to energy transformation and conservation. After her participation in the energy unit, Mabel seems well positioned to develop a sophisticated conception of energy that incorporates the ideas of quantitative conservation and degradation.

#### *Overview of 8<sup>th</sup> grade case examples*

Taylor, Kyle, and Mabel illustrate three different levels of conceptual development during the course of the energy unit. All three students moved toward the activity/product frameworks in their second round interview, and it seems that their conceptual development was largely related to the extent that they were able to move away from these frameworks and toward the transformation framework. It is important to note that students' conceptual growth during the unit does not seem to be predicated on their prior knowledge of science. Among the three case examples, Taylor seems to have entered with the most science content knowledge, yet had the smallest conceptual growth. On the other hand, the student with the least apparent prior knowledge was Kyle, and although Kyle had the most to gain, Mabel demonstrated more productive movement through the frameworks.

Overall, my analysis of interview data suggested that students progress toward the transformation framework in a manner that is neither smooth nor without its challenges. Not surprisingly, some students seemed to overcome these challenges more successfully than others. In the next section, I turn my attention to the quantitative data that I gathered from all class members to analyze their growth on these measures and to determine whether student characteristics such as prior knowledge and gender had an effect on student outcomes.

### **Whole-class growth on quantitative measures**

I used a paired t-test to examine the extent to which students' scores on the three quantitative measures changed during their participation in the unit. The results of these paired t-tests are shown in Table 5.6.

**Table 5.6. Results of paired-samples t-test comparing students' performance on quantitative measures before and after instruction.**

<b>Measure</b>	<b>Pretest mean (SD)</b>	<b>Posttest mean (SD)</b>	<b>Effect size</b>	<b>Paired difference (SD)</b>	<b>df</b>	<b>t-statistic</b>
Learning goals test	15.2 (4.0)	26.9 (5.0)	2.9	11.7 (4.8)	75	21.3***
Energy content questionnaire	6.6 (2.2)	9.4 (2.5)	1.3	2.7 (2.6)	69	8.8***
Energy concept questionnaire	8.2 (2.8)	11.2 (1.8)	1.1	3.0 (2.6)	73	9.9***

\*\*\*  $p \leq .001$

\*\*  $p \leq .01$

\*  $p \leq .05$

~  $p \leq .1$

These results indicate strongly significant growth on all measures by students in the energy unit. On average, students' scores on the learning goals test increased by nearly three standard deviations, while their scores on the energy content and concept questionnaires increased by more than one standard deviation.

Because students' scores on the energy concept questionnaire had a strong positive correlation with the transformation framework and a negative correlation with all but one undesirable framework, these data suggest that students tend to move away from undesirable energy frameworks and toward the transformation framework during the energy unit. At the same time, students showed strong growth in terms of their ability to perform on both proximal and distal content-based assessments. While the overall picture showed substantial growth, I also investigated whether students' teacher, gender, or prior knowledge affected their end of unit achievement.

#### *Influence of student characteristics on outcomes*

I ran two simultaneous regression models investigate the influence of student characteristics on their energy content knowledge and the overall quality of their energy conception demonstrated at the end of the unit. I did not have access to student-level data such as age, socioeconomic status, or minority status, so my regression models include only predictors for students' gender, teacher, and pretest scores. Before creating the regression models, I created z-scores all pretest and posttest scores, dummy coded students' gender and teacher variables, and created a composite content score by adding students' posttest and energy content questionnaire scores together and converting them to z-scores. The variables used in my analysis are shown in Table 5.7.

**Table 5.7. Descriptive statistics used in regression analyses (N = 82)**

Variable	Mean (SD)
% of female students	48.8
% of students in Mrs. Geller's class	56.1
Composite content pretest <sup>a</sup>	0 (1)
Composite content posttest <sup>a</sup>	0 (1)
Energy concept questionnaire pretest <sup>a</sup>	0 (1)
Energy concept questionnaire posttest <sup>a</sup>	0 (1)

a. z-scored variable

The regression models for each outcome are shown in Tables 5.8 and 5.9. Because all continuous variables were converted into z-scores, the regression coefficients reported in my regression models are in units of effect sizes. That is, the effect of being one standard deviation above the mean (or being in the identified categorical group) in units of standard deviations on the outcome measure.

**Table 5.8. Results of simultaneous regression investigating the effects of student characteristics on their content knowledge at the end of instruction (N = 62).**

Predictor Variables	Effect Size
Student is female	.074
Student was taught by Mrs. Geller	.203
Composite content pretest	.455***
Energy concept questionnaire pretest	.086
Constant	-.348
R <sup>2</sup>	.237

\*\*\*  $p \leq .001$

\*\*  $p \leq .01$

\*  $p \leq .05$

~  $p \leq .1$

**Table 5.9. Results of simultaneous regression investigating the effects of student characteristics on their energy concept questionnaire posttest (N = 67).**

Predictor Variables	Effect Size
Student is female	.298~
Student was taught by Mrs. Geller	-.077
Composite content pretest	.230*
Energy concept questionnaire pretest	.194*
Constant	-.001
R <sup>2</sup>	.278

\*\*\*  $p \leq .001$

\*\*  $p \leq .01$

\*  $p \leq .05$

~  $p \leq .1$

Neither of the models suggested that students' teacher or gender was a significant predictor of their performance for either outcome, although gender did approach significance on the energy concept questionnaire posttest. Because gender did not have a strong effect for both models and none of my other analyses suggested a gender effect, I have no reason to believe that the effect size for gender, which approached significance, is indicative of an underlying gender effect. Considering to the high degree of collaboration and support among students and faculty members at Fairmeadows, it is not surprising that there is no significant effect of students' teacher or gender on their composite content posttest or energy concept questionnaire posttest.

While the students' composite content pretest was a significant predictor for both their composite content and energy concept questionnaire posttests, the energy concept questionnaire was only a significant predictor for itself. These results suggest that prior knowledge does play a role in students' learning during the unit, but neither model explained more than 30% of the variance in either outcome. Thus, more than 70% of the variance in each outcome is unexplained by students' gender, teacher, and prior

knowledge. These results support the idea that prior knowledge affects subsequent knowledge construction (Smith, et al. National Research Council, 1999; Smith, et al., 1993-1994), but that students' conceptual development and content knowledge achievement are largely due to the learning opportunities afforded to students within the energy unit.

The results of my regression analysis and paired t-tests on quantitative measures suggest that students make substantial gains on assessments that were administered as pre/post measures. Of course, it is not unusual to see students make substantial gains on assessments that have been administered immediately before and after instruction. In the next section, I turn my attention to the extent to which students' conceptual development that I observed in my pilot study was sustained one year after instruction.

### **Energy conceptions one year after instruction (Research question 2)**

During both the 2004-2005 and 2005-2006 enactments of the energy unit, students moved from almost uniformly toward a transformation framework in interview round three, but slightly away from it in round four. Also, many alternative frameworks that students held prior to instruction resurfaced (albeit more weakly) in round four after being seemingly absent in round three. Although the overall movement of students' conceptions during instruction was in a desirable direction, the data leave open the possibility that students' conceptions may degrade over time. I investigated this possibility by interviewing the six students who participated in my pilot study and were still enrolled at Fairmeadows.

As I discussed previously, students in the 2004-2005 enactment progressed in a very similar fashion to students in the 2005-2006 enactment. They largely moved toward the transformation framework, tended to reason from a mechanistic perspective, and had difficulty developing a deep understanding of what energy conservation means. When I re-interviewed the students who were interviewed in my pilot study one year after their participation in the energy unit, I found no deterioration in the quality of their conceptions. In fact, I found a decrease in the number of students exhibiting the undesirable anthropocentric, deposit, and product frameworks, and an increase in the number of students exhibiting the desirable transformation framework. Figure 5.7 shows how the frameworks exhibited by this group of students changed from their final 8<sup>th</sup> grade interview to their 9<sup>th</sup> grade interview.

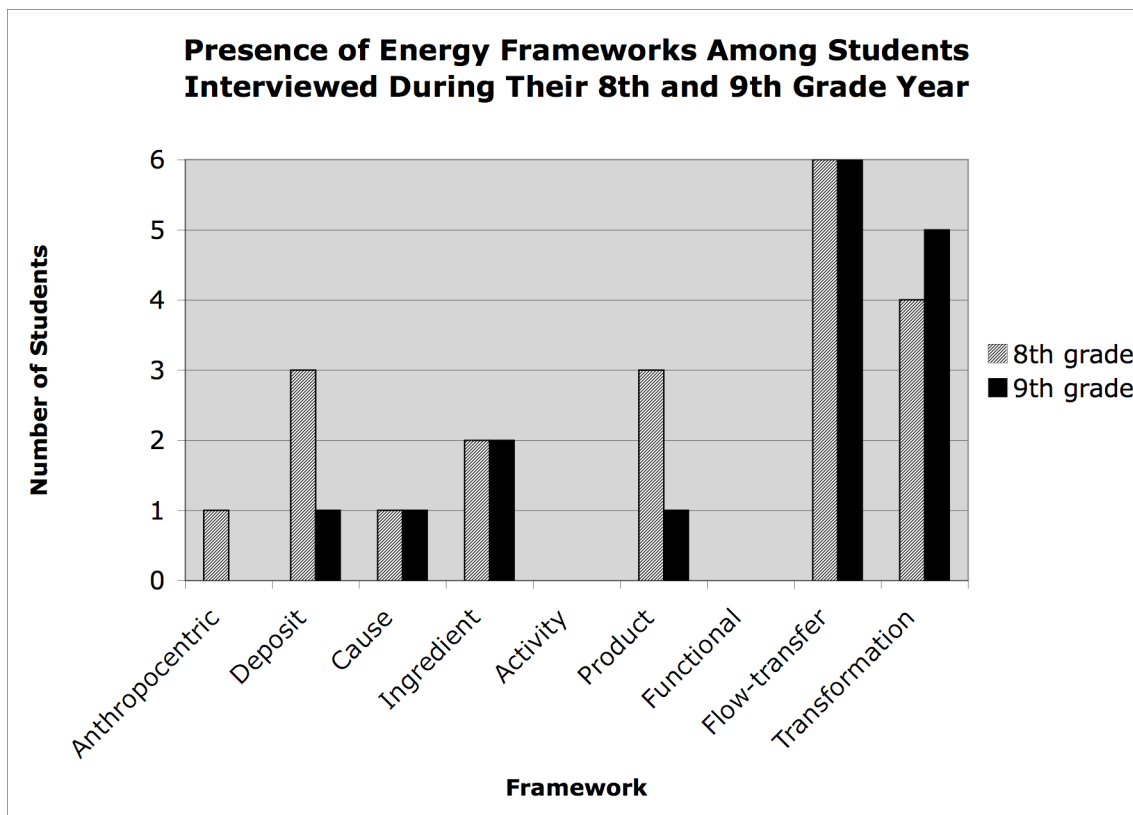


Figure 5.7. Comparison of energy frameworks present in 8<sup>th</sup> and 9<sup>th</sup> grade for students who were interviewed both years.

Rather than degrading, it seems that as a group, the quality of students' conceptions has improved in the year since they participated in the energy unit. Students also seemed to improve individually. Several students exhibited fewer alternative frameworks in 9<sup>th</sup> grade compared to 8<sup>th</sup> grade, but the most substantial change seemed to be a more sophisticated view of energy transformation.

Allen is an example of a student who exhibited fewer alternative frameworks and who developed a more sophisticated understanding of transformation. When interviewed immediately after the energy unit, Allen exhibited the transformation framework, but his responses indicated that he held the product, ingredient, flow-transfer, and deposit frameworks as well. When he was interviewed in 9<sup>th</sup> grade, only the transformation and



flow-transfer frameworks remained. Furthermore, his view of transformation seemed to be more closely tied to the idea of quantitative conservation than it had in the past.

Responding to the battery, light bulb, and switch scenario in the 8<sup>th</sup> grade, Allen and I had the following exchange:

- Allen: The battery converts chemical energy to electric energy through some process, which, I have no idea what it does. And since it will burn the chemicals inside of the battery, it will slowly deplete until it has none left.
- Jeff Nordine: After the battery runs out, what happens to the light energy and thermal energy and the other types that you mentioned?
- Allen: They all drop. They're all, well, the light bulb goes out so they all just stop because there's no more electricity. I'm pretty sure that's what happens.

While he invoked the idea of transformation, he seemed to be teetering on the edge of an activity framework as well, because he indicated that as the battery runs out, the energy types just 'stop'. He did not use the ideas of transformation and conservation to explain what had become of those energy types. In 9<sup>th</sup> grade, Allen responded to the same scenario:

- Allen: The electrical and I suppose some of the chemical energy in the filament is transferred over to the same amount of energy in light and heat.
- Jeff Nordine: You mentioned 'the same amount of energy'. Why is that the same amount?
- Allen: Energy is never created or destroyed, it is only reassembled, I guess, in the equation. It's an equation, it's equal, like, that's the definition. It also works to a certain extent with mass.

Although his understanding of the function of a light bulb is somewhat flawed, Allen took it upon himself to stress that there is as much energy after the transformation process as before it, and he alluded to the fact that conservation of energy is defined by a mathematical equation.

In addition to exhibiting more sophisticated transformation frameworks, students were more likely to invoke the transformation framework unprompted. In 8<sup>th</sup> grade, two of the six students invoked the transformation framework prior to prompting, while in 9<sup>th</sup> grade, four of the six used transformation ideas prior to prompting. This suggests that the idea of energy transformation may have a higher cuing priority for these students than it had the year before.

Anthony is a student who invoked the transformation framework unprompted in his 9<sup>th</sup> grade interview but did not do so in his final 8<sup>th</sup> grade interview. In 8<sup>th</sup> grade, his response to the battery, light bulb, and switch scenario was:

Well, there's electrical energy in there, and when the switch is turned on, there will be light energy. And when the switch is being flipped on and off, there's kinetic energy.

In his initial response, Anthony did not use the idea of transformation to explain the phenomenon, and he included a reference to kinetic energy that, while true, was almost completely irrelevant to the scenario depicted. In his 9<sup>th</sup> grade interview, Anthony's initial response was more focused on energy transformations that were central to the phenomenon:

There's electrical energy in that, and some heat...(unintelligible). The battery has stored chemical energy, the light bulb is converting that energy into light and heat energy to make the light, which is on.

Anthony's 8<sup>th</sup> grade response indicated that he was reasoning from a mechanistic perspective, in which he searched the scenario for familiar indicators and assigned energy types accordingly, with little regard for the relevance of those energy types. In 9<sup>th</sup> grade, he seemed to reason from a more transformation-based perspective, in which he considered what kinds of energy transformations are most relevant to the scenario.

Based upon the six students from my pilot study sample who remained at Fairmeadows, it seems that their energy conceptions improved during the year since they completed the energy unit. It seems possible that some of the improvement that I perceived in these six students is due to students' repeated participation in the interview, since this was the third time they have responded to the same interview scenarios. However, a chi-square test revealed no difference between students who were interviewed in both 8<sup>th</sup> and 9<sup>th</sup> grade and students who were interviewed only in 9<sup>th</sup> grade in terms of how many students exhibited the desirable transformation framework,  $\chi^2(1, N=15) = 0.069$ ,  $p = \text{NS}$ . Table 5.10 shows the number of students who fell into each category.

**Table 5.10. Students who exhibited the transformation framework in 9<sup>th</sup> grade, by whether they participated in my pilot study**

	Did not exhibit transformation framework	Exhibited transformation framework
Interviewed in 8 <sup>th</sup> and 9 <sup>th</sup> grade	1	5
Interviewed in 9 <sup>th</sup> grade only	2	7

This result, along with the finding that these groups' scores on the energy concept questionnaire were not significantly different, provides evidence that the six students I interviewed are not exceptional among their peers. Therefore, it is reasonable to assume that students' improvement in the year since they took the energy unit is due to continued energy-related learning and not to repeated interview participation.

### **Energy conceptions across grade levels (Research question 3)**

My results indicate that students progress toward the transformation framework while in the energy unit and that the quality of their conception seems to have improved, rather than deteriorated, one year after instruction. While these findings are important, they are insufficient to justify a claim that the energy unit is superior to the energy-related instruction that preceded it at Fairmeadows. To make this comparison, I interviewed samples of 16 students in chemistry and physics who were the most recent classes of students to go through 8<sup>th</sup> grade science at Fairmeadows before the energy unit was introduced. After classifying the frameworks exhibited by all students in all four grades, I compiled the results into Figure 5.8.

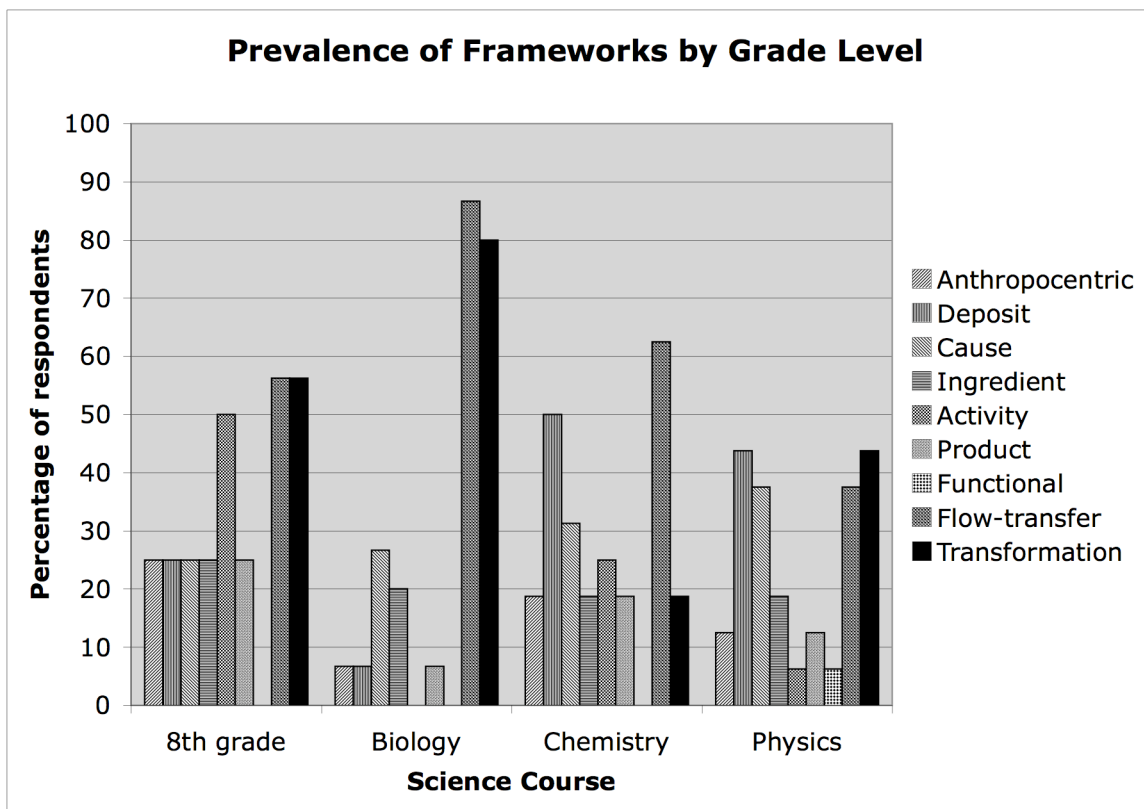


Figure 5.8. Energy frameworks present in 8<sup>th</sup> grade science, biology, chemistry, and physics students at Fairmeadows who have been enrolled there since the beginning of their 8<sup>th</sup> grade year.

Figure 5.8 shows that differences exist between grade levels in terms of the number and type of frameworks they exhibit. While 56% of 8<sup>th</sup> grade students and 80% of biology students who were interviewed exhibited the transformation framework, only 19% of chemistry students and 44% of physics students exhibited the transformation framework during their interviews. A chi-square test revealed that this difference is not likely due to chance alone,  $\chi^2(3, N=63) = 12.14, p \leq .01$ . There is little doubt that this difference is due to the heavy emphasis that the energy unit places on interpreting everyday phenomena within an energy transformation perspective. Even though more students in 8<sup>th</sup> and 9<sup>th</sup> grade exhibited the transformation framework than students in 11<sup>th</sup> grade physics, the

typical physics student who exhibited a transformation framework demonstrated a far more sophisticated understanding of energy transformation and conservation than did the typical 8<sup>th</sup> grade student who exhibited the transformation framework. I will devote more attention to the differences between students' understanding of transformation later, when I describe case examples of students from each grade.

Another notable difference between grade levels is that 8<sup>th</sup> grade students exhibited the activity framework more often than their older counterparts. The results of a chi-square test suggested that this variation was almost certainly non-random,  $\chi^2(3, N=63) = 14.96, p \leq .01$ . It is difficult to use this result to draw a conclusion about the energy unit, since no biology students exhibited the activity framework in their interview. One possibility is that the unit pushes students to adopt the activity framework as a sort of intermediate abstraction on their way to the transformation framework, and students need adequate time to move fully away from the activity framework. My analysis of the longitudinal interview data that I collected while students were participating in the unit suggest that students begin to move away from the activity framework while instruction is ongoing, but that many students have trouble moving fully away from it (and/or the closely-related product framework). The cross-sectional results shown in Figure 5.8 suggest that students may continue to move away from the activity/product frameworks as they continue to mature and to learn about energy-related concepts in their biology course.

Figure 5.8 also shows that fewer students who had participated in the energy unit displayed the deposit framework than students who had not participated, and the results of a chi-square test suggest that this variation between grade levels is non-random,

$\chi^2(3, N=63) = 8.73, p \leq .05$ . In the deposit framework, energy is contained within some objects and is used up by other objects when certain processes occur. The difference between energy unit participants and non-participants likely arose due to the emphasis on transformation within the energy unit. Because they are repeatedly asked to account for energy types that are present as phenomena occur, students began to understand that when an object “uses” energy, this really means that it has transformed energy from one type to another. During her interview after the energy unit, Angelina (8<sup>th</sup> grade) demonstrated that she understands that an object that “uses” energy does not use it up.

Jeff Nordine: If you turn the switch on and leave it on, what happens as time goes on?

Angelina: Well the battery, like it will run, like all of its energy will be used, like in the light bulb, and so yeah, it will be dead then.

Jeff Nordine: And once the energy gets used, what happens to it?

Angelina: Well, it is converted into another thing, I guess, like, so when it left the battery it turned into light and thermal and then, yeah, it’s still there, it’s just in a different form.

While Angelina exhibited the transformation framework in her response, Michelle (chemistry) exhibited the deposit framework when responding to the same question, posed during the same scenario:

Jeff Nordine: If you were to switch this switch on and leave it for a while, what would happen as time goes on?

Michelle: The energy will run out.

Jeff Nordine: What does it mean for energy to run out?

Michelle: There’s a certain amount of energy in the battery that’s transferred to the light bulb, but then, um, the energy’s just used up.

Buford (physics) also demonstrated the deposit framework when he responded to the same question in the same scenario:

Jeff Nordine: If you turn this switch on and just let it run for a while, what happens as time goes on?

Buford:           The energy starts to, it's starts to burn out the energy as it uses it, and it needs to have another source.

Some students who had participated in the energy unit also exhibited the deposit framework, but based on the number of these students compared to the number of students in chemistry and physics who demonstrated this framework, it seems that the energy unit helps students to understand more clearly what it means for objects to “use” energy.

While there seems to be a difference across grade levels in the number and type of energy frameworks students exhibited, these differences alone do not tell the whole story. During the interviews, it was clear that some students held frameworks more strongly or weakly than other students, that there were differences in the cuing priority of certain ideas, and that students' understanding of energy transformation had different levels of sophistication. The case examples that follow are intended to more clearly illustrate the conceptions of individual students who had less developed, moderately developed, and more developed conceptions relative to their grade level peers.

*Case example of a biology student with a less developed conception: Betty*

Betty is a student who participated in the energy unit the year before being interviewed, and it was clear that she still retained a good command over the indicator and factor framework. In her initial responses, Betty tended to list the energy types present in scenarios, but she did not describe how they are related to each other and frequently included energy types that were essentially irrelevant to the phenomenon depicted. For example, her initial response to the battery, light bulb, and switch scenario was:



It has light energy because the light bulb goes on and gives off a light when you turn on the switch, and when you turn on the switch, that's kinetic energy because the switch is going on and off. And then, I think there's chemical energy in the battery.

In her response, Betty discussed the kinetic energy of the moving light switch, which is irrelevant to the phenomenon, and failed to related one energy type to another. When prompted to related the energy types she listed, she explained:

If you don't turn on the switch, then you don't get the light energy, and if you don't have the battery then the light won't go on either, and without the light bulb, its just kind of a pointless little switch and battery.

Betty seems to view the scenario as a series of events that are related to each other, each of which has an energy type associated with it, rather than a series of energy transformations that must happen in order for the light bulb to glow. In other words, Betty seems to reason primarily from a mechanistic perspective rather than a transformation-based perspective.

When I asked her to account for what happens to the chemical energy in the battery when it runs out, she claimed that "It got transferred into light energy in the light bulb." Because she did not call this a transformation and did not emphasize the importance of the transformation in the scenario, her response did not qualify for the transformation framework. Her response did indicate that she understood the qualitative conservation of energy, that is, when an energy type seems to disappear, it simply exists in some other form. Later in the interview, she recalled, "From what I remember, I think that you can't create or destroy energy."

It seems that Betty's adherence to the conservation of energy without a full appreciation for the role of transformations in phenomena had its consequences. During the scenario depicting a girl eating a meal, Betty claimed that a person's stomach "uses

[food] to make energy in your body.” This is an apparent contradiction to the idea that energy cannot be created or destroyed, and when I pressed her to explain what she meant, she claimed that, “The energy in the food before is like, not – it’s like kind of concealed or something, in it. And when you eat it, it kind of comes out and you can use it then.”

It seems that Betty understands a few basic rules about energy, but does not fully appreciate the importance of energy transformation. Her scores of 12 on the energy concept questionnaire and 11 on the energy content questionnaire were slightly above the biology mean scores, which indicate that she is not a poor student. Rather, it seems likely that Betty has the foundation in place to develop a more sophisticated understanding of transformation and conservation, but has not done so yet.

*Case example of a biology student with a moderately developed conception: Riley*

Riley is one of six biology students who exhibited the only the flow-transfer and transformation frameworks and one of eight students who invoked the transformation framework unprompted. While he did invoke the transformation framework unprompted, his initial responses tended to focus on energy transfers that were occurring in the scenarios. Riley’s response to the scenario depicting a man pushing a barrel up a ramp illustrated his tendency to focus on energy transfer and his ability to incorporate ideas of transformation and conservation upon prompting:

- Riley: The barrel’s got the kinetic energy because it’s moving, and it’s coming from the person, who’s able to push it because they ate and because like, took in energy and stuff.
- Jeff Nordine: What does it mean for energy to be coming from some place?
- Riley: Uh, the energy’s not being created, but the person got energy from whatever they ate and then, it’s just being

- transferred to the barrel.
- Jeff Nordine: What happens to the energy that that person was, uh, had to push the barrel originally?
- Riley: It's turning into, um, gravity energy of the barrel...the higher up it goes, the more gravity energy it has.

Instead of searching the scenarios for the presence of indicators and listing the associated energy types, Riley focused on the dynamic role of energy in the scenario as it was transferred from the man to the barrel. Without knowing it, Riley was describing the process of doing work.

In his initial response to the scenario depicting a heater, Riley demonstrated an understanding of the quantitative conservation of energy:

Well, if it's plugged into the wall, it's got electrical energy from the outlet, and it's being turned into thermal energy. It's being transferred from the socket, and then it comes out and it might make a little noise, so you won't get quite the entire amount of energy, but it will warm up the room.

During his interview, Riley demonstrated that he understood the role of energy transfer, energy transformation, and energy conservation in various scenarios, but he also seemed to regard energy as a concrete entity that can be moved between objects.

*Case example of a biology student with a well developed conception: Chadd*

Chadd is a student who is clearly interested in science and is the only biology student to have solely exhibited the transformation framework in his responses. In his initial response to the chemical reaction scenario, Chadd demonstrated his ability to combine an energy transformation perspective with the mechanism of the reaction:

Well, it's got the bub – notice, I have the bubbles in the air, that's um, chemical being transferred into kinetic energy, in the form of little gas molecules escaping from the liquid. Um, you also might have heat energy. You might have some sound energy as the bubbles pop and rise.

Rather than assigning energy types based on the presence of their indicators, Chadd first discussed the central energy transformation driving the phenomenon and then identified the moving gas molecules as the objects with kinetic energy. Later in the scenario, I prompted Chadd to discuss how energy was involved in the scenario before the reaction took place:

Jeff Nordine: Before you mix these two chemicals together, suppose it's baking soda and vinegar – before you mix them together, there obviously wouldn't be any bubbling or anything like that, but when you mix them together there is, so, how do those energies get there?

Chadd: The energies were there. The energies were there, because both baking soda and vinegar have some amount of chemical energy in their molecules, in their covalent bonds...

In biology class, Mrs. Forest teaches students that energy is released when covalent bonds are broken, and it seems that Chadd has incorporated this idea into his transformational view of energy. Later in the same scenario, I prompted Chadd to compare the amount of energy before, during, and after the chemical reaction. He responded in the following way:

Chadd: Provided this is a completely closed system?

Jeff Nordine: Sure.

Chadd: Providing it was a completely closed system, everything would be exactly the same, because energy doesn't dissipate – isn't destroyed – can't be created or destroyed, it's just there, it just transfers into other forms.

While many of his peers hold a view of energy conservation that requires energy can never be created or destroyed, Chadd has incorporated a systems perspective into his understanding. He insisted that the amount of energy would only be exactly the same provided the reaction took place in a completely closed system. While he may never

have calculated a numerical value for the amount of energy in a system, he already seems to understand the premise for quantitative energy conservation.

*Case example of a chemistry student with a less developed conception: Missie*

Missie scored a 9 on the energy concept questionnaire and a 9 on the energy concept questionnaire, placing her almost exactly at the mean scores of her peers. Although she demonstrated a fairly typical ability to answer energy-related questions, it seems that she had devoted very little thought to energy as a unified scientific concept. In her interview, Missie seemed to view energy in many contradictory ways that were situation-specific. During situations involving humans, she indicated that living objects have energy whereas non-living object do not, but in other situations, she indicated that non-living objects objects can create energy when something happens.

In the scenario depicting a man pushing a barrel up a ramp, Missie exhibited a classic anthropocentric framework:

- Missie: You have to use your energy to push the barrel.
- Jeff Nordine: What does that mean to use your energy?
- Missie: I don't know, I guess the energy you have when you wake up in the morning, you're re-energized, that's what you're using.
- Jeff Nordine: What about the barrel?
- Missie: I don't think of it as having energy, because it's not a live object.

In the very next scenario, she indicated that a battery, light bulb and a switch illustrated energy because "...just something that a light bulb's coming on. Something happens to create that effect." Later, during the chemical reaction scenario, Missie indicated that "when two substances react together, they create a new energy." When I asked her to

explain what happens to this energy once the reaction is complete, she responded, “Um, it disappears. It leaves the, wherever the substances are reacting. It evaporates or something.”

During her interview, it seemed that each scenario led Missie to default to a particular way of thinking and talking about energy based on factors such as the presence of a human being. Missie has likely never had the impetus to consider how a person’s energy may be related to the energy involved when two chemicals react, consequently, she holds many simultaneous and contradictory ideas about energy that are not linked to each other as a unified scientific construct. Although she seems to appreciate that energy is involved whenever processes occur, she is clearly not bound by the law of conservation of energy and does not seem to understand the omnipresent role of energy transformations in phenomena.

*Case example of a chemistry student with a moderately developed conception: Frederick*

Frederick is a student with a good amount of science content knowledge who seems to regard energy as necessary for certain processes to occur and as something that can be contained within certain objects. When I asked him to explain what it means for the man pushing the barrel to use energy, Frederick responded, “...he’s using nutrients that he took in from food and such and turning that into energy. It’s called like ATP energy or something.” His response indicates that people use food to synthesize something called ATP energy that is stored in the body and used when a person engages in some activity.

Frederick also indicated that energy is contained within some things and used to drive processes in his response to the battery, light bulb, and switch scenario. After initially indicating that flowing electrons were important for making the light glow, I asked him to explain what happens as time goes on:

Jeff Nordine: What happens as time goes on?

Frederick: I think the battery's going to wear out, it's going to lose some of its energy that it uses for those electrons, and it's going to become useless.

Jeff Nordine: What happens to that energy once it is lost?

Frederick: Well, I'm not entirely sure. I think it will just go into the atmosphere.

In his response, Frederick demonstrated a loose adherence to the conservation of energy, in that he believes that the lost energy does not disappear, but goes into the atmosphere. Later, in the chemical reaction scenario, Frederick again claimed that energy goes into the atmosphere after it is released during the chemical reaction, saying, "I think it just goes back to the atmosphere. I know there's some sort of scientific law that states what happens after it is used." When I asked if he remembered what the law said, he replied, "Conservation of energy...I think it's like, mass can neither be created nor destroyed or something like that."

Despite being somewhat familiar with the idea that energy can neither be created nor destroyed, he implied that it could be created in his response to the scenario depicting a girl eating a meal:

Jeff Nordine: Before she eats the food, is there energy at that point?

Frederick: I think so, but probably less of it at that point and you know, compared to after she ate the apple.

Jeff Nordine: So, after she ate the apple, there's going to be more energy than before?

Frederick: Yeah.

In his interview, Frederick consistently referred to energy as something that was needed for certain processes to occur, and he loosely adhered to the idea that energy can neither be created nor destroyed. His ideas seem somewhat consistent with notions of energy transfer, but do not account for the role of energy transformation and quantitative conservation.

*Case example of a chemistry student with a well developed conception: Nikolas*

Nikolas was one of three chemistry students to display the transformation framework, and he was the only student to do so unprompted. He seems to adhere to the flow-transfer, deposit, and transformation frameworks in his responses, and invokes the flow-transfer framework most often. When he responded to the scenario depicting a man pushing a barrel up a ramp, I asked him to explain what he meant when he referred to energy being “used”:

Jeff Nordine: So what does it mean for energy to be used?

Nikolas: Energy to be used is that, um, energy is moved from one object to another object, like energy is applied when moving something.

I asked him to elaborate his response by explaining why the person would eventually get tired when pushing the barrel. He replied, “Um, the person’s put in so much energy that they’ve used their energy, so they need to recuperate and get more energy, I guess.”

Nikolas’ responses indicate that that he thinks of energy as a substance that can be deposited in some places and transferred to others when it is used.

His response to the battery, light bulb, and switch scenario indicated similar thinking that indicated the flow-transfer framework:

Nikolas: Eventually the battery would drain the energy, then it



- wouldn't work anymore, then, yeah.
- Jeff Nordine: And after the energy's drained, what happens to the energy that was originally there?
- Nikolas: Well, it goes back into the battery, but into the other side of the battery.

Despite his adherence to the flow-transfer framework, Nikolas also indicated that energy could exist in different forms. When I asked him what it meant for energy to be in different forms, he responded, "Just like, how it's used. The energy is the same thing, but how it's used is what differs about it rather than the energy itself." Even though he is aware that energy can exist in different forms, he seems to think that energy is some sort of fuel that can be used in different ways. In response to the scenario depicting a book sitting on a table, Nikolas provided further evidence that he thinks of energy as a sort of fuel that can be contained within objects and used in different ways when he said, "[The book] has energy as well, the energy's not being used at that moment, but it has potential energy contained within it."

Nikolas' thinking about energy seems primarily defined by the ideas that it is a fuel that can be used and that when it is used, it is transferred from one thing to another. Thinking of energy as something of a concrete entity allows Nikolas to abide by the law of conservation of energy and to interpret energy exchange between objects. His idea of energy as a concrete entity is probably best summed up in his own words, "Energy isn't created or destroyed, it's only transferred, kind of like matter."

*Case example of a physics student with a less developed conception: Tanya*

Tanya does not seem to feel that energy is important to all phenomena; she is one of four students who felt that two or more of the scenarios did not illustrate energy, and one

of two students who only identified the battery, light bulb and switch scenario and the heater as illustrative of energy. When she did discuss energy's involvement in scenarios, she exhibited the cause (active deposit) framework, in which energy is viewed as a necessary catalyst for certain processes to occur. In this framework, the mere presence of energy is enough to make a process happen – no transformations need take place. In the heater scenario, she described the involvement of energy as:

The electrical energy is what makes the heater run, and the act of just putting the hot air into the cooler air is not, like, putting energy into the air, it's just heat, so it's just all electrical energy when I think about it now.

In her response, she indicates that electrical energy makes the heater run, but that this does not result in energy being transferred into the air. While in this scenario, she does not suggest that energy is transferred or transformed in the heater, she does discuss energy as being “expended” in the battery, light bulb, and switch scenario. After she mentioned that the battery powers the light bulb, I asked her to explain what happens to energy when it powers something:

Jeff Nordine: Once the energy gets to the light bulb and powers it, then what happens to that energy?

Tanya: I think it's expended, so as the energy keeps on flowing through, the battery will eventually die down. Usually energy isn't conserved, at least not in this situation.

In her response, Tanya makes a special effort to state that energy is usually not conserved. I asked her to explain this statement further:

Jeff Nordine: Um, you mentioned energy being, usually not conserved. What is that – what do you mean by that?

Tanya: In physics, we've done momentum conservation, and a few weeks ago we did energy conservation, so you know, we did work with springs...it was like, giving energy back once you like pulled down the spring...the light bulb is giving off light so that's heat energy or light energy, so it's not electrical energy.

While Tanya has heard the idea of energy conservation, she has misinterpreted it to mean that you get back the same energy type that you put into a system. Her reference to the spring system suggests that this misunderstanding comes out of a discussion of conservative vs. non-conservative forces. As long as only conservative forces act in a closed system, the total amount of mechanical energy remains the same (an assumption often made when studying spring systems in physics class). If non-conservative forces (e.g., friction) act in a closed system, then the total amount of mechanical energy decreases as it is transformed into thermal energy, but the total energy (mechanical plus thermal) of the system remains the same in either case. The law of energy conservation states that the total amount of energy in a closed system remains the same regardless of the energy transformations that occur, but Tanya seems to believe that energy conservation refers to getting the same form of energy out of a system than is put into it.

Related to her misunderstanding of energy conservation is her misinterpretation of another term common in physics classes – potential energy. In the scenario depicting a book sitting on a table, Tanya initially responded, “Well, I guess there’s potential energy like, if you wanted to slide it, the potential energy might be converted into kinetic or whatever. Um, yeah, no energy there.” While she recognizes the existence of something called potential energy, she does not view this as bona fide energy. This sentiment was echoed in her initial response to the scenario depicting a girl eating a meal, when she said:

Not really, I mean, I can still think of, you know, you’re making energy in your body by eating stuff, by breaking down all of the food, and then you have energy to run around or something, but you’re not quite to that step yet.

Tanya thinks of energy as something that is necessary for some processes to occur, but does not appreciate the importance of energy transformations and does not seem to understand energy conservation in either a qualitative (energy is never created or destroyed) or quantitative (the total energy in a closed system is constant) sense.

*Case example of a physics student with a moderately developed conception: Lillian*

Lillian's ideas about energy are clearly influenced by what she has learned in science class, because her answers are laden with references to work, molecular bonds, potential energy, and energy conservation. Yet, it is evident that she does not have a full appreciation for how these concepts tie together into a single overarching energy framework.

In the scenario depicting a man pushing a barrel up a ramp, Lillian initially responded that, "It takes energy to push the barrel up the ramp." When I prompted her to explain this response, she continued, "Well, I guess the guy is doing work, or that's what we learned in physics. I don't know what that has to do with energy. But – yeah." She has a sense of how to identify when work is done and has an instinct that work is related to energy, but was unable to describe work as an energy transfer via a force.

Lillian was aware, however, that energy can be transferred between objects and transformed during phenomena. In the battery, light bulb, and switch scenario, Lillian explained that,

The battery has energy, electrical energy, and then it turns on the light bulb because the current goes through and the light bulb's like, "Light!" And then, that's light energy as well, and then the switch turns on and off the circuit so that the energy can travel, or the electrical energy can travel or not.

When I asked her whether chemical energy and light energy that she mentioned were related, she responded,

Well, they can cause each other I guess. Hmm. Well, electrical energy can be converted into light and heat energy, which the light bulb is also giving off. I'm not highly certain of how.

In this response, she indicated that chemical energy from the battery was converted into light energy, but she also mentioned that energy types cause each other. This idea of energy as a causal entity was common in her responses to other scenarios. In the chemical reaction scenario, she mentioned that "it takes energy to cause that reaction, to excite the atoms and molecules to do the funky reaction."

Later in the chemical reaction scenario, I asked Lillian to relate the amount of energy before, during, and after the reaction. After initially guessing that it would decrease, then that it would increase, she concluded,

Lillian: You know what, they're the same aren't they, before and after.  
Jeff Nordine: And why do you say that?  
Lillian: Energy conservation, but we didn't do it with chemicals.  
Jeff Nordine: What's energy conservation?  
Lillian: That they're the same before and after? And you can never totally get rid of energy, it just changes form.

It seems that Lillian loosely adhered to the ideas of energy transformation and conservation during her interview. During the scenario depicting a girl eating a meal, Lillian initially violated conservation by claiming that food gives the person energy, but does not have energy before she eats it. In this exchange, she struggles to reconcile this contradiction:

Jeff Nordine: Is there energy before we [digest the food]?  
Lillian: I'm sure the answer is yes, but I can't think of how, so I'll say no.  
Jeff Nordine: You were sure the answer is yes. Why do you have that

instinct?  
Lillian: Well, just because like, there's always potential for another type of energy, potential energy, like if the food is there and it can give you energy, then there must have been a potential for energy before that.

Lillian invoked the concept of potential energy in order to preserve her notion of energy conservation, but her description of potential energy as “a potential for energy” revealed a common misunderstanding of the term.

Although Lillian referred to several energy-related scientific concepts during her interview, she did not seem to fully understand or appreciate each of them. She seemed to feel constrained by her ideas of energy conservation, and to a lesser extent, transformation, but her most common references to energy treated it as something that was needed to cause an event or process.

*Case example of a physics student with a well developed conception: Rachel*

Rachel was one of five physics students who solely exhibited the transformation framework during her interview. She was among a group of physics students who were clearly very interested in physics and did physics-related reading on her own. In fact, at one point in her interview, she exclaimed, “That's electricity! I was just reading about that in this book.” In her responses to scenarios, Rachel frequently and correctly invoked the ideas of energy transfer, work, transformation, and conservation.

Unlike some other physics students who attempted to use the concept of work to explain the scenario depicting a man pushing a barrel up a ramp, Rachel correctly explained that, “work is transferring energy,” and “the amount of work done is the

change in energy.” Later, during the scenario depicting a girl eating a meal, Rachel again invoked the concept of work:

Rachel: To do anything, to move, to breathe, you have to do work, and you need energy to be able to do that.  
Jeff Nordine: What happens to the energy when you do work?  
Rachel: When you move, it gets converted into some other kind of energy. I guess it depends on what you’re doing.

I then prompted her to explain what it means for energy to be converted, to which she responded:

Well, energy has to conserve, so the total amount of all the energies at the beginning has to be equal to the total amount of all the energies at the end, but that doesn’t mean, say, that the kinetic energy has to equal the kinetic energy at the end.

This quote illustrates the stark contrast between Rachel’s conception of energy transformation and conservation and most other students. She not only seems to believe that the ideas of transformation and conservation are different sides of the same coin, but she also stresses that conservation does not apply to energy types individually, which was a common misconception among 8<sup>th</sup> grade science students.

Her nuanced understanding of energy is perhaps best summarized by her response when I asked whether there is energy before the reactants are mixed in a chemical reaction:

There’s energy in the system, you have to have something to like, with the heat, you have to have something that heats it...you’ve got energy everywhere. A change in the type of energy or a transfer of energy is really what makes people think of energy specifically. So, there’s no transfer of energy or change in the energy.

In this quote, Rachel demonstrated that she understands the heart of the energy concept: energy, while everywhere, really only becomes meaningful when it undergoes some transformation or transfer between systems.

### *Comparison of case examples across grade levels*

Without question, the most accurate and sophisticated conceptions of energy were demonstrated by physics students, yet so were some of the most poorly developed conceptions. While physics students like Rachel were capable of developing a deep understanding of energy transformation and conservation, others like Tanya struggled to understand energy as a unified concept and to see its relevance in all scenarios. This wide variation was present among chemistry students as well, although the well-developed chemistry conceptions were not nearly on the same level as the well-developed physics conceptions. On the other hand, 8<sup>th</sup> grade students and biology students generally had a more tightly constrained concept of energy, even though they may have demonstrated some lingering adherence to the activity or product frameworks.

Looking across students who demonstrated a well-developed conception relative to their grade level peers, Mabel (8<sup>th</sup> grade), Chadd (biology), and Rachel (physics) all seemed to have a conception that was mainly focused on the importance of energy transformation in scenarios, while Nikolas (chemistry) did not. Even though Nikolas invoked the transformation framework, he focused on energy transfer rather than transformation and consequently seemed to view energy as a causal entity, the mere presence of which could make something happen. While all students in this category seemed to have an appreciation for the quantitative conservation of energy, Mabel, Chadd, and Rachel demonstrated the best understanding of how the principles of transformation and conservation were related and how they constrain the behavior of systems.



Among student with low and moderately developed conceptions, it seems that age and additional science instruction did not necessarily lead to a more coherent conception of energy. While chemistry and physics students could more capably discuss the scientific terms and processes related to the scenarios, they did not tend to demonstrate a view of energy that was consistent from one scenario to the next or that was bound by the overarching principles of transformation and conservation. Missie (low chemistry), Frederick (moderate chemistry), and Tanya (low physics) seemed to have few reservations about claiming that processes create energy that wasn't there before or that energy may simply no longer exist when it is used. On the other hand, Taylor (low 8<sup>th</sup> grade), Kyle (moderate 8<sup>th</sup> grade), and Betty (low biology) seemed bound by some version of energy conservation, even though they did not fully understand the principle.

The major theme that emerges when comparing the case examples across grades is the variation that existed between classmates. While 8<sup>th</sup> grade and biology grade students seemed to be at different locations along the same road, chemistry and physics students seemed to be all over the map. Despite having more science instruction and being increasingly self-selected for an interest in science, students in chemistry and physics seemed far more widely varied in their understanding of energy transformation and conservation.

The interview case examples demonstrate that while the energy unit does not necessarily catapult students past their older peers, it seems to help all students develop a more coherent cognitive structure upon which they can build in the future.

*Cross-sectional results from the energy concept questionnaire*

The student interviews allowed me to look in-depth at the energy conceptions of a sample of 16 students per grade level, but they did not directly provide information about the non-interviewed students in the classes. The energy concept questionnaire allowed me to make an overall assessment of how closely the conceptions of students in each grade level aligned with experts conceptions. Table 5.11 shows the grade level means for each class.

**Table 5.11. Grade level means on the energy concept questionnaire**

	<b>N</b>	<b>Mean (SD)</b>
8th grade science	79	11.3 (1.9)
Biology	55	11.5 (2.2)
Chemistry	35	9.0 (2.5)
Physics	22	11.8 (2.9)
Total	191	11.0 (2.4)

A one-way ANOVA suggested non-random variation between groups,  $F(3,187) = 11.4$ ,  $p \leq .001$ . To determine the source of this non-random variation, I compared individual grade levels using orthogonal contrasts. These results are shown in Table 5.12.

**Table 5.12. Contrasts between grade levels on the energy concept questionnaire**

<b>Contrast</b>	<b>df</b>	<b>t-statistic</b>
8 <sup>th</sup> grade science vs. biology	187	-.657
8 <sup>th</sup> grade science vs. chemistry	187	4.94***
8 <sup>th</sup> grade science vs. physics	187	-.972
Biology vs. chemistry	187	5.17***
Biology vs. physics	187	-.471

\*\*\*  $p \leq .001$

\*\*  $p \leq .01$

\*  $p \leq .05$

~  $p \leq .1$

The ANOVA results indicate that 8<sup>th</sup> grade, biology, and physics students' scores were on par with each other, but that both 8<sup>th</sup> grade students and biology students outscored chemistry students, and these differences were strongly significant.

It is possible that the one-way ANOVA results conceal some relatively small difference between 8<sup>th</sup> grade students and physics students. The boxplots shown in Figure 5.9 reveal some left skew and the presence of a possible outlier in the physics distribution.

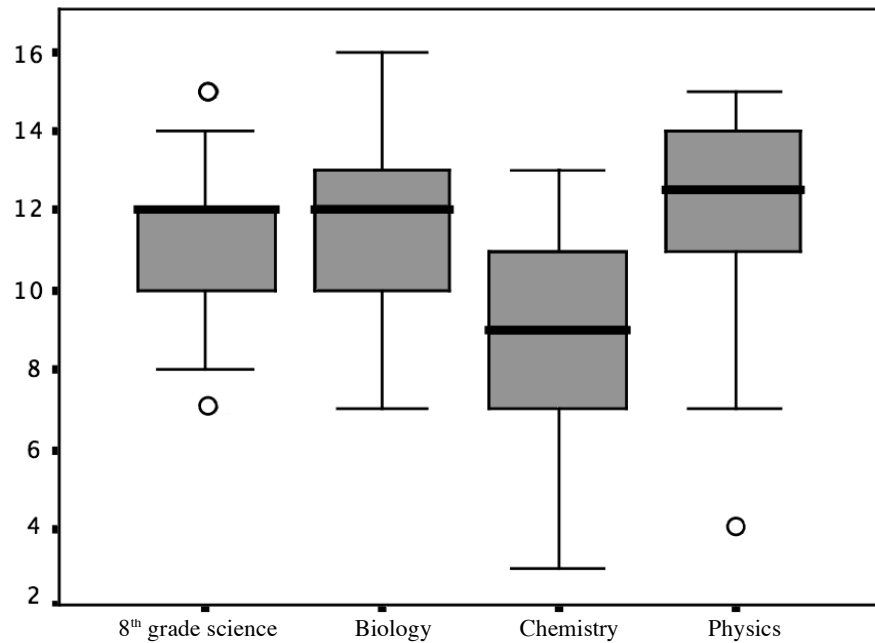


Figure 5.9. Boxplot showing the distribution of scores on the energy concept questionnaire, by grade level.

The distribution of physics scores suggests that there may be a small ceiling effect (although no physics students scored a perfect score of 16) and that the outlier may have had a disproportionate effect on the mean and standard deviation of the physics sample. If the outlier was excluded and the ANOVA recalculated, the contrast between 8<sup>th</sup> grade students and physics students approached significance,  $t(186) = -1.7, p \leq .1$ . I chose not to exclude the outlier from my analysis for two reasons. First, the student was part of the interview sample, and her energy concept questionnaire score was not out of line with her responses to interview scenarios, so it is unlikely that her low questionnaire score reflects measurement error. Second, excluding this score entirely would exert significant upward pressure on the mean by underrepresenting the group of low scoring physics students who clearly did not have well developed energy conceptions.

Despite the fact that there may have been small differences between groups that were not detected in the ANOVA results, the overall picture is quite clear. In terms of the degree to which students' responses to the energy concept questionnaire match up the experts, 8<sup>th</sup> grade students, biology students, and physics students were virtually the same. On the other hand, 8<sup>th</sup> grade students and biology students' mean scores were 26% and 28% higher, respectively, than the chemistry students.

Taken together, the student interview results and energy concept questionnaire results suggest that students who have participated in the energy unit get a leg up relative to their older peers in terms of developing a high quality energy conception more quickly than they otherwise would have.

While helping students develop a high quality energy conception was certainly a goal of the unit developers, the curriculum was primarily designed to address the middle school national standards and benchmarks dealing with energy. In the next section, I discuss the extent to which the energy unit was responsible for helping students demonstrate proficiency on the middle school energy benchmarks by comparing students' performance on the energy content questionnaire across grade levels.

#### **Performance on energy benchmark assessments (Research question 4)**

I conducted a one-way ANOVA with orthogonal contrasts to compare the performance of students across grade levels on the energy content questionnaire. Table 5.13 shows the mean score for each grade level.

**Table 5.13. Grade level means on the energy content questionnaire**

	<b>N</b>	<b>Mean (SD)</b>
8th grade science	77	9.4 (2.5)
Biology	55	10.3 (2.1)
Chemistry	35	8.6 (1.8)
Physics	29	11.2 (2.3)
Total	195	9.8 (2.4)

The differences in means were strongly significant ( $F(3,191) = 9.20, p \leq .001$ ).

While the overall results of the one-way ANOVA indicate that the variation between groups is non-random, it does not reveal the source of this variation. Using orthogonal contrasts enabled me to look for variation between specific grade levels. Table 5.14 shows these results.

**Table 5.14. Contrasts between grade levels on the energy content questionnaire**

<b>Contrast</b>	<b>df</b>	<b>t-statistic</b>
8 <sup>th</sup> grade science vs. biology	191	-2.39*
8 <sup>th</sup> grade science vs. chemistry	191	1.63
8 <sup>th</sup> grade science vs. physics	191	-3.86***
Biology vs. chemistry	191	3.49***
Biology vs. physics	191	-1.83~

\*\*\*  $p \leq .001$

\*\*  $p \leq .01$

\*  $p \leq .05$

~  $p \leq .1$

The ANOVA results indicate that 8<sup>th</sup> grade students were significantly outscored by biology students who took the energy unit the previous year, and by physics students who did not participate in the energy unit but had gone through a year of physics instruction.

The results also indicate that while 8<sup>th</sup> graders had a higher mean score than the 10<sup>th</sup> grade

chemistry students, this difference in means was not statistically significant. Besides outscoring the 8<sup>th</sup> grade science students who had recently completed the energy unit, biology students also outperformed the chemistry students who were a year older and who had studied an extra year of science. Biology students were outscored by physics students, and the difference in their means approached significance.

The ANOVA results suggest that 8<sup>th</sup> and 9<sup>th</sup> grade students who have participated in the energy unit are in a better position to succeed on assessments targeted the middle school energy benchmarks than are the older 10<sup>th</sup> grade chemistry students who did not participate in the energy unit. Physics students, who outperformed all groups, seem to be in the best position to succeed on benchmark assessments.

It is no surprise that physics students performed best on the energy concept questionnaire since they are the oldest, have had the most science instruction, and are likely the most self-selected for an interest in science. While it may be no surprise that physics students performed best on this measure, it is noteworthy that the 9<sup>th</sup> grade students outscored the 8<sup>th</sup> grade students. This result suggests that, rather than forgetting what they learned about energy during the 8<sup>th</sup> grade, 9<sup>th</sup> grade students may have been better prepared for future energy-related learning in their biology class. To test for this, I separated the energy content questionnaire into two scores: one for items which were targeted to physical science benchmarks and one for items which were targeted to life science benchmarks. I repeated the one-way ANOVA with the same orthogonal contrasts to look for differences between grade levels on physical science items and life science items. The results are shown in Tables 5.15 and 5.16.

**Table 5.15. Grade level means on physical science items and life science items from the energy content questionnaire**

	N	Mean for physical science items (SD)	Mean for life science items (SD)
8th grade science	77	6.6 (1.7)	2.8 (1.1)
Biology	55	7.1 (1.6)	3.2 (0.9)
Chemistry	35	5.8 (1.5)	2.8 (0.9)
Physics	29	7.9 (1.8)	3.4 (1.0)
Total	195	6.8 (1.8)	3.0 (1.0)

**Table 5.16. Contrasts between grade levels on physical science items and life science items from the energy content questionnaire**

Contrast	df	t-statistic for physical science items	t-statistic for life science items
8 <sup>th</sup> grade science vs. biology	191	-1.65	-2.60*
8 <sup>th</sup> grade science vs. chemistry	191	2.37*	-.320
8 <sup>th</sup> grade science vs. physics	191	-3.46***	-2.74**
Biology vs. chemistry	191	3.59***	2.11*
Biology vs. physics	191	-2.02*	-.749

\*\*\*  $p \leq .001$

\*\*  $p \leq .01$

\*  $p \leq .05$

~  $p \leq .1$

While biology students' mean score on physical science items was not significantly higher than 8<sup>th</sup> grade students, their mean score on life science items was significantly higher ( $p \leq .05$ ). Furthermore, biology students significantly outscored chemistry students on physical science items ( $p \leq .001$ ) and on life science items ( $p \leq .05$ ). Despite the fact that 10<sup>th</sup> grade students had taken virtually the same biology course as 9<sup>th</sup> grade students, they were outscored on energy-related life science items by the 9<sup>th</sup> grade students who had participated in the energy unit during their 8<sup>th</sup> grade year.



These results suggest that students who had gone through the energy unit learned about energy in their biology course more successfully than students who went through virtually the same biology class but did not participate in the energy unit. To investigate whether the differences between 8<sup>th</sup>, 9<sup>th</sup>, and 10<sup>th</sup> grade students were likely a result of preparation for future learning, I investigated several possible alternative explanations for these results.

The first alternative explanation is that the 9<sup>th</sup> graders simply learned more about energy when they participated in the energy unit than did the 8<sup>th</sup> graders. To test for this, I examined 8<sup>th</sup> and 9<sup>th</sup> grade students learning goals pretest and posttest scores in an effort to determine whether it was reasonable to assume that the two classes were equal at the end of the energy unit. I ran a one-way ANOVA to test for differences in 8<sup>th</sup> and 9<sup>th</sup> graders scores on the learning goals test, and the results of this ANOVA are shown in Table 5.17.

**Table 5.17. ANOVA results comparing the learning goals test scores of 8<sup>th</sup> grade students and 9<sup>th</sup> grade students.**

Measure	Mean (SD)		df	t-statistic
	8 <sup>th</sup> grade students	9 <sup>th</sup> grade students		
Learning goals pretest	15.2 (4.0)	13.8 (4.9)	129	1.81~
Learning goals posttest	27.0 (4.9)	27.8 (4.8)	130	.978
Gain	11.7 (4.8)	14.0 (5.8)	125	2.59*

\*\*\*  $p \leq .001$

\*\*  $p \leq .01$

\*  $p \leq .05$

~  $p \leq .1$

The results of this ANOVA indicate that there was likely a difference between students' prior knowledge at the beginning of the unit, but that there was no significant difference

between students' scores on the posttest. It is impossible to know for sure why students pretest scores are different, but it seems a likely result of the fact that Mrs. Nelson and Mrs. Geller began incorporating some of the ideas from the energy unit into the weather and life science units that came earlier in the curriculum. Because the 8<sup>th</sup> grade students had higher pretest scores than the 9<sup>th</sup> grade students, their gain scores are lower. While it may be true that 8<sup>th</sup> graders learned more about energy on their own or that 9<sup>th</sup> graders learned more successfully during their participation in the energy unit, the most plausible scenario is that the 8<sup>th</sup> and 9<sup>th</sup> graders did not have significantly different learning experiences during the energy unit and that there was no significant difference between 8<sup>th</sup> and 9<sup>th</sup> graders at the conclusion of the energy unit. As a result, it remains possible that the differences that I observed between 8<sup>th</sup> and 9<sup>th</sup> grade students on the energy content questionnaire were a result of 9<sup>th</sup> grade students learning more about energy during their biology class.

The second alternative explanation that I tested for was that the differences in test scores occurred because of a newly increased emphasis on energy during the biology course. In her interview, Mrs. Forest indicated that the biology curriculum remained largely the same during recent years, yet she mentioned that she may have used the term "transformation" more frequently. If the biology course did in fact emphasize energy more than it had in the past, then 9<sup>th</sup> graders who were new to Fairmeadows should have outscored 10<sup>th</sup> graders who enrolled at Fairmeadows at the beginning of their 9<sup>th</sup> grade year. While I do not know anything about these students' experiences prior to their enrollment, I can say for sure that they did not participate in the energy unit. If an increased emphasis on energy in the biology course was responsible 9<sup>th</sup> grade students

scoring higher than 10<sup>th</sup> grade students among students who have been at Fairmeadows since their 8<sup>th</sup> grade year, then I would expect to see the same effect for students who enrolled at Fairmeadows at the beginning of their 9<sup>th</sup> grade year. I used a one-way ANOVA with orthogonal contrasts to compare the scores of students who were new to Fairmeadows in their 9<sup>th</sup> grade year. Tables 5.18 and 5.19 show the results of the contrast between 9<sup>th</sup> and 10<sup>th</sup> grade students.

**Table 5.18. Grade level means on physical science items and life science items from the energy content questionnaire for students who were new to Fairmeadows in their 9<sup>th</sup> grade year.**

	N	Mean for physical science items (SD)	Mean for life science items (SD)	Total score
Biology	24	6.4	3.0	9.4
Chemistry	12	5.8	3.6	9.3
Physics	11	7.1	3.6	10.6
Total	47	6.5	3.3	9.7

**Table 5.19. Contrasts between grade levels on physical science items and life science items from the energy content questionnaire for students who were new to Fairmeadows in their 9<sup>th</sup> grade year.**

Contrast	df	t-statistic for physical science items	t-statistic for life science items	t-statistic for total score
Biology vs. chemistry	44	1.12	-1.83~	.110
Biology vs. physics	44	-1.10	-1.66	-1.57

\*\*\*  $p \leq .001$

\*\*  $p \leq .01$

\*  $p \leq .05$

~  $p \leq .1$

Unlike students who had participated in the energy unit, biology students who were new to Fairmeadows in the 9<sup>th</sup> grade did not outscore their 10<sup>th</sup> grade counterparts on the life

science items in the energy content questionnaire. This finding refutes the idea that students received more energy instruction in the biology course during the 2005-2006 school year than students received in previous years, and reinforces the assertion that participating in the energy unit prepares students for future learning about energy.

A third alternative explanation for why 9<sup>th</sup> graders who have gone through the energy unit have outscored 8<sup>th</sup> graders and 10<sup>th</sup> graders is that they simply have a higher academic aptitude. I tested for this to some extent when I compared learning goals test scores between 8<sup>th</sup> and 9<sup>th</sup> grade students and found that there was no significant difference in their posttest scores. Unfortunately, student-level data for large-scale standardized assessments were not available to me, so I could not compare students between grade levels on such measures. Therefore, it remains possible that students in 9<sup>th</sup> grade simply have a higher aptitude than their counterparts in 8<sup>th</sup> and 10<sup>th</sup> grade.

Although academic aptitude may be a confounding variable in my analyses, it is unlikely any difference between classes fully accounts for the variation I observed across all measures. My results suggest that participation in the energy unit helps Fairmeadows students to be better prepared than they otherwise would have been to succeed on distal assessments targeted at the energy-related benchmarks. Furthermore, evidence suggests that participation in the energy unit prepares students for future energy-related learning.

In the next chapter, I summarize all of the results from my study and tie them together to discuss how the energy unit seems to have promoted students' development of coherent conceptions of energy and preparation for future energy-related learning.

## **CHAPTER SIX**

### **DISCUSSION**

This study explores the effectiveness of a novel approach to middle school energy instruction in terms of its ability to promote students' development a coherent understanding of energy. This approach, which draws upon the guidelines of high quality curricula set forth by Kesidou and Roseman (2002), varies from typical energy instruction because it uses project-based pedagogy to emphasize the role of energy transformations in non-ideal phenomena that students are likely to encounter outside of school. I hypothesized that such a highly-contextualized approach organized around the central idea of transformation would help students to form coherent understandings of energy, that is, to form links between their scientific ideas and their intuitive ideas such that their ability to make sense of their experiences was improved (Linn & Eylon, 2000; National Research Council, 2007; Roseman & Linn, 2007).

I observed that participation in the energy unit had both an immediate effect of improving the coherence of students' energy conceptions and a long-term effect of preparing students for future energy-related learning. In this chapter, I summarize results suggesting that students developed more coherent conceptions of energy and that they were prepared for future energy-related learning, present a model to explain why coherent understandings may promote future learning, and discuss the features of our

energy curriculum that supported students' conceptual development and preparation for future learning. Finally, I outline the implications of this work for future middle school energy curriculum and instruction.

### **Summary of results**

To investigate the effectiveness of our approach, I tracked students' conceptual development during the unit, followed up with students one year after instruction, and compared energy unit participants to older non-participants in the same school in terms of their energy conceptions and ability to perform on distal assessment items targeted at the National Science Education Standards and Benchmarks for Science Literacy standards for energy.

I hypothesized that if students' ideas became more coherent as a result of instruction, this would be manifest in several ways: during instruction, 8<sup>th</sup> grade students would become more able to link their energy ideas to form consistent responses across a variety of interview scenarios, energy unit participants would be more likely to exhibit the transformation framework and less likely to exhibit alternative frameworks, and students would score higher on the energy concept questionnaire because it measured the degree to which students' responses aligned with expert responses.

Prior to instruction, I observed that 8<sup>th</sup> grade students' descriptions of the role of energy in interview scenarios were highly context dependent. This finding supports other studies which assert that students' initial ideas are not strongly linked (diSessa, 1993; Smith, *et al.*, 1993-1994) and refutes studies which suggest that students' uninstructed ideas are better described as naïve theories (Carey, 1985; McCloskey, 1983; McCloskey,

Caramazza, & Green, 1980; Vosniadou, 1994). Overall, 8<sup>th</sup> grade students interviewed prior to instruction classified less than 80% of scenarios as illustrative of energy and tended to exhibit different frameworks in different scenarios. As they progressed through the unit, students began to see the role of energy in more scenarios and their ideas seemed to become more connected as they reorganized their cognitive structures. Yet, not all reorganizations are productive (Clark, 2006), and 8<sup>th</sup> grade students almost uniformly moved toward the alternative activity/product frameworks in interview round two, indicating that the idea of energy as an obvious activity or as a product of an obvious activity was given higher cuing priority during lesson set one. This is not surprising, considering that students had learned a system of *factors* and *indicators* to identify when different types of energy were present or changing, but had not yet learned how to account for energy changes in terms of transformations. During interview round three, students moved dramatically toward the transformation framework, and this movement corresponds with students' participation in activities that emphasize tracking energy transformations in phenomena. After instruction, students' exhibition of the transformation framework had declined somewhat relative to round three, but their responses indicated a strong move toward coherent understanding during the unit. While students interviewed prior to instruction classified less than 80% of scenarios as illustrative of energy, they classified more than 97% of the scenarios in this way after instruction. Also, students' responses demonstrated much more consistency across scenarios. Kyle, the 8<sup>th</sup> grade student who demonstrated moderate conceptual development, was an excellent example of this. Prior to instruction, Kyle indicated that energy could be used up in some processes, created in others, that people gain energy by

“warming up”, and that energy was primarily useful for running electronic devices. After instruction, Kyle’s ideas were clearly more organized around the principles of transformation and conservation, although he seemed to continue to hold activity/product ideas with relatively high cuing priority.

The conceptual changes that I observed among 8<sup>th</sup> grade students reinforce the knowledge-in-pieces perspective of conceptual change. Students were clearly not constrained by individual frameworks, as they frequently constructed “hybrid” responses during interviews (such as indicating that energy types were conserved individually by going into a dormant state when their indicators were no longer active – a combination of the activity framework and the idea of conservation), displayed different frameworks in different scenarios, and seemed to reorganize their thinking by emphasizing and de-emphasizing certain ideas (such as transformation and energy as an obvious activity) throughout the course of instruction. In the end, 8<sup>th</sup> grade students’ displayed more conceptual coherence by moving substantially from a set of disconnected ideas about energy toward a understanding in which their ideas were more connected, which helped them to use their energy ideas to interpret a wider range of interview scenarios.

It is important from the perspective of coherence that students’ understandings were not merely more connected, but that they were more organized around the central principle of energy transformation. During instruction, the frequency with which 8<sup>th</sup> grade students exhibited alternative frameworks (non-transformation) decreased relative to the frequency with which they exhibited the transformation framework. Looking across grade levels (see Figure 5.8), students’ who had participated in the energy unit were more likely to exhibit the transformation framework relative to the likelihood that



they would exhibit an alternative framework. Conversely, the majority of non-participants did not exhibit the transformation framework and exhibited more alternative frameworks more frequently. These results suggest that the energy unit helps students to connect their ideas around the central principle of transformation by assigning it a higher cueing and reliability priority in a wider range of contexts. This productive rearrangement of ideas around the principle of transformation is a hallmark of a coherent conception (Linn & Eylon, 2000; National Research Council, 2007; Roseman & Linn, 2007).

As students develop more connected understandings that are organized around the big ideas of science, their understanding begins to resemble that of an expert (Chi *et al.*, 1981). In this study, I measured the correspondence between students' and experts' ideas with the energy concept questionnaire. These results indicate that students moved toward an expert understanding during instruction (see Table 5.6) and that students who had participated in the energy unit were much more likely than chemistry students, and about as likely as physics students, to have a energy conception that resembled that of an expert (see Table 5.14). Overall, results suggest that students' ideas about energy become more connected during instruction, that these connections are more organized around the idea of transformation, and that energy unit participants move toward conceptions that resemble expert conceptions of energy – three important manifestations of a coherent energy concept.

My results suggest that instruction can have a powerful effect on students' development of a coherent energy conception. Because younger students who had participated in the energy unit displayed conceptions that were more sophisticated, coherent, and applicable than older students, my results refute the claims of other studies

that students' acquisition of the energy concept is primarily mediated by maturational factors (Liu & McKeough, 2005; Warren, 1986). Instead, my results confirm studies which assert that instruction plays a crucial role in students' concept acquisition (Klahr & Nigam, 2004; Linn, Lee, Tinker, Husic, & Chiu, 2006; Smith, Maclin, Houghton, & Hennessey, 2000; White & Frederiksen, 1998). My results extend the findings of these studies by demonstrating that instruction can have a lasting positive effect well after the conclusion of the instructional intervention. This result echoes that of Linn and Eylon (2000), who found that students with coherent understandings of displaced volume continued to develop more predictive views after instruction. Besides developing a more coherent concept of energy during instruction, energy unit participants continued to learn productively about energy in the year after their participation in the energy unit had ended.

Results from the energy content questionnaire indicate that the energy unit helped to prepare students for future energy-related learning in their biology course (see Table 5.16). On this measure, 9<sup>th</sup> grade energy unit participants who took the unit one year earlier significantly outscored the 8<sup>th</sup> graders who had just completed the unit, despite the fact that their learning goals posttest scores at the end of instruction were not significantly different. Furthermore, 9<sup>th</sup> graders scored significantly higher on life science questions than 8<sup>th</sup> graders, but not significantly higher on physical science questions, suggesting that differences on the energy content questionnaire were largely due to 9<sup>th</sup> graders' energy-related learning in their 9<sup>th</sup> grade biology course. This additional energy-related learning was not simply an effect of the biology course, because 10<sup>th</sup> graders who had taken a nearly identical biology course were also significantly outscored by 9<sup>th</sup> graders on

the energy-related life science items (and physical science items as well). Finally, among 9<sup>th</sup> and 10<sup>th</sup> graders who joined Fairmeadows at the beginning of 9<sup>th</sup> grade, the 10<sup>th</sup> graders significantly outscored their 9<sup>th</sup> grade counterparts, which suggests that the additional energy learning benefit of 9<sup>th</sup> grade biology existed only for students who had previously participated in the energy unit.

diSessa and Wagner (2005) provide a model that sheds light on why students' participation in the energy unit had the effect of preparing students for future energy-related learning. They argue that future learning is mediated by the extent to which learners' existing ideas are coherent. Because energy unit participants had more coherent understandings of energy, they were better prepared than non-participants to learn about energy in their 9<sup>th</sup> grade biology course. In the next section, I elaborate diSessa and Wagner's model to explain the mechanism by which coherent understandings operate to prepare students for future learning.

### **Coherent understanding and preparation for future learning**

When people use information learned at one time in one context to reason about new situations at a later time, this is known as *transfer of learning* (Royer, Mestre, & Dufresne, 2005). Bransford and Schwartz (1999) argue for the consideration of a type of transfer that they call *preparation for future learning* (PFL), which focuses on the impact of previous learning on people's ability to continue learning in knowledge-rich environments. Unlike the notion that children can be generally prepared for "learning to learn" (Brown & Kane, 1988), the PFL perspective refers to the relationship between learning in specific content areas and existing prior knowledge.

diSessa and Wagner's (2005) model explains why coherent understandings are likely to promote learners' preparation for future learning. They describe learners' conceptual understandings as *coordination classes* of connected ideas, which function as lenses through which learners can view new information and situations in a way that is consistent with a particular concept. If learners possess a coherent understanding of a scientific concept, then they are capable of using this prior knowledge to discriminate new information, choose what is relevant, and to understand the new context within the framework of their existing cognitive structure. This process is different from the Piagetian notion of *assimilation* (Piaget & Inhelder, 1971), because the PFL perspective emphasizes the role of learners in thinking critically about what they already know in order to formulate appropriate questions to improve their learning (Bransford & Schwartz, 1999).

diSessa and Wagner note that naïve ideas often lack *span* (applicability in different contexts) and *alignment* (the ability to use information reliably across different contexts), while coherent understandings have more span and alignment, which makes them more useful for making sense of new information encountered in new situations (diSessa & Wagner, 2005). Learners will always activate their prior knowledge when they encounter new situations (Brooks & Brooks, 1993; diSessa, 1993; McCloskey, 1983; von Glaserfeld, 1998), but when they possess more coherent understandings, they are more likely to be successful choosing which knowledge to activate and using it to reason about new information.

Schwartz, Bransford and Sears (2005) suggest that the nature of instructional interventions play a large part in determining whether students are prepared for future

learning. An important feature of instruction that effectively prepares students for future learning is that it encourages them to grapple with their ideas across many meaningful contexts. When learners activate their prior knowledge to reason in a variety of contexts, they are more likely to transfer their knowledge to new situations (National Research Council, 1999; Schwartz & Bransford, 1998; Schwartz et al., 2005). By focusing on the energy transformations that occur in a wide variety of everyday phenomena, our unit promoted the type of coherent understanding that served as the foundation for students' future energy-related learning. In the next section, I discuss the specific features of the energy unit that supported students' development of coherent conceptions and preparation for future learning.

### **How does the energy unit promote coherence and future learning?**

To support coherent understanding of science concepts, Roseman and Linn (2007) suggest that curriculum should be organized around big ideas, should connect with students' experiences, and should encourage student reflection and metacognition. To address these design principles, we used project-based pedagogy to organize instruction in the energy unit around the driving question, "How can I use trash to power my stereo?" This question was chosen because it met the characteristics of a good driving question outlined by Krajcik, Czerniak, and Berger (2003), but more specifically, because it is most sensibly answered using the idea of energy transformation. By using a project-based approach with a driving question that necessitated the study of energy transformation, we were able to organize instruction within a real-world context and around the big idea of transformation. Furthermore, we were able to encourage students'

reflection and metacognition by asking them to use their understanding of energy transformation to iteratively complete the design project and city energy plans. The conceptual development and content knowledge gains that students made during the unit echoed the results of other studies that suggest that project-based pedagogy is an effective way to foster students' ability to interpret and explain real-world phenomena and to understand scientific concepts (Blumenfeld et al., 1991; Geier et al., in press; Kuhn & Reiser, 2005; Marx et al., 2004; McNeill et al., 2006).

It is not project-based pedagogy alone that contributed to the differences between energy unit participants and non-participants at Fairmeadows, because the 8<sup>th</sup> grade science curriculum consisted entirely of project-based units before the energy unit was introduced. Differences, therefore, must be due to features of smaller grain size than the overall instructional model. These specific design choices relevant to the particular topic of energy were critical in giving students the tools they would need to develop and refine their ideas and to connect these ideas to their out-of-school experiences.

Prior to the introduction of the energy unit, 8<sup>th</sup> grade science consisted of a year of energy-themed instruction, but the design of this instruction was different from the energy unit in two important ways. First, energy types were treated largely independently of each other without emphasizing the importance of energy transformations. Prior to the introduction of the energy unit, the 8<sup>th</sup> grade curriculum included the following units: "Where do plants get their energy?" that focused on photosynthesis and green plants, "Where do you get all of your energy?" that focused on digestion and respiration, and "How can you hear what I'm saying?" that focused on sound energy. While each of these units was designed to help students learn about

energy, none of them included a specific focus on the role of energy transformations in phenomena. As a result, students were not encouraged to link their ideas across units to consider how sound energy may be related to a plant's energy. Without making this link, students' intuitive and instructed ideas are unlikely to be connected within a coherent framework. It seems, therefore, that the energy unit's emphasis on using energy transformations to predict and explain phenomena is part of the reason why energy unit participants were more likely to display a coherent, transformation-based energy concept than non-participants.

A second important difference between the energy unit and the instruction that preceded it is a focus on everyday, easily observable phenomena. Although previous instruction focused on phenomena that were central to students' lives such as digestion, photosynthesis, and hearing, these phenomena are very difficult for students to interact with and manipulate. On the other hand, energy unit participants study phenomena that are ubiquitous in students' lives and easy to interact with, such as toasters, glow sticks, low-energy firecrackers, and personal music devices. By focusing on phenomena that are real-world, easily observable, and non-idealized, the in-class activities serve as models for how students can use energy concepts to make sense of their everyday experiences, which helps them to connect between their intuitive and instructed knowledge (diSessa, 2000; Kesidou & Roseman, 2002).

A focus on everyday phenomena would not have been productive, however, were it not for the systems of factors and indicators developed within the unit. While a fully quantitative approach would not be practical for interpreting everyday phenomena because students would become overwhelmed with detail, the factor and indicator system

provided students with a semi-quantitative tool for recognizing when certain energy types were involved in phenomena and whether their magnitude was increasing or decreasing. Equipped with this tool, students could empirically investigate the idea of energy transformation (as students notice that an increase in one energy type must always be accompanied by the decrease of another, and vice versa) and make sense out of a wide range of familiar contexts while maintaining a focus on the importance of transformations without getting lost in the details of calculation.

A major function of the energy unit is to increase the explanatory power of students' energy concept by providing them with appropriate conceptual tools and modeling the use of energy for making sense of everyday phenomena. Students' ability to use scientific ideas to make sense of their experiences is an indication of coherent understanding (National Research Council, 2007; Roseman & Linn, 2007), and the results of this study suggest that students who participated in the energy unit were more capable of using their knowledge of energy to make sense of the everyday situations depicted in the interview scenarios.

My results indicate that students' coherent understanding has both an immediate effect of enhancing students' ability to make sense of new situations and a lasting positive effect on their future learning about energy. While my study was not specifically intended as a study of students' preparation for future learning, this is an important result because students' future learning happened in an authentic rather than an experimentally contrived context. The energy unit promotes students' preparation for future learning by continuously encouraging them to use their existing understanding of energy and its transformation to make sense of a variety of relevant phenomena. During instruction,



this process leads to a more coherent energy concept, and after instruction, students are able to use their coherent energy concept to interpret the new information they encounter in biology within the lens of their existing knowledge. Compared to students with a set of disconnected ideas about energy, students with coherent understandings are much more likely to learn new information effectively. It seems that participation in the energy unit had both a short-term effect of promoting more coherent conceptions of energy and a long-term effect of preparing students for future energy-related learning.

### **Implications**

In this study, I used a cross-sectional design to investigate the impact of a novel, standards-based, energy curriculum on students' energy concept and content knowledge. The results, therefore, have implications for the appropriateness of the standards upon which the curriculum was based and the design of future middle school energy curricula.

We developed the energy unit using a learning-goals driven approach that was intended to address the energy standards in the Benchmarks for Science Literacy (American Association for the Advancement of Science, 1993) and National Science Education Standards (National Research Council, 1995), which advocate middle school energy curricula that are phenomena-rich and focused on the importance of energy transformations. As such, the results of my study provide empirical evidence that this focus is appropriate and useful for middle school students.

Contrary to those who suggest that young students cannot develop rich understandings of energy (Liu & McKeough, 2005; Warren, 1986), my study affirms that the learning trajectory recommended by the national standards documents can promote

meaningful understandings of energy in middle school students that many adults never acquire. This result echoes those of other studies that suggest that contextualized instruction plays a major role in developing sophisticated conceptual understandings even in younger students (Blumenfeld et al., 1991; Klahr & Nigam, 2004; Linn, Lee, Tinker, Husic, & Chiu, 2006; Smith, Maclin, Houghton, & Hennessey, 2000; White & Frederiksen, 1998).

Of course, simply focusing on energy transformations or contextualizing instruction through project-based pedagogy is not enough. Besides its focus on energy transformations in everyday phenomena, our unit is different from traditional middle school instruction in two important ways: it uses a qualitative approach to analysis of systems, and it does not provide students with an operational “definition” for energy.

While traditional approaches often focus students attention on performing simple calculations of energy quantities (e.g., work, kinetic energy, gravitational potential energy), such an emphasis necessarily limits the range of phenomena that students are equipped to understand and risks burying the central ideas of energy in detail (Kesidou & Roseman, 2002). In our approach, students are never asked to calculate a numerical value for energy. Instead, our system of factors and indicators provides students with a qualitative tool that is useful for tracing transformation by identifying which energy types are involved and how their magnitudes are changing. Equipped with this tool, students can interpret and explain the behavior of everyday systems without becoming overwhelmed with the details of calculation. Our approach is not intended to suggest that rigorous calculations of energy are unimportant; rather, such calculations are best left for later. This is in line with the learning progression described in the most recent *Atlas for*

*Science Literacy* (American Association for the Advancement of Science, 2007) which recommends that middle school students focus on energy transformation and high school students focus on its quantitative conservation.

Another important between traditional approaches and our unit is that traditional approaches tend to begin by offering a simple “definition” for energy, such as the ability to do work or to cause a change, but our curriculum offered no such definition. While this difference seems somewhat cosmetic, it reflects a fundamental difference between our approach and the traditional approach. In our unit, we focus on using the scientific idea of energy to predict and explain the behavior of phenomena that students are likely to encounter. Rather than focusing on what energy is, the unit focuses on using the concept of energy to predict and explain phenomena. As Richard Feynman noted, “...in physics today, we have no knowledge of what energy *is*. It is just an abstract thing that always comes out with the same numerical value, without telling us anything about a *mechanism* or a *reason*” (Feynman, Leighton, and Sands, 1989). In other words, the value of energy lies not in what it is, but in how it can be used to interpret the behavior of systems. While this is generally true for any scientific idea, focusing students’ attention on the behavior of systems rather than the nature of energy has the added educational benefit of grounding the unit more firmly within students’ experiences, thereby helping them access their intuitive ideas about energy and to connect them with new instructed ideas into a more explanatory conceptual framework (Clark, 2006; diSessa, 1993, 2000; diSessa & Sherin, 1998).

The results of this study suggest that future middle school energy curriculum will more effectively promote a coherent understanding of energy if it focuses students’

attention on using the idea of energy transformation to interpret and explain everyday phenomena. Because energy is a central unifying concept in science, students with a more coherent conception of energy are well positioned for future science learning (National Research Council, 1999) – an effect that I saw in this study. With a coherent conception of energy that promotes future science learning and enhances their understanding of everyday phenomena, students are much better positioned to address the energy-related challenges facing our world, both as scientists working to develop new technologies and as citizens capable of making more informed decisions.

## **APPENDIX A: BENCHMARKS AND STANDARDS ADDRESSED BY THE ENERGY UNIT**

### **Benchmarks for Science Literacy (BSL)**

- Energy cannot be created or destroyed, but only changed from one type into another. (4E/M1)
- Most of what goes on in the universe—from exploding stars and biological growth to the operation of machines and the motion of people—involves some type of energy being transformed into another. Energy in the form of heat is almost always one of the products of an energy transformation. (4E/M2)
- Energy appears in different types. (4E/M4)
- Energy can change from one type to another, although in the process some energy is always converted to heat. (8C/M1)
- Electrical energy can be produced from a variety of energy sources and can be transformed into almost any other type of energy. Moreover, electricity is used to distribute energy quickly and conveniently to distant locations. (8C/M4)
- Plants use the energy in light to make sugars out of carbon dioxide and water. This food can be used immediately for fuel or materials or it may be stored for later use. Organisms that eat plants break down the plant structures to produce the materials and energy they need to survive. Then they are consumed by other organisms. (5E/M1)
- Energy can change from one type to another in living things. Animals get energy from oxidizing their food, releasing some of its energy as heat. Almost all food energy comes originally from sunlight. (5E/M3)

- The amount of food energy (calories) a person requires varies with body weight, age, sex, activity level, and natural body efficiency. Regular exercise is important to maintain a healthy heart/lung system, good muscle tone, and bone strength. (6E/M1)
- Different ways of obtaining, transforming, and distributing energy have different environmental consequences. (8C/M2)
- Energy from the sun (and the wind and water energy derived from it) is available indefinitely. Because the flow of energy is weak and variable, very large collection systems are needed. Other sources don't renew or renew only slowly. (8C/M5)
- Different parts of the world have different amounts and kinds of energy resources to use and use them for different purposes. (8C/M6)
- In many instances, manufacturing and other technological activities are performed at a site close to an energy source. Some types of energy are transported easily, others are not. (8C/M3)
- Thinking about things as systems means looking for how every part relates to others. The output from one part of a system (which can include material, energy, or information) can become the input to other parts. (11A/M2)

## **National Science Education Standards (NSES)**

- Energy is a property of many substances and is associated with heat, light, electricity, mechanical motion, sound, and the nature of a chemical. Energy is transformed in many ways. (Physical Science - Standard B3.1)
- In most chemical reactions, energy is transferred into or out of a system. Heat, light, mechanical motion, or electricity might all be involved in such transfers (Physical Science-Standard B3.4)
- Electrical circuits provide a means of transforming electrical energy when heat, light, sound, and chemical changes are produced. (Physical Science -Standard B3.3)
- For ecosystems, the major source of energy is sunlight. Energy entering ecosystems as sunlight is transformed by producers into chemical energy through photosynthesis. That energy then passes from organism to organism in food webs. (Life Science -Standard C4.3)

**APPENDIX B: LEARNING GOALS TEST**

**Name:** \_\_\_\_\_ **Class Hour:** \_\_\_\_\_

**Teacher's Name:** \_\_\_\_\_ **Date:** \_\_\_\_\_

This questionnaire consists of both multiple-choice and short-answer questions. Multiple-choice questions have 4 possible answers, marked A to D. Closely read all the answers and circle the letter of the correct answer.

**Example:**

Which of the following is a liquid at room temperature?

A) Iron

B) Salt

C) Sugar

D) Water

On short-answer questions, write your response in the space provided.

1. Watch what happens as your teacher places a strip of magnesium in acid. Then, watch the phenomenon again, this time in a video recording.

a. What types of energy are involved in the phenomenon?

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b. For each type of energy you listed in part a, explain how you know that type of energy is involved.

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c. Which types of energy are increasing in the phenomenon? Which types of energy are decreasing in the phenomenon?

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d. For each increasing type of energy you listed in part c, explain how you know that it is increasing. For each decreasing type of energy you listed in part c, explain how you know that it is decreasing.

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e. Draw an energy-transformation diagram for the phenomenon.

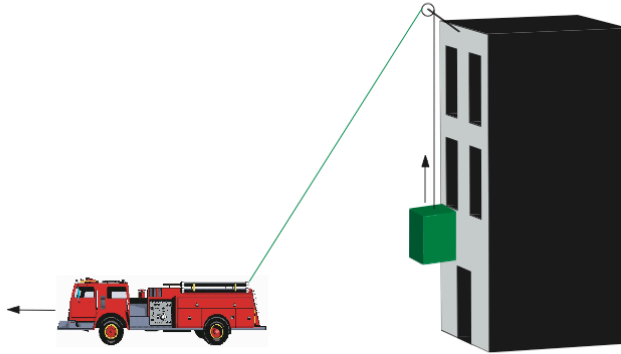
2. Think about whether each phenomenon shown below involves the transformation of gravitational energy. Check box next to the correct answer.

Rolling a heavy ball on a table to hit a spring



Does this process involve the transformation of gravitational energy?  yes  no

Using a truck and a pulley to lift a heavy crate.



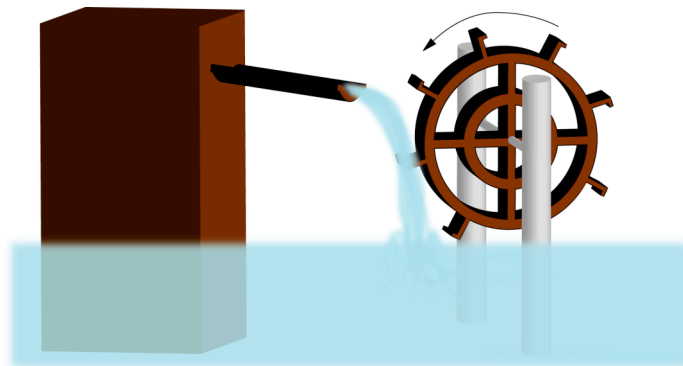
Does this process involve the transformation of gravitational energy?  yes  no

A raw egg falling from a table



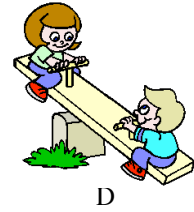
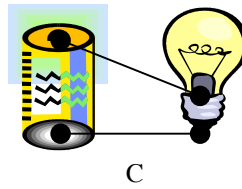
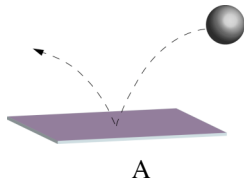
Does this process involve the transformation of gravitational energy?  yes  no

Using water to turn a waterwheel



Does this process involve the transformation of gravitational energy?  yes

3. Consider four different phenomena: A) a ball bouncing on the floor; B) a candle burning; C) a lit light bulb connected to a battery; and D) two children playing on a see-saw.

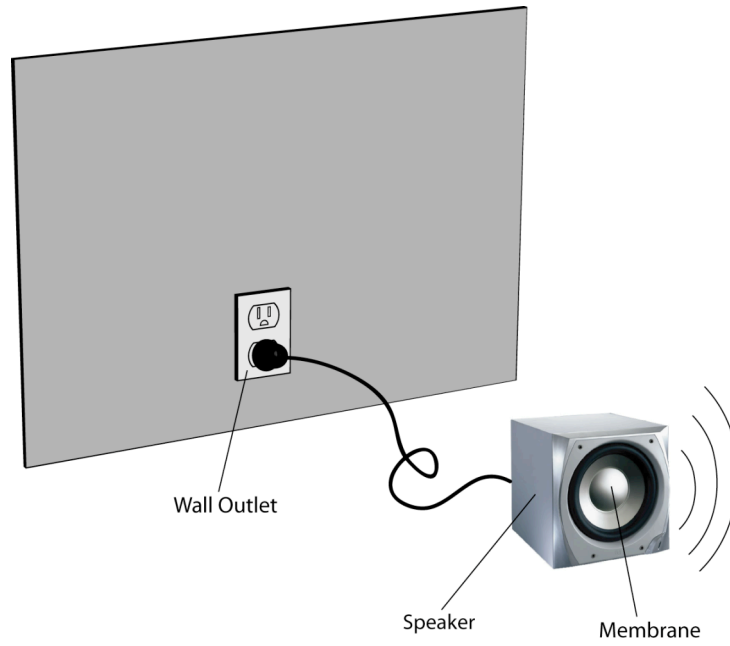


The table below lists several types of energy transformations. In the box under each type of energy transformation, write the letter of each phenomenon that involves that type energy transformation.

**There may be more than letter in each box, and each letter may appear in more than one box.**

Kinetic $\rightarrow$ Gravitational	Chemical $\rightarrow$ Light	Chemical $\rightarrow$ Kinetic	Electrical $\rightarrow$ Thermal	Chemical $\rightarrow$ Thermal

4.



The following diagram is the energy-transformation diagram for the speaker shown above. There are mistakes in this diagram.



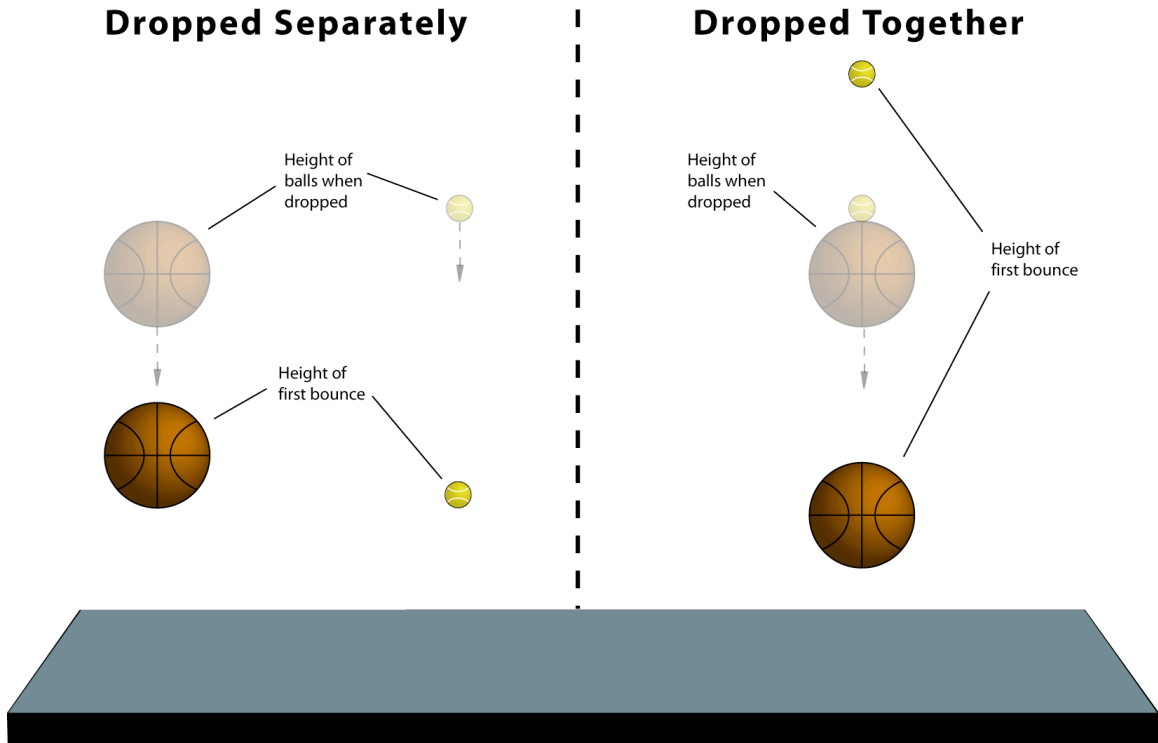
Redraw the energy-transformation diagram so that it is correct.

5. An inventor claims that the battery she has invented can generate electricity without ever needing to be recharged or replaced. Which of the following is the best explanation for why the inventor's claim cannot be true?
- A) When electricity is generated, thermal energy is produced, so batteries must put out more energy than is put into them.
  - B) The Earth has a limited number of energy resources, so energy can never be generated endlessly.
  - C) Batteries transform chemical energy into electrical energy, and this chemical energy must eventually run out.
  - D) Electricity contains more energy than the type of energy used to generate it, so all batteries must eventually die out.

6.

When a ball is dropped, it tends to bounce lower with each bounce. A scientist has proven that this is not the case! By dropping a tennis ball on top of a basketball, the tennis ball bounces higher than the height from which it was dropped. The scientist claims that energy is produced in this phenomenon.

Watch your teacher demonstrate this phenomenon and examine the picture below.



Is the scientist correct? Explain why it is correct or why it is not correct to say that energy is produced in this phenomenon.

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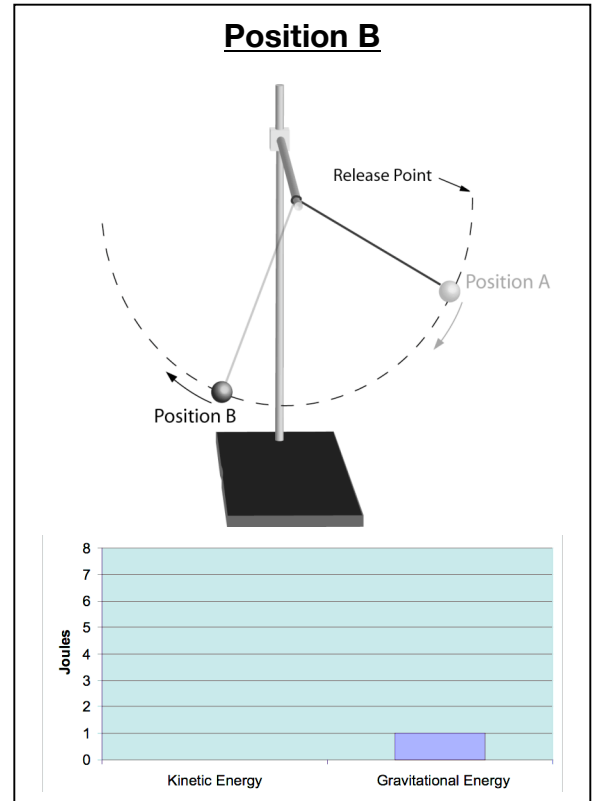
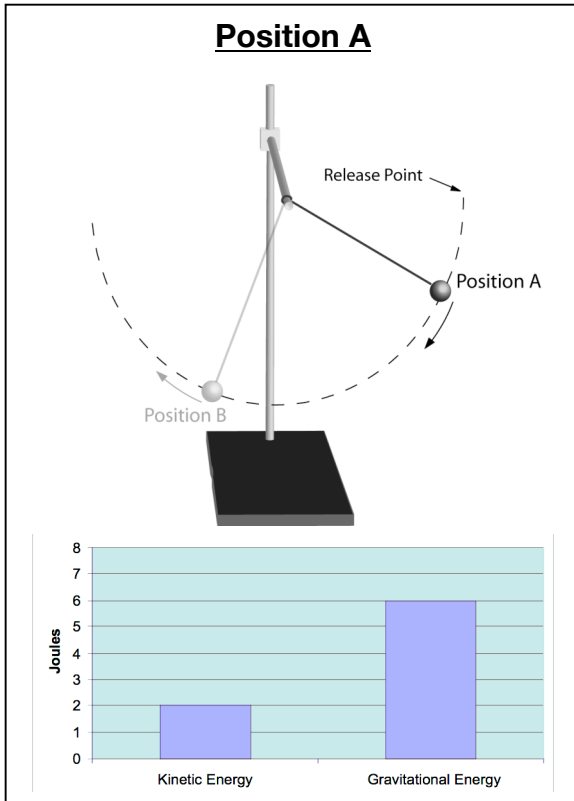
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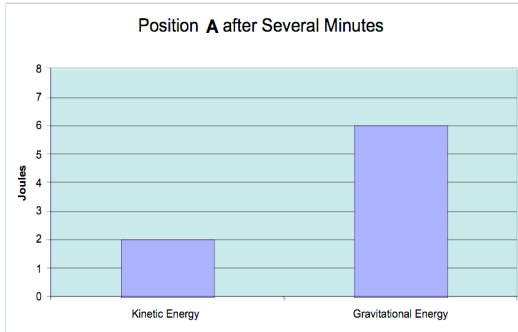
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7. A pendulum is released and allowed to swing freely. The graphs below show the kinetic and gravitational energy of the pendulum as it swings through position A and position B for the first time. *The kinetic energy bar in the graph of position B has not been drawn yet.*

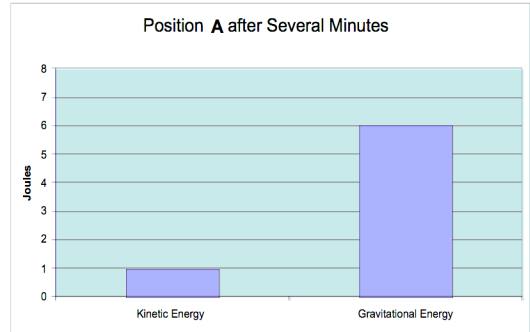


- How does the gravitational energy in position A compare to the gravitational energy in position B?
  - It is greater at position A than position B
  - It is greater at position B than position A
  - It is the same at both positions
  - There is no gravitational energy at either position.
- The pendulum's gravitational energy increases as:
  - The pendulum swings downward.
  - The pendulum swings faster.
  - The pendulum's mass decreases.
  - The pendulum swings upward.
- Draw the missing kinetic energy bar on the graph for position B shown above.

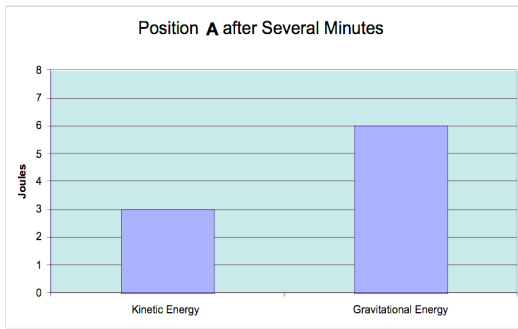
- d. After swinging back and forth for several minutes the pendulum once again moves through position A. Which one of the following graphs correctly shows the kinetic and gravitational energies the pendulum has after several minutes? Circle the letter of the correct graph.



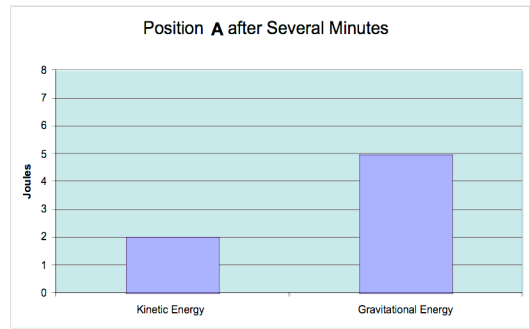
A



B



C



D

- e. Explain why the graph you chose correctly shows the kinetic and gravitational energies of the pendulum at position A after a few minutes.

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8. In order to move, your body uses chemical energy. Where does this energy come from?
- A) Gravity
  - B) Light
  - C) Air
  - D) Water
9. Which of the following sets of energy resources are renewable?
- A) Natural gas, nuclear, wind
  - B) Nuclear, wind, solar
  - C) Wind, solar, hydroelectric
  - D) Solar, hydroelectric, natural gas
10. Identify one energy resource that is not practical for use in Michigan and explain why.

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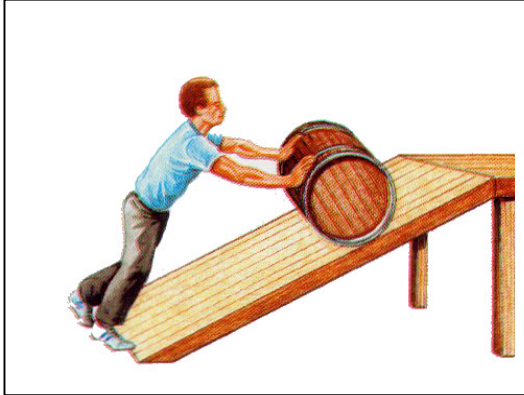
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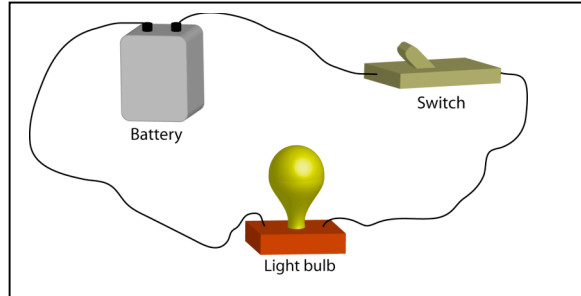
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## APPENDIX C: INTERVIEW SCENARIOS

8<sup>th</sup> Grade Round 1 & 4; 9<sup>th</sup>, 10<sup>th</sup>, and 11<sup>th</sup> Grade



Pushing a barrel up a ramp



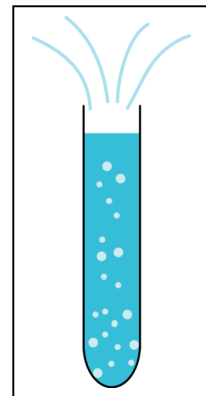
Battery, light bulb, and switch



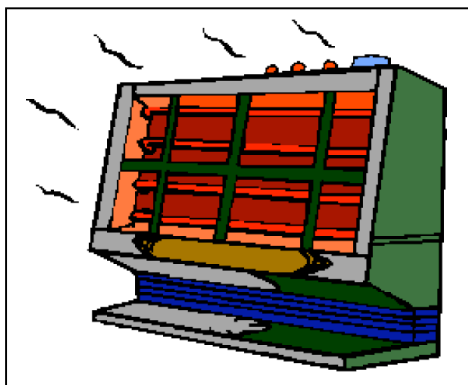
Eating a meal



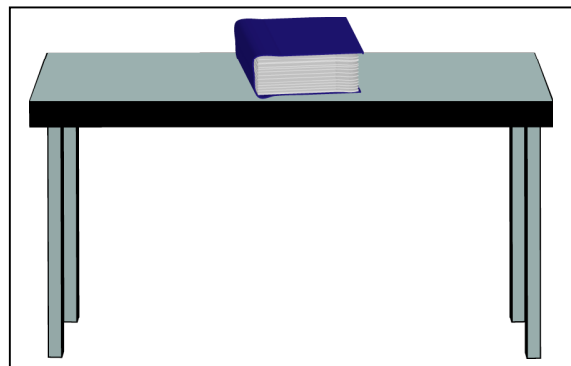
Melting ice



Chemical Reaction

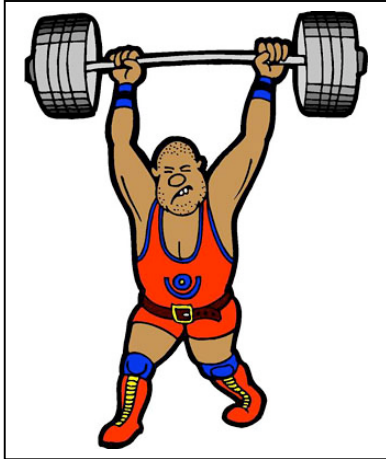


Heater

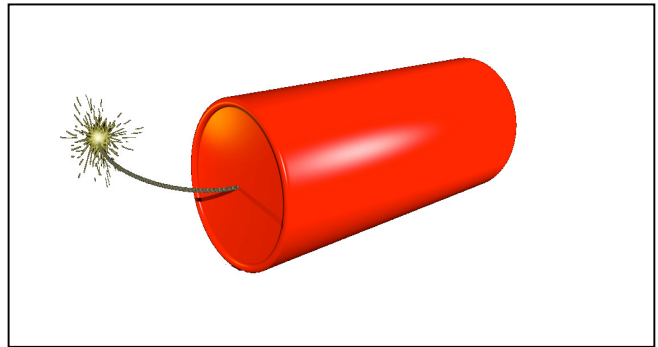


Book sitting on a table

8<sup>th</sup> Grade Round 2



Person holding a weight



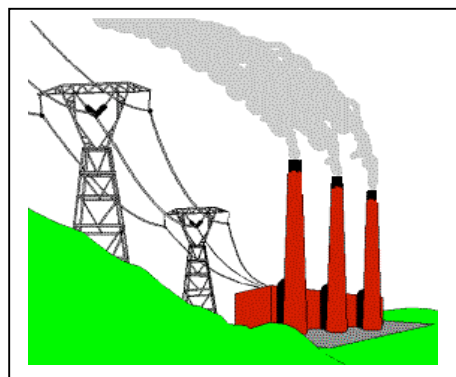
Firecracker



Train

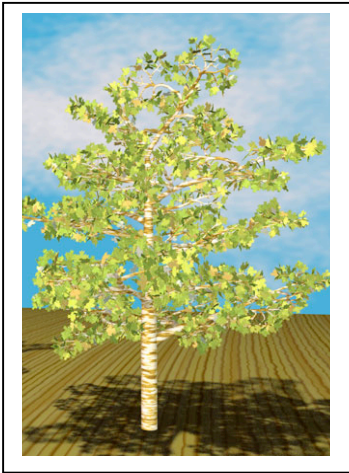


Glass of ice water



Power Station

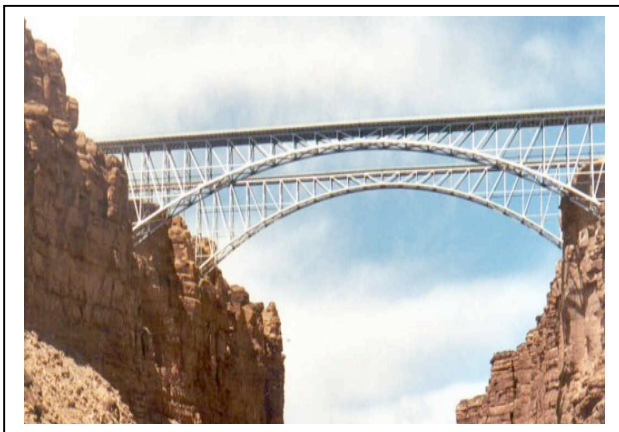
8<sup>th</sup> Grade Round 3



Growing Tree



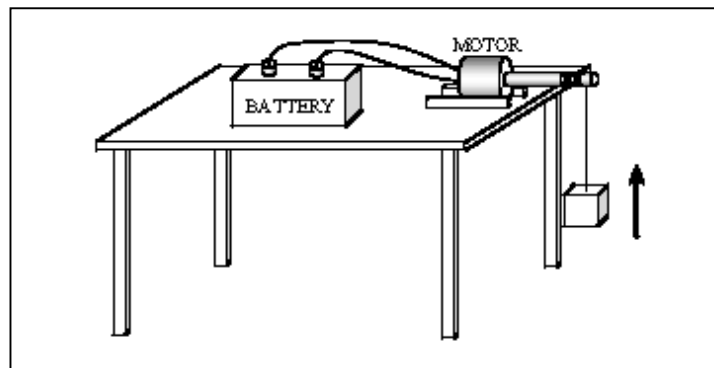
Solar Car



Bridge



Icicle



Electric motor lifting a block

## APPENDIX D: ENERGY CONCEPT QUESTIONNAIRE

NOTE: Items with an asterisk received over 80% consensus among expert respondents.

### Energy Questionnaire

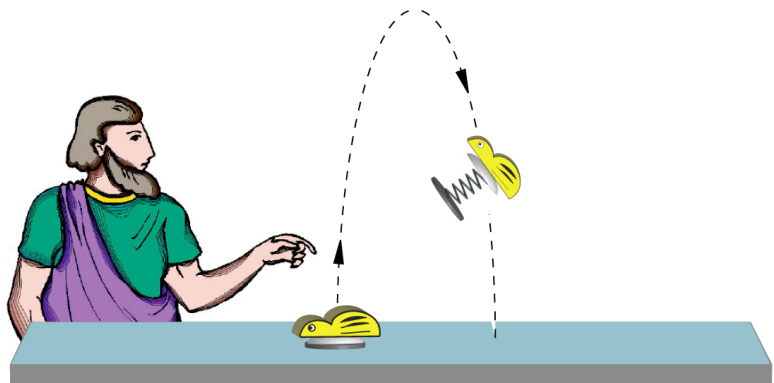
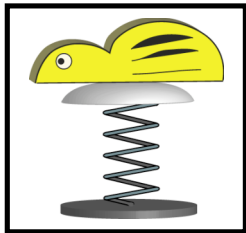
Name: \_\_\_\_\_ Class Hour: \_\_\_\_\_

Teacher's Name: \_\_\_\_\_ Date: \_\_\_\_\_

There are no right or wrong answers to this questionnaire, and it will not be graded.

Please record your ideas for the questions below.

The picture below shows a toy “jumping bug”. A person compresses the spring so that the suction cup sticks to the base of the toy, then places the jumping bug on a table. After a short time, the suction cups come apart and the bug pops into the air and falls back on the table.



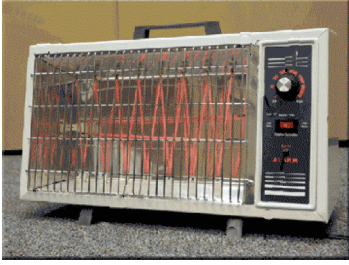
For the following statements, check the appropriate box.

- \* 1. When the bug's spring is compressed, but before it pops up, the toy has energy.  
 Agree     Disagree     Not sure     Don't understand
- \* 2. When it's moving, after the spring is uncoiled, the toy has energy.  
 Agree     Disagree     Not sure     Don't understand
- \* 3. At the top of its flight, when it is moving neither moving up nor down, the toy has no energy.  
 Agree     Disagree     Not sure     Don't understand
- 4. The toy's energy remains the same throughout its flight.  
 Agree     Disagree     Not sure     Don't understand

CONTINUE



The picture below shows an electric heater that is plugged into the wall. The heater is switched on and the bars are glowing.



**For the following statements, check the appropriate box.**

- \* 5. The energy from the power station which supplies this heater did not exist before it was generated at the station.

Agree    Disagree    Not sure    Don't understand

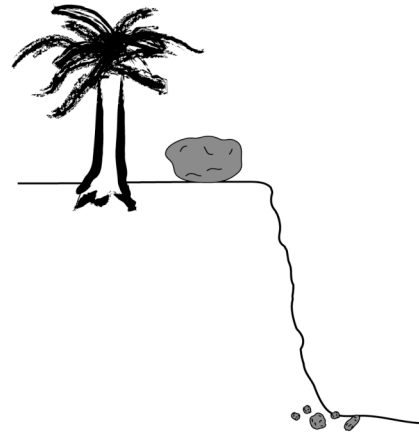
6. Only some of the energy from the heater goes into heating up the room

Agree    Disagree    Not sure    Don't understand

- \* 7. The energy from the heater goes into the room and disappears.

Agree    Disagree    Not sure    Don't understand

The picture to the right shows a rock lying next to a tree near the edge of a cliff. The land beneath the rock erodes away until the rock is right at the edge of the cliff. Further erosion causes it to fall down the cliff.



**For each of the following statements, check the appropriate box.**

- \* 8. Since it can't do anything, the stationary rock initially doesn't have energy.

Agree    Disagree    Not sure    Don't understand

- \* 9. The rock has no energy because it is not a living thing.

Agree    Disagree    Not sure    Don't understand

- \* 10. The rock has energy when it's passed the point of balance and starts to fall.

Agree    Disagree    Not sure    Don't understand

- \* 11. As the rock falls its energy increases.

Agree    Disagree    Not sure    Don't understand

CONTINUE



The picture below shows a soccer player who has kicked a ball that is rolling along the ground.



**For each of the following statements, check the appropriate box.**

12. The energy of the ball rolling is the same energy from the food that the soccer player ate earlier.

Agree  Disagree  Not sure  Don't understand

\* 13. After she runs for a while to warm up, the player has more energy.

Agree  Disagree  Not sure  Don't understand

The picture to the right shows a pair of fresh batteries that are connected with wires to a light bulb. The circuit stays connected until the bulb starts to dim and eventually goes out when the batteries are dead.



**For each of the following statements, check the appropriate box.**

14. In this circuit, the battery has the energy and the light bulbs use the energy until it is gone.

Agree  Disagree  Not sure  Don't understand

\* 15. The energy leaves the battery from one terminal, travels through the wires to the light bulb, and returns to the other terminal.

Agree  Disagree  Not sure  Don't understand

\* 16. After the battery is dead, all of its energy has been used by the light bulb and no longer exists.

Agree  Disagree  Not sure  Don't understand

\* 17. After the battery is dead, the energy that was originally in the battery still exists somewhere.

Agree  Disagree  Not sure  Don't understand

\* 18. The amount of energy in the battery, wires, and bulb remain the same because energy is conserved.

Agree  Disagree  Not sure  Don't understand

**CONTINUE**



**For each of the following questions, please check all of the statements with which you agree**

\* 19. What happens to the electrical energy used to operate a toaster after the toaster is finished toasting?

It still exists in the toast and toaster, around the toaster, and in the air.

It is returned to the electric company.

It is consumed by the toast.

It gradually disappears until none of it remains anywhere.

It disappears immediately after the toaster is turned off.

20. A balloon is inflated with a mixture of natural gas and air. A burning match is touched to the balloon, and the mixture explodes. The energy released by the explosion

was originally in the natural gas and air.

came from the match.

was not originally in the natural gas and air but was produced in the reaction between the natural gas and air.

was originally in only the natural gas.



\* 21. A puck sitting on level ice is pushed back against a spring that is attached to a wall. This partially compresses the spring. The puck is released, and the spring propels it. If you have only this spring, but a variety of different pucks, how could another puck be given more energy?

Use a puck with less mass.

Use a puck with more mass.

Compress the spring more.





22. A living tree in its environment

- does not possess energy.
- possesses energy that it has received from the sun.
- possesses energy that it has made as well as energy it has received from the sun.
- possesses only energy that it has made.
- possesses energy from the sun and the energy of its life force.

23. A dead tree in its environment

- does not possess energy.
- possesses energy that it has received from the sun.
- possesses energy that it has made as well as energy it has received from the sun.
- possesses energy that it has made.
- possesses energy from the sun and still a little energy from its life force.

## APPENDIX E: ENERGY CONTENT QUESTIONNAIRE

NOTE: The Benchmark(s) to which each item is targeted is given in parentheses at the end of each item stem.

### Energy Questions

Name: \_\_\_\_\_

Class Hour: \_\_\_\_\_

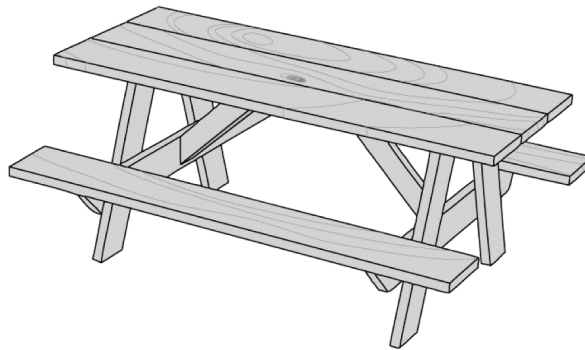
Teacher's Name: \_\_\_\_\_

Date: \_\_\_\_\_

Please answer the following questions to the best of your ability. Your responses will not affect your grade in any way.

**For each of the following questions, please circle the letter of the best answer**

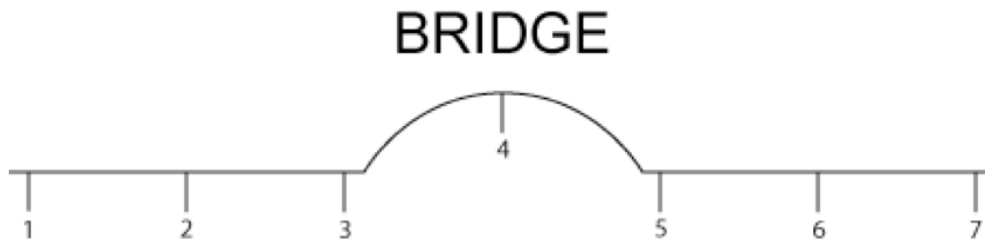
1. A table is made from wood. The wood comes from a tree. From where did the tree originally get the energy to make the wood? (5E/M1:c)



- A. From minerals in the soil.  
B. From water in the ground.  
C. From carbon dioxide in the air.  
D. From sunlight.
2. A student began a swimming workout by diving straight down into the pool from a 5-meter-high board. At which point in the dive did the student have the most kinetic energy? (4E/M4:b)
- E. At the top of the ladder prior to the dive.  
F. Just after the dive began.  
G. In the middle of the dive  
H. Just prior to entering the water.

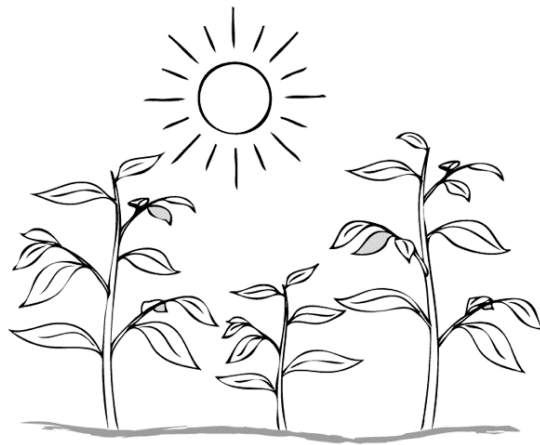


3. The picture shows a side view of a bike path. The path is flat from point 1 to point 3, goes over a small bridge from point 3 to point 5, and then is flat from point 5 to point 7.



Alfredo and his friends rode their bikes on the path. They pedaled as fast as they could from point 1 to point 2, and then they stopped pedaling and coasted to a stop at point 7. They noticed that they were going faster at point 5 than at point 4. Why?  
(4E/M4:b,d,f,g)

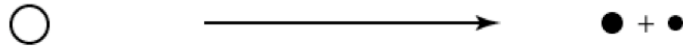
- A. Because their kinetic energy at point 4 changed to thermal energy at point 5.  
B. Because their chemical energy at point 4 changed to mechanical energy at point 5.  
C. Because their gravitational energy at point 4 changed to kinetic energy at point 5.  
D. Because their kinetic energy at point 4 changed to mechanical energy at point 5.
4. What happens to the energy from sunlight that shines on plants? (5E/M1:c)



- A. Some of the energy is changed into matter.  
B. Some of the energy is turned into chemical energy in the sugars.  
C. All the energy from sunlight is turned into heat when the sugars are made.  
D. All the energy from sunlight is used up while making sugars.

**CONTINUE** 

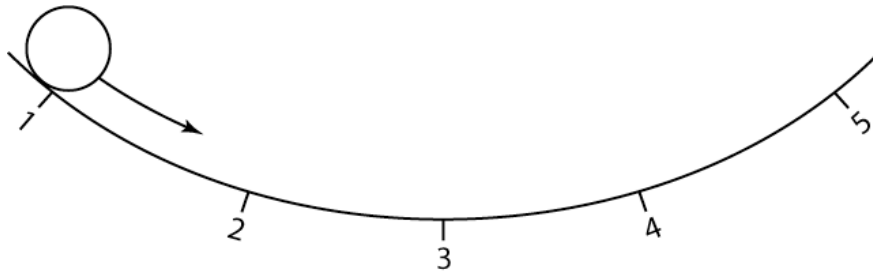
5. Refer to the following diagram:



Note:  $\bigcirc$ ,  $\bullet$  and  $\bullet$  represent different types of atoms.

The energy changes associated with the diagram are explained by the theories of (4E/H6a)

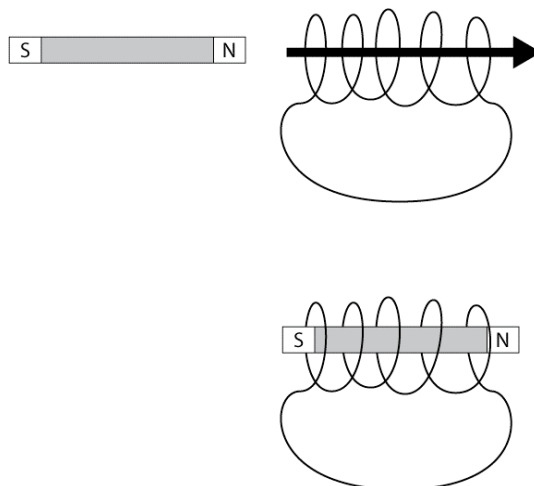
- A. Einstein
  - B. Kepler
  - C. Newton
  - D. Galileo
6. Windmills are used to convert wind energy into a more useable form. In most cases, there are three steps in this process. The energy is in a different form at each step. Which is the most likely order of the forms of energy? (4E/M2a; 4E/M4g,h)
- A. wind energy --> mechanical energy --> electrical energy
  - B. wind energy --> mechanical energy --> solar energy
  - C. wind energy --> solar energy --> electrical energy
  - D. wind energy --> thermal energy --> mechanical energy
7. The illustration below shows the path of a ball, starting from rest, as it rolls down and then up a curved track.



Which of the following statements is true? (4E/M4:b,d)

- A. As the ball moves, the kinetic energy stays the same, and the gravitational energy stays the same.
- B. As the ball moves, the kinetic energy changes, and the gravitational energy stays the same.
- C. As the ball moves, the kinetic energy stays the same, and the gravitational energy changes.
- D. As the ball moves, the kinetic energy changes, and the gravitational energy changes.





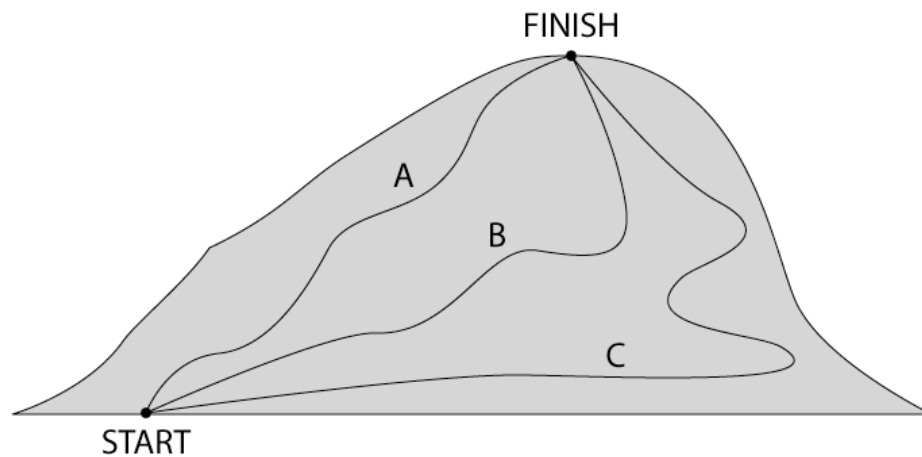
8. Which of these forms of energy can be produced by moving the magnet through the coil of wire? (4E/H6a; 4E/M4f,h)
- A. Nuclear energy
  - B. Electrical energy
  - C. Light energy
  - D. Chemical energy
9. A student said that animals get energy from the plants and animals they eat. Is the student correct? (5E/M3:b)
- A. Yes, because animals change what they eat completely into energy.
  - B. Yes, because animals break down their food and use some of the released energy.
  - C. No, because animals do not get energy from the animals they eat.
  - D. No, because water is the source of energy for animals.
10. Most of the chemical energy of the gasoline burned in a car is not used to move the car but is changed into (4E/M2a; 4E/M4b,f,g)
- A. electrical energy
  - B. thermal energy
  - C. nuclear energy
  - D. gravitational energy



11. Electrical energy is used to power a lamp. Select the correct statement. (4E/M4a,h; 4E/M2a)

- A. The amount of light energy produced by the lamp is more than the amount of electrical energy used by the lamp.
- B. The amount of light energy produced by the lamp is less than the amount of electrical energy used by the lamp.
- C. The amount of light energy produced by the lamp is the same as the amount of electrical energy used by the lamp.

12. Use the diagram below to answer the question.



Paths A, B, and C go from the bottom of a mountain to the top. A person going from the bottom to the top along which path would gain the most gravitational energy? (4E/M4d)

- A. Path A
- B. Path B
- C. Path C
- D. The gain is the same for paths A, B, and C.

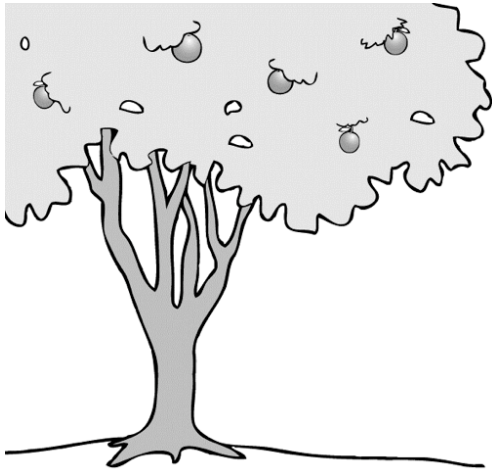
13. Which of these best shows a change from solar energy to chemical energy? (4E/M4c,f)

- A. Nuclear changes in Sun
- B. Heating of pavement
- C. Photosynthesis in leaves
- D. Formation of rainbows

CONTINUE



14. What is the source of chemical energy in the sugars in an orange? (5E/M1:c)



- A. Light from the Sun.
- B. Minerals from the soil.
- C. Water from the soil.
- D. Sugars do not have chemical energy.

## APPENDIX F: SCORING RUBRIC FOR LEARNING GOALS TEST

Note:

1. Student responses mentioned in the coding tables given below are only indicative and not normative. Responses similar (i.e. differently expressed but having similar underlying idea) to those given as examples in coding tables need to be included in the same coding categories.
2. While 1 point should be given for every correct element to a question, 1 point should be taken away for every incorrect element. If all the correct elements are present PLUS a red element, the student does not receive more than the maximum. Thus, for example in the first question, if a student answers:
  - a. Chemical, kinetic, and sound, they get 3 points. If they answer
  - b. Chemical, kinetic, sound, and thermal, they still get 3 points. If they answer
  - c. Chemical and kinetic, they get 2 points, but if they answer
  - d. Chemical, kinetic, and thermal they get 3 points.
  - e. If they answer Chemical, kinetic, and elastic (an erroneous element) they get 2 -1 = 1 point.
3. Ignore Q1e.
4. Q6. is of 4 points – 1 point for energy conservation, 1 for energy transfer, 1 for lower height of basketball, and 1 for saying that scientist was not correct.
5. Q7e has two points – one for KE and the other for PE.

1. Watch what happens as your teacher places a strip of magnesium in acid. Then, watch the phenomenon again, this time in a video recording.

1a. What types of energy are involved in the phenomenon?

Sample Correct Response: Chemical, kinetic, sound, light, **thermal**. (4 points – 1 each for the first four)

*Coding:*

<i>Student Response</i>	<i>Code</i>	<i>Points</i>
<i>Complete correct response</i>	<i>CR</i>	<i>4</i>
<i>Mentions chemical energy only</i>	<i>C</i>	<i>1</i>
<i>Mentions kinetic energy only</i>	<i>K</i>	<i>1</i>
<i>Mentions sound energy only</i>	<i>S</i>	<i>1</i>
<i>Mentions light energy only</i>	<i>L</i>	<i>1</i>
<i>Mentions thermal energy only</i>	<i>T</i>	<i>1</i>
<i>Mentions chemical and some other incorrect/irrelevant energy</i>	<i>CI</i>	<i>0</i>
<i>Mentions kinetic and some other incorrect/irrelevant energy</i>	<i>KI</i>	<i>0</i>
<i>Mentions sound and some other incorrect/irrelevant energy</i>	<i>SI</i>	<i>0</i>
<i>Mentions light and some other incorrect/irrelevant energy</i>	<i>LI</i>	<i>0</i>
<i>Mentions thermal and some other incorrect/irrelevant energy</i>	<i>TI</i>	<i>0</i>



<i>Mentions chemical and two other incorrect/irrelevant energies</i>	<i>CII</i>	<i>-1</i>
<i>Mentions kinetic and two other incorrect/ irrelevant energies</i>	<i>KII</i>	<i>-1</i>
<i>Mentions sound and two other incorrect/ irrelevant energies</i>	<i>SII</i>	<i>-1</i>
<i>Mentions light and two other incorrect/irrelevant energies</i>	<i>LII</i>	<i>-1</i>
<i>Mentions thermal and two other incorrect/irrelevant energies</i>	<i>TII</i>	<i>-1</i>
<i>Mention chemical and kinetic energies</i>	<i>CK</i>	<i>2</i>
<i>Mention chemical and sound energies</i>	<i>CS</i>	<i>2</i>
<i>Mention chemical and light energies</i>	<i>CL</i>	<i>2</i>
<i>Mention chemical and thermal energies</i>	<i>CT</i>	<i>2</i>
<i>Mention light and thermal energies</i>	<i>LT</i>	<i>2</i>
<i>Mention C, K and S</i>	<i>CKS</i>	<i>3</i>
<i>Similarly other correct (but incomplete) responses are to be coded</i>	<i>---</i>	<i>3</i>
<i>Other Response/Incorrect Response</i>	<i>IR</i>	<i>-1 (for each incorrect response.)</i>
<i>No Response/ Don't know</i>	<i>NR</i>	<i>0</i>

1b. For each type of energy you listed in part a, explain how you know that type of energy is involved.

Sample Correct Response:

Chemical – the strip of Magnesium disappears

Kinetic – the strip moves around in the acid

Sound – there is a fizzing noise

Light – emission of light

**Thermal – the system heats up** (4 points – 1 each for each correct explanation; if student explains thermal energy, then see note above)

*Coding:*

<i>Student Response</i>	<i>Code</i>	<i>Points</i>
<i>Complete correct response</i>	<i>CR</i>	<i>4</i>
<i>Correctly explains chemical energy only</i>	<i>C</i>	<i>1</i>
<i>Correctly explains kinetic energy only</i>	<i>K</i>	<i>1</i>
<i>Correctly explains sound energy only</i>	<i>S</i>	<i>1</i>
<i>Correctly explains light energy only</i>	<i>L</i>	<i>1</i>
<i>Correctly explains thermal energy only</i>	<i>T</i>	<i>1</i>
<i>Incorrectly explains chemical energy only</i>	<i>~C</i>	<i>-1</i>
<i>Incorrectly explains kinetic energy only</i>	<i>~K</i>	<i>-1</i>
<i>Incorrectly explains sound energy only</i>	<i>~S</i>	<i>-1</i>
<i>Incorrectly explains light energy only</i>	<i>~L</i>	<i>-1</i>
<i>Incorrectly explains thermal energy only</i>	<i>~T</i>	<i>0</i>
<i>Correctly explains chemical energy, but also includes an explanation of some other irreverent energy.</i>	<i>CI</i>	<i>0</i>
<i>Correctly explains kinetic energy, but also includes an explanation of some other irreverent energy.</i>	<i>KI</i>	<i>0</i>
<i>Correctly explains sound energy, but also includes an explanation of some other irreverent energy.</i>	<i>SI</i>	<i>0</i>
<i>Correctly explains light energy, but also includes an explanation of some other irreverent energy.</i>	<i>LI</i>	<i>0</i>
<i>Correctly explains thermal energy, but also includes an explanation of some other irreverent energy.</i>	<i>TI</i>	<i>0</i>
<i>Correctly explains chemical and two other incorrect/irrelevant energies</i>	<i>CII</i>	<i>-1</i>
<i>Correctly explains kinetic and two other incorrect/ irrelevant energies</i>	<i>KII</i>	<i>-1</i>
<i>Correctly explains sound and two other incorrect/ irrelevant energies</i>	<i>SII</i>	<i>-1</i>
<i>Correctly explains light and two other incorrect/irrelevant energies</i>	<i>LII</i>	<i>-1</i>
<i>Correctly explains thermal and two other incorrect/irrelevant energies</i>	<i>TII</i>	<i>-1</i>
<i>Correctly explains chemical and kinetic energies</i>	<i>CK</i>	<i>2</i>
<i>Correctly explains chemical and sound energies</i>	<i>CS</i>	<i>2</i>
<i>Correctly explains chemical and light energies</i>	<i>CL</i>	<i>2</i>
<i>Correctly explains chemical and thermal energies</i>	<i>CT</i>	<i>2</i>
<i>Correctly explains light and thermal energies</i>	<i>LT</i>	<i>2</i>
<i>Incorrectly explains chemical energy, but also includes an explanation of some other irreverent energy.</i>	<i>~CI</i>	<i>-2</i>
<i>Incorrectly explains kinetic energy, but also includes an explanation of some other irreverent energy.</i>	<i>~KI</i>	<i>-2</i>
<i>Incorrectly explains sound energy, but also includes an explanation of some other irreverent</i>	<i>~SI</i>	<i>-2</i>

<i>energy.</i>		
<i>Incorrectly explains light energy, but also includes an explanation of some other irreverent energy.</i>	<i>~LI</i>	<i>-2</i>
<i>Incorrectly explains thermal energy, but also includes an explanation of some other irreverent energy.</i>	<i>~TI</i>	<i>-2</i>
<i>Correctly explains C, K and S</i>	<i>CKS</i>	<i>3</i>
<i>Similarly other correct (but incomplete) responses are to be coded</i>	<i>---</i>	<i>3</i>
<i>Correctly explains chemical energy but errs in explaining kinetic energy</i>	<i>C~K</i>	<i>0</i>
<i>Correctly explains chemical and kinetic energy but errs in explaining sound energy</i>	<i>CK~S</i>	<i>2-1=1</i>
<i>Similarly other partially incorrect responses are to be coded</i>	<i>--~</i>	<i>2-1=1</i>
<i>Correctly explains C, K and S, but errs in explaining L</i>	<i>CKS~L</i>	<i>2</i>
<i>Correctly explains C, K and L, but errs in explaining S</i>	<i>CK~SL</i>	<i>2</i>
<i>Correctly explains C, S and L, but errs in explaining K</i>	<i>C~KSL</i>	<i>2</i>
<i>Correctly explains K, S and L, but errs in explaining C</i>	<i>~CKSL</i>	<i>2</i>
<i>Correctly explains C, S and L, but errs in explaining T</i>	<i>CSL~T</i>	<i>3</i>
<i>Correctly explains C, S and T, but errs in explaining L</i>	<i>CS~LT</i>	<i>2</i>
<i>Correctly explains C, L and T, but errs in explaining S</i>	<i>C~SLT</i>	<i>2</i>
<i>Correctly explains S, L and T, but errs in explaining C</i>	<i>~CSLT</i>	<i>2</i>
<i>Correctly explains C, and K, but errs in explaining S and L</i>	<i>CK~S~L</i>	<i>0</i>
<i>Correctly explains C, and L, but errs in explaining K and S</i>	<i>C~K~SL</i>	<i>0</i>
<i>Correctly explains C, and S, but errs in explaining K and L</i>	<i>C~K~SL</i>	<i>0</i>
<i>Correctly explains S, and L, but errs in explaining C and K</i>	<i>~C~KSL</i>	<i>0</i>
<i>Correctly explains K, and L, but errs in explaining C and S</i>	<i>~CK~SL</i>	<i>0</i>
<i>Correctly explains K, and S, but errs in explaining C and L</i>	<i>~CKS~L</i>	<i>0</i>
<i>Other Response/Incorrect Response</i>	<i>IR</i>	<i>-1 (for each incorrect response.)</i>

1c. Which types of energy are increasing in the phenomenon? Which types of energy are decreasing in the phenomenon?

Sample Correct Response:

Chemical energy decreases.

Light energy increases and then decreases.

Sound energy increases and then decreases.

Kinetic energy both increases and decreases.

Thermal energy increases. (3 points – 1 point each for correct explanation of chemical, light and sound energy; for kinetic and thermal energy see the note above).

*Coding:*

<i>Student Response</i>	<i>Code</i>	<i>Points</i>
<i>Complete correct response</i>	<i>CR</i>	<i>4</i>
<i>Correctly explains chemical energy only</i>	<i>C</i>	<i>1</i>
<i>Correctly explains kinetic energy only</i>	<i>K</i>	<i>1</i>
<i>Correctly explains sound energy only</i>	<i>S</i>	<i>1</i>
<i>Correctly explains light energy only</i>	<i>L</i>	<i>1</i>
<i>Correctly explains thermal energy only</i>	<i>T</i>	<i>1</i>
<i>Correctly explains chemical and kinetic energies</i>	<i>CK</i>	<i>2</i>
<i>Correctly explains chemical and sound energies</i>	<i>CS</i>	<i>2</i>
<i>Correctly explains chemical and light energies</i>	<i>CL</i>	<i>2</i>
<i>Correctly explains chemical and thermal energies</i>	<i>CT</i>	<i>2</i>
<i>Correctly explains light and thermal energies</i>	<i>LT</i>	<i>2</i>
<i>Correctly explains C, K and S</i>	<i>CKS</i>	<i>3</i>
<i>Correctly explains chemical energy, but also includes an explanation of some other irreverent energy.</i>	<i>CI</i>	<i>0</i>
<i>Correctly explains kinetic energy, but also includes an explanation of some other irreverent energy.</i>	<i>KI</i>	<i>0</i>
<i>Correctly explains sound energy, but also includes an explanation of some other irreverent energy.</i>	<i>SI</i>	<i>0</i>
<i>Correctly explains light energy, but also includes an explanation of some other irreverent energy.</i>	<i>LI</i>	<i>0</i>
<i>Correctly explains thermal energy, but also includes an explanation of some other irreverent energy.</i>	<i>TI</i>	<i>0</i>
<i>Correctly explains chemical and two other incorrect/irrelevant energies</i>	<i>CII</i>	<i>-1</i>
<i>Correctly explains kinetic and two other incorrect/ irrelevant energies</i>	<i>KII</i>	<i>-1</i>
<i>Correctly explains sound and two other incorrect/ irrelevant energies</i>	<i>SII</i>	<i>-1</i>
<i>Correctly explains light and two other</i>	<i>LII</i>	<i>-1</i>

<i>incorrect/irrelevant energies</i>		
<i>Correctly explains thermal and two other incorrect/irrelevant energies</i>	<i>TII</i>	<i>-1</i>
<i>Incorrectly explains kinetic energy, but also includes an explanation of some other irreverent energy.</i>	<i>~KI</i>	<i>-2</i>
<i>Incorrectly explains sound energy, but also includes an explanation of some other irreverent energy.</i>	<i>~SI</i>	<i>-2</i>
<i>Incorrectly explains light energy, but also includes an explanation of some other irreverent energy.</i>	<i>~LI</i>	<i>-2</i>
<i>Incorrectly explains thermal energy, but also includes an explanation of some other irreverent energy.</i>	<i>~TI</i>	<i>-2</i>
<i>Correctly explains chemical energy but errs in explaining kinetic energy</i>	<i>C~K</i>	<i>0</i>
<i>Correctly explains chemical and kinetic energy but errs in explaining sound energy</i>	<i>CK~S</i>	<i>2-1=1</i>
<i>Similarly other partially incorrect responses are to be coded</i>	<i>--~_</i>	<i>2-1=1</i>
<i>Correctly explains C, K and S, but errs in explaining L</i>	<i>CKS~L</i>	<i>2</i>
<i>Correctly explains C, K and L, but errs in explaining S</i>	<i>CK~SL</i>	<i>2</i>
<i>Correctly explains C, S and L, but errs in explaining K</i>	<i>C~KSL</i>	<i>2</i>
<i>Correctly explains K, S and L, but errs in explaining C</i>	<i>~CKSL</i>	<i>2</i>
<i>Correctly explains C, S and L, but errs in explaining T</i>	<i>CSL~T</i>	<i>3</i>
<i>Correctly explains C, S and T, but errs in explaining L</i>	<i>CS~LT</i>	<i>2</i>
<i>Correctly explains C, L and T, but errs in explaining S</i>	<i>C~SLT</i>	<i>2</i>
<i>Correctly explains S, L and T, but errs in explaining C</i>	<i>~CSLT</i>	<i>2</i>
<i>Correctly explains C, and K, but errs in explaining S and L</i>	<i>CK~S~L</i>	<i>0</i>
<i>Correctly explains C, and L, but errs in explaining K and S</i>	<i>C~K~SL</i>	<i>0</i>
<i>Correctly explains C, and S, but errs in explaining K and L</i>	<i>C~K~SL</i>	<i>0</i>
<i>Correctly explains S, and L, but errs in explaining C and K</i>	<i>~C~KSL</i>	<i>0</i>
<i>Correctly explains K, and L, but errs in explaining C and S</i>	<i>~CK~SL</i>	<i>0</i>
<i>Correctly explains K, and S, but errs in explaining C and L</i>	<i>~CKS~L</i>	<i>0</i>
<i>Other Response/Incorrect Response</i>	<i>IR</i>	<i>-1 (for</i>

		<i>each incorrect response.)</i>
<i>No Response/ Don't know</i>	<i>NR</i>	<i>0</i>

1d. For each increasing type of energy you listed in part c, explain how you know that it is increasing. For each decreasing type of energy you listed in part c, explain how you know that it is decreasing.

Sample correct response:

Chemical energy is decreasing because there is less and less of the strip left, or, since the chemical reaction eventually died out, the chemical energy must have decreased.

There was no sound energy at the beginning, then there was sound, then it was quiet again.

There was no light energy at the beginning, then there was light, then there was no emission of light again.

As the strip begins to move, kinetic energy increases. However, it loses mass at the same time, so it is hard to be sure whether it is increasing or decreasing.

The thermal energy increases because the system gets warmer, or, because energy transformations are occurring, which means some energy is converted to thermal energy. (3 points – 1 each for correct explanation of chemical, light and sound energy; for kinetic and thermal energy see the note above.)

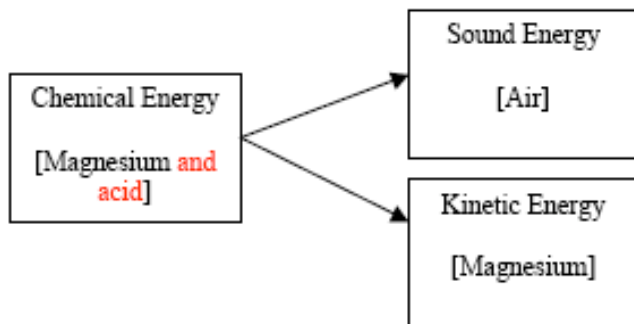
*Coding:*

<i>Student Response</i>	<i>Code</i>	<i>Points</i>
<i>Complete correct response</i>	<i>CR</i>	<i>4</i>
<i>Correctly explains chemical energy only</i>	<i>C</i>	<i>1</i>
<i>Correctly explains kinetic energy only</i>	<i>K</i>	<i>1</i>
<i>Correctly explains sound energy only</i>	<i>S</i>	<i>1</i>
<i>Correctly explains light energy only</i>	<i>L</i>	<i>1</i>
<i>Correctly explains thermal energy only</i>	<i>T</i>	<i>1</i>
<i>Correctly explains chemical and kinetic energies</i>	<i>CK</i>	<i>2</i>
<i>Correctly explains chemical and sound energies</i>	<i>CS</i>	<i>2</i>
<i>Correctly explains chemical and light energies</i>	<i>CL</i>	<i>2</i>
<i>Correctly explains chemical and thermal energies</i>	<i>CT</i>	<i>2</i>
<i>Correctly explains C, K and S</i>	<i>CKS</i>	<i>3</i>
<i>Correctly explains chemical energy, but also includes an explanation of some other irreverent energy.</i>	<i>CI</i>	<i>0</i>
<i>Correctly explains kinetic energy, but also includes an explanation of some other irreverent energy.</i>	<i>KI</i>	<i>0</i>
<i>Correctly explains sound energy, but also includes an explanation of some other irreverent energy.</i>	<i>SI</i>	<i>0</i>
<i>Correctly explains light energy, but also includes an explanation of some other irreverent energy.</i>	<i>LI</i>	<i>0</i>
<i>Correctly explains thermal energy, but also includes an explanation of</i>	<i>TI</i>	<i>0</i>

<i>some other irreverent energy.</i>		
<i>Correctly explains chemical and two other incorrect/irrelevant energies</i>	<i>CII</i>	<i>-1</i>
<i>Correctly explains kinetic and two other incorrect/ irrelevant energies</i>	<i>KII</i>	<i>-1</i>
<i>Correctly explains sound and two other incorrect/ irrelevant energies</i>	<i>SII</i>	<i>-1</i>
<i>Correctly explains light and two other incorrect/irrelevant energies</i>	<i>LII</i>	<i>-1</i>
<i>Correctly explains thermal and two other incorrect/irrelevant energies</i>	<i>TII</i>	<i>-1</i>
<i>Incorrectly explains kinetic energy, but also includes an explanation of some other irreverent energy.</i>	<i>~KI</i>	<i>-2</i>
<i>Incorrectly explains sound energy, but also includes an explanation of some other irreverent energy.</i>	<i>~SI</i>	<i>-2</i>
<i>Incorrectly explains light energy, but also includes an explanation of some other irreverent energy.</i>	<i>~LI</i>	<i>-2</i>
<i>Incorrectly explains thermal energy, but also includes an explanation of some other irreverent energy.</i>	<i>~TI</i>	<i>-2</i>
<i>Similarly other correct (but incomplete) responses are to be coded</i>		<i>3</i>
<i>Correctly explains chemical energy but errs in explaining kinetic energy</i>	<i>C~K</i>	<i>0</i>
<i>Correctly explains chemical and kinetic energy but errs in explaining sound energy</i>	<i>CK~S</i>	<i>2-1=1</i>
<i>Similarly other partially incorrect responses are to be coded</i>	<i>~</i>	<i>2-1=1</i>
<i>Correctly explains C, K and S, but errs in explaining L</i>	<i>CKS~L</i>	<i>2</i>
<i>Correctly explains C, K and L, but errs in explaining S</i>	<i>CK~SL</i>	<i>2</i>
<i>Correctly explains C, S and L, but errs in explaining K</i>	<i>C~KSL</i>	<i>2</i>
<i>Correctly explains K, S and L, but errs in explaining C</i>	<i>~CKSL</i>	<i>2</i>
<i>Correctly explains C, S and L, but errs in explaining T</i>	<i>CSL~T</i>	<i>3</i>
<i>Correctly explains C, S and T, but errs in explaining L</i>	<i>CS~LT</i>	<i>2</i>
<i>Correctly explains C, L and T, but errs in explaining S</i>	<i>C~SLT</i>	<i>2</i>
<i>Correctly explains S, L and T, but errs in explaining C</i>	<i>~CSLT</i>	<i>2</i>
<i>Correctly explains C, and K, but errs in explaining S and L</i>	<i>CK~S~L</i>	<i>0</i>
<i>Correctly explains C, and L, but errs in explaining K and S</i>	<i>C~K~SL</i>	<i>0</i>
<i>Correctly explains C, and S, but errs in explaining K and L</i>	<i>C~K~SL</i>	<i>0</i>
<i>Correctly explains S, and L, but errs in explaining C and K</i>	<i>~C~KSL</i>	<i>0</i>
<i>Correctly explains K, and L, but errs in explaining C and S</i>	<i>~CK~SL</i>	<i>0</i>
<i>Correctly explains K, and S, but errs in explaining C and L</i>	<i>~CKS~L</i>	<i>0</i>
<i>Other Response/Incorrect Response</i>	<i>IR</i>	<i>-1 (for each incorrect response.)</i>
<i>No Response/ Don't know</i>	<i>NR</i>	<i>0</i>

1e. Draw an energy-transformation diagram for the phenomenon.

Correct response:



(4 points – One point each for the following energies: chemical, kinetic, light and sound. Thermal energy is extra. The transformation sequence has to be correct in order for points to be awarded.

Mention of substance along with energy not required. Hence no points for them.)

*Coding*

<i>Student Response</i>	<i>Code</i>	<i>Points</i>
<i>The diagram is correctly drawn as shown in the sample student response.</i>	<i>CR</i>	<i>4</i>
<i>The student's diagram correctly identifies chemical energy as the energy that gets transformed into other forms as a result of the reaction, and identifies correctly some (but not all) of the resulting forms of energy (including thermal energy)</i>	<i>A</i>	<i>1 point for correct energy, and –1 for incorrect energy</i>
<i>The student's diagram correctly identifies chemical energy as the energy that gets transformed into other forms as a result of the reaction, but get at least some of the resulting forms of energy wrong.</i>	<i>B</i>	<i>1 point for correct energy, and –1 for each incorrect energy.</i>
<i>The student's diagram correctly identifies the resulting forms of energy after transformation but errs in identifying the energy that gets transformed as a result of the reaction.</i>	<i>C</i>	<i>1 point for correct energy, and –1 for each incorrect energy.</i>
<i>Other Response/Incorrect Response</i>	<i>IR</i>	<i>1 point for correct energy, and –1 for each incorrect energy.</i>
<i>No response/"Don't know".</i>	<i>NR</i>	<i>0</i>

2. Think about whether each phenomenon shown below involves the transformation of gravitational energy. Check box next to the correct answer.



2a. Rolling a heavy ball on a table to hit a spring.

Does this process involve the transformation of gravitational energy?

Correct response: No. (1 point)

*Coding*

<i>Student Response</i>	<i>Code</i>	<i>Points</i>
<i>The student chooses "no"</i>	<i>N</i>	<i>1</i>
<i>The student chooses "yes"</i>	<i>Y</i>	<i>-1</i>
<i>No response.</i>	<i>NR</i>	<i>0</i>

2b. Using a truck and pulley to lift a heavy crate.

Does this process involve the transformation of gravitational energy?

Correct response: Yes. (1 point)

*Coding*

<i>Student Response</i>	<i>Code</i>	<i>Points</i>
<i>The student chooses "no"</i>	<i>N</i>	<i>-1</i>
<i>The student chooses "yes"</i>	<i>Y</i>	<i>1</i>
<i>No response.</i>	<i>NR</i>	<i>0</i>

2c. A raw egg falling from a table

Does this process involve the transformation of gravitational energy?

Correct response: Yes. (1 point)

*Coding*

<i>Student Response</i>	<i>Code</i>	<i>Points</i>
<i>The student chooses "no"</i>	<i>N</i>	<i>-1</i>
<i>The student chooses "yes"</i>	<i>Y</i>	<i>1</i>
<i>No response.</i>	<i>NR</i>	<i>0</i>

2d. Using water to turn a waterwheel

Does this process involve the transformation of gravitational energy?  
 Correct response: Yes.

*Coding*

<i>Student Response</i>	<i>Code</i>	<i>Points</i>
<i>The student chooses “no”</i>	<i>N</i>	<i>-1</i>
<i>The student chooses “yes”</i>	<i>Y</i>	<i>1</i>
<i>No response.</i>	<i>NR</i>	<i>0</i>

3. Consider four different phenomena: A) a ball bouncing on the floor; B) a candle burning; C) a lit light bulb connected to a battery; and D) two children playing on a see-saw.

The table below lists several types of energy transformations. In the box under each type of energy transformation, write the letter of each phenomenon that involves that type energy transformation.

**There may be more than letter in each box, and each letter may appear in more than one box.**

Correct response:

Kinetic→ Gravitational	Chemical→ Light	Chemical→ Kinetic	Electrical→ Thermal	Chemical → Thermal
A	B	B	C	B
D	C	C		C
		D		D

(1 point for each correct response, -1 for each incorrect. The red response C in Chemical to Kinetic counts as a correct response only if one or more of the other two correct responses is missing; otherwise, it is neutral, does not give positive or negative points. Thus the total for this question is 10 points.)

*Q3a: Coding for Kinetic → Gravitational*

<i>Student Response</i>	<i>Code</i>	<i>Points</i>
<i>The student chooses "A" only</i>	<i>A</i>	<i>1</i>
<i>The student chooses "D" only</i>	<i>D</i>	<i>1</i>
<i>The student chooses "B" only</i>	<i>B</i>	<i>-1</i>
<i>The student chooses "C" only</i>	<i>C</i>	<i>-1</i>
<i>The student chooses "A" and "B"</i>	<i>AB</i>	<i>0</i>
<i>The student chooses "A" and "D"</i>	<i>AD</i>	<i>2</i>
<i>The student chooses "A" and "C"</i>	<i>AC</i>	<i>0</i>
<i>The student chooses "B" and "C"</i>	<i>BC</i>	<i>-2</i>
<i>The student chooses "B" and "D"</i>	<i>BD</i>	<i>0</i>
<i>The student chooses "C" and "D"</i>	<i>CD</i>	<i>0</i>
<i>The student chooses "A", "B" and "C"</i>	<i>ABC</i>	<i>-1</i>
<i>The student chooses "A", "C" and "D"</i>	<i>ACD</i>	<i>1</i>
<i>The student chooses "B", "C" and "D"</i>	<i>BCD</i>	<i>-1</i>
<i>The student chooses "A", "B" and "D"</i>	<i>ABD</i>	<i>1</i>
<i>No response.</i>	<i>NR</i>	<i>0</i>

*Q3b: Coding for Chemical → Light*

<i>The student chooses "A" only</i>	<i>A</i>	<i>- 1</i>
<i>The student chooses "B" only</i>	<i>B</i>	<i>1</i>
<i>The student chooses "C" only</i>	<i>C</i>	<i>1</i>
<i>The student chooses "D" only</i>	<i>D</i>	<i>- 1</i>
<i>The student chooses "A" and "B"</i>	<i>AB</i>	<i>0</i>
<i>The student chooses "A" and "C"</i>	<i>AC</i>	<i>0</i>
<i>The student chooses "B" and "C"</i>	<i>BC</i>	<i>2</i>
<i>The student chooses "A" and "D"</i>	<i>AD</i>	<i>-2</i>
<i>The student chooses "B" and "D"</i>	<i>BD</i>	<i>0</i>
<i>The student chooses "C" and "D"</i>	<i>CD</i>	<i>0</i>
<i>The student chooses "A", "B" and "C"</i>	<i>ABC</i>	<i>1</i>
<i>The student chooses "A", "C" and "D"</i>	<i>ACD</i>	<i>-1</i>
<i>The student chooses "B", "C" and "D"</i>	<i>BCD</i>	<i>1</i>
<i>The student chooses "A", "B" and "D"</i>	<i>ABD</i>	<i>-1</i>
<i>No response.</i>	<i>NR</i>	<i>0</i>

*Q3c: Coding for Chemical → Kinetic*

<i>Student Response</i>	<i>Code</i>	<i>Points</i>
<i>The student chooses "A" only</i>	<i>A</i>	<i>- 1</i>
<i>The student chooses "B" only</i>	<i>B</i>	<i>1</i>
<i>The student chooses "C" only</i>	<i>C</i>	<i>1</i>
<i>The student chooses "D" only</i>	<i>D</i>	<i>1</i>
<i>The student chooses "A" and "B"</i>	<i>AB</i>	<i>0</i>
<i>The student chooses "A" and "C"</i>	<i>AC</i>	<i>0</i>
<i>The student chooses "B" and "C"</i>	<i>BC</i>	<i>2</i>
<i>The student chooses "A" and "D"</i>	<i>AD</i>	<i>0</i>
<i>The student chooses "B" and "D"</i>	<i>BD</i>	<i>2</i>
<i>The student chooses "C" and "D"</i>	<i>CD</i>	<i>2</i>
<i>The student chooses "A", "B" and "C"</i>	<i>ABC</i>	<i>1</i>
<i>The student chooses "A", "C" and "D"</i>	<i>ACD</i>	<i>1</i>
<i>The student chooses "B", "C" and "D"</i>	<i>BCD</i>	<i>3</i>
<i>The student chooses "A", "B" and "D"</i>	<i>ABD</i>	<i>1</i>
<i>No response.</i>	<i>NR</i>	<i>0</i>

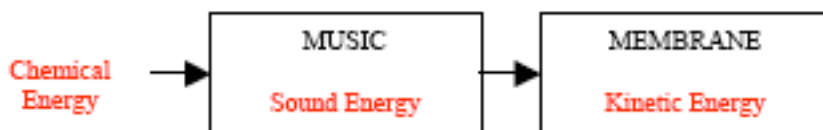
*Q3d: Coding for Electrical → Thermal*

<i>Student Response</i>	<i>Code</i>	<i>Points</i>
<i>The student chooses "A" only</i>	<i>A</i>	<i>- 1</i>
<i>The student chooses "B" only</i>	<i>B</i>	<i>- 1</i>
<i>The student chooses "C" only</i>	<i>C</i>	<i>1</i>
<i>The student chooses "D" only</i>	<i>D</i>	<i>-1</i>
<i>The student chooses "A" and "B"</i>	<i>AB</i>	<i>-2</i>
<i>The student chooses "A" and "C"</i>	<i>AC</i>	<i>0</i>
<i>The student chooses "B" and "C"</i>	<i>BC</i>	<i>0</i>
<i>The student chooses "A" and "D"</i>	<i>AD</i>	<i>-2</i>
<i>The student chooses "B" and "D"</i>	<i>BD</i>	<i>-2</i>
<i>The student chooses "C" and "D"</i>	<i>CD</i>	<i>0</i>
<i>The student chooses "A", "B" and "C"</i>	<i>ABC</i>	<i>-1</i>
<i>The student chooses "A", "C" and "D"</i>	<i>ACD</i>	<i>-1</i>
<i>The student chooses "B", "C" and "D"</i>	<i>BCD</i>	<i>-1</i>
<i>The student chooses "A", "B" and "D"</i>	<i>ABD</i>	<i>-3</i>
<i>No response.</i>	<i>NR</i>	<i>0</i>

Q3e: Coding for Chemical → Thermal

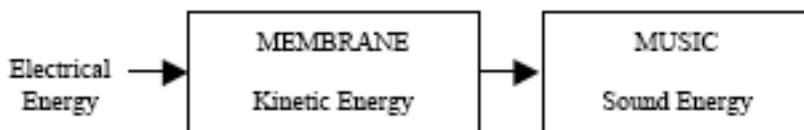
Student Response	Code	Points
The student chooses "A" only	A	- 1
The student chooses "B" only	B	1
The student chooses "C" only	C	1
The student chooses "D" only	D	1
The student chooses "A" and "B"	AB	0
The student chooses "A" and "C"	AC	0
The student chooses "B" and "C"	BC	2
The student chooses "A" and "D"	AD	0
The student chooses "B" and "D"	BD	2
The student chooses "C" and "D"	CD	2
The student chooses "A", "B" and "C"	ABC	1
The student chooses "A", "C" and "D"	ACD	1
The student chooses "B", "C" and "D"	BCD	3
The student chooses "A", "B" and "D"	ABD	1
No response.	NR	0

4. The following diagram is the energy-transformation diagram for the speaker shown above. There are mistakes in this diagram.



Redraw the energy-transformation diagram so that it is correct.

Correct response:



(2 points. The correct response requires two changes to the incorrect response proposed in the question: a) changing the order of the boxes, and b) changing chemical energy to electrical energy on the LH arrow. This is there are only 2 points for this question. Any other changes the students make should be given negative points, one for each incorrect change. If they do not make a required change, such as switching the order of the boxes, they are not to be negatively scored for this.)

*Coding*

<i>Student Response</i>	<i>Code</i>	<i>Points</i>
<i>The diagram is correctly drawn as shown in the 'correct response'.</i>	<i>CR</i>	<i>2</i>
<i>The diagram shows the correct order of the boxes, but does not correct the source energy.</i>	<i>O</i>	<i>1</i>
<i>The student's diagram corrects the source energy as electrical energy, but leaves the order of the boxes unchanged.</i>	<i>E</i>	<i>1</i>
<i>The diagram shows the correct order of the boxes, but substitutes another wrong choice as source energy.</i>	<i>A</i>	<i>1-1=0</i>
<i>The student's diagram corrects the source energy as electrical energy, but makes incorrect changes in the order or content of energy boxes.</i>	<i>B</i>	<i>1-1=0</i>
<i>The student's diagram does not correct the source energy, but makes incorrect changes in the order or content of energy boxes.</i>	<i>C</i>	<i>-1</i>
<i>Totally Incorrect Response</i>	<i>IR</i>	<i>-2</i>
<i>No response/"Don't know"/Redraws the diagram as given in the question.</i>	<i>NR</i>	<i>0</i>

5. An inventor claims that the battery she has invented can generate electricity without ever needing to be recharged or replaced. Which of the following is the best explanation for why the inventor's claim cannot be true?

- A) When electricity is generated, thermal energy is produced, so batteries must put out more energy than is put into them.
- B) The Earth has a limited number of energy resources, so energy can never be generated endlessly.
- C) Batteries transform chemical energy into electrical energy, and this chemical energy must eventually run out.
- D) Electricity contains more energy than the type of energy used to generate it, so all batteries must eventually die out.

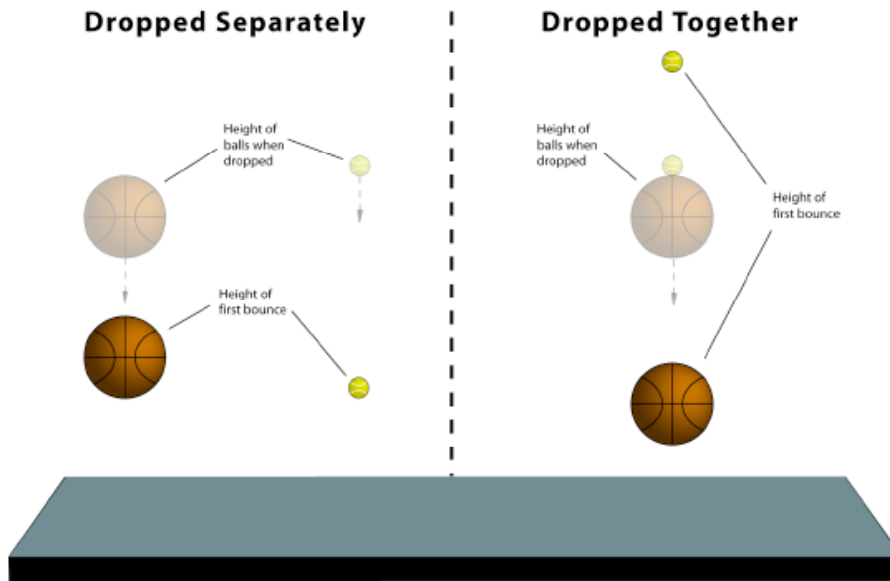
Correct response: C (1 point)

*Coding:*

<i>Student Response</i>	<i>Code</i>	<i>Points</i>
<i>Student chooses option A.</i>	<i>A</i>	<i>-1</i>
<i>Student chooses option B.</i>	<i>B</i>	<i>-1</i>
<i>Student chooses option C (Correct response)</i>	<i>CR</i>	<i>1</i>
<i>Student chooses option D.</i>	<i>D</i>	<i>-1</i>
<i>No response.</i>	<i>NR</i>	<i>0</i>

6. When a ball is dropped, it tends to bounce lower with each bounce. A scientist has proven that this is not the case! By dropping a tennis ball on top of a basketball, the tennis ball bounces higher than the height from which it was dropped. The scientist claims that energy is produced in this phenomenon.

Watch your teacher demonstrate this phenomenon and examine the picture below.



Is the scientist correct? Explain why it is correct or why it is not correct to say that energy is produced in this phenomenon.

Sample correct response:

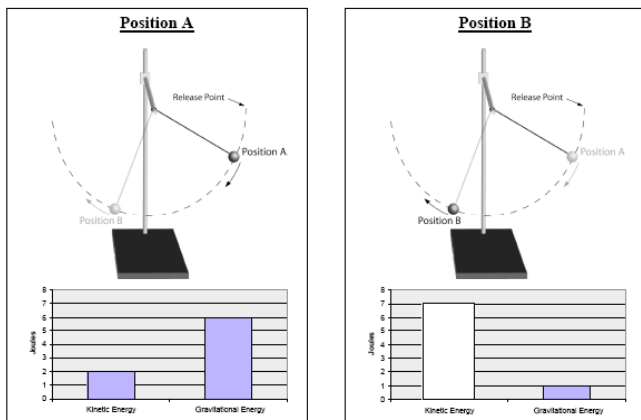
No, the scientist is not correct. (1) Energy is not produced during the phenomenon because energy cannot be created or destroyed. (2) Even though the tennis ball bounced higher, the basketball bounced lower the second time. (3) Some of the energy that was initially in the basketball was transferred to the tennis ball. (total 4 points – 1 point for energy conservation; 1 point for energy transfer; 1 point for mention of basketball bouncing lower; 1 point for mentioning that the scientist is incorrect. If the explanation in the response is correct but not relevant then there should be no negative scoring.)

*Coding:*

<i>Student Response</i>	<i>Code</i>	<i>Points</i>
<i>Student answers the whole question correctly</i>	<i>CR</i>	<i>1+1+1+1=4</i>
<i>Student says that the scientist is not correct, but gives totally wrong reasons for that.</i>	<i>A</i>	<i>1 point for correct statement, and -1 for each incorrect statement.</i>
<i>Student says that the scientist is not correct, and gives factually correct but irrelevant reasons for that.</i>	<i>B</i>	<i>1</i>
<i>Student says the scientist is correct, and gives (wrong) reasons; or just says the scientist is correct and does not give any reasons.</i>	<i>IR</i>	<i>1 point for correct statement, and -1 for each incorrect statement</i>
<i>Student says the scientist is not correct, and gives incomplete but relevant and reasons involving conservation of energy principle.</i>	<i>C</i>	<i>1 point for correct statement, and -1 for each incorrect statement</i>
<i>Student says the scientist is not correct, and gives incomplete but relevant and correct reasons involving transfer of energy from basket ball to tennis ball.</i>	<i>D</i>	<i>1 point for correct statement, and -1 for each incorrect statement</i>
<i>Student says the scientist is not correct, but gives no explanations</i>	<i>I</i>	<i>1</i>
<i>Student says the scientist is correct, and gives factually/scientifically (in themselves) correct BUT INOPERATIVE reasons.</i>	<i>E</i>	<i>-1 for each incorrect statement</i>
<i>Student says the scientist is not correct, but gives incorrect explanations</i>	<i>F</i>	<i>1 point for correct statement, and -1 for each incorrect statement</i>
<i>Any other incorrect response</i>	<i>OIR</i>	<i>-1 for each incorrect statement</i>
<i>No response.</i>	<i>NR</i>	<i>0</i>



7. A pendulum is released and allowed to swing freely. The graphs below show the kinetic and gravitational energy of the pendulum as it swings through position A and position B for the first time. *The kinetic energy bar in the graph of position B has not been drawn yet.*



a. How does the gravitational energy in position A compare to the gravitational energy in position B?

- A) It is greater at position A than position B
- B) It is greater at position B than position A
- C) It is the same at both positions
- D) There is no gravitational energy at either position.

Correct response: A (1 point)

*Coding:*

<i>Student Response</i>	<i>Code</i>	<i>Points</i>
<i>Student chooses option A.</i>	<i>CR</i>	<i>1</i>
<i>Student chooses option B.</i>	<i>B</i>	<i>-1</i>
<i>Student chooses option C (Correct response)</i>	<i>C</i>	<i>-1</i>
<i>Student chooses option D.</i>	<i>D</i>	<i>-1</i>
<i>No response.</i>	<i>NR</i>	<i>0</i>

b. The pendulum's gravitational energy increases as:

- A) The pendulum swings downward.
- B) The pendulum swings faster.
- C) The pendulum's mass decreases.
- D) The pendulum swings upward.

Correct response: D (1 point)

*Coding:*

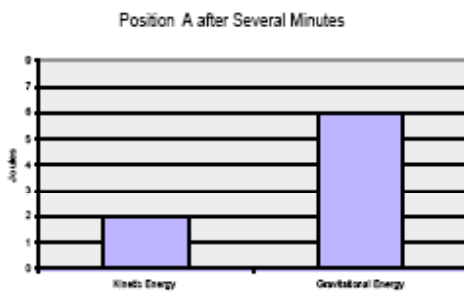
<i>Student Response</i>	<i>Code</i>	<i>Points</i>
<i>Student chooses option A.</i>	<i>A</i>	<i>-1</i>
<i>Student chooses option B.</i>	<i>B</i>	<i>-1</i>
<i>Student chooses option C (Correct response)</i>	<i>C</i>	<i>-1</i>
<i>Student chooses option D.</i>	<i>CR</i>	<i>1</i>
<i>No response.</i>	<i>NR</i>	<i>0</i>

c. Draw the missing kinetic energy bar on the graph for position B shown above.  
 Correct response: A bar that goes equal to or higher than 6 joules (1 point).

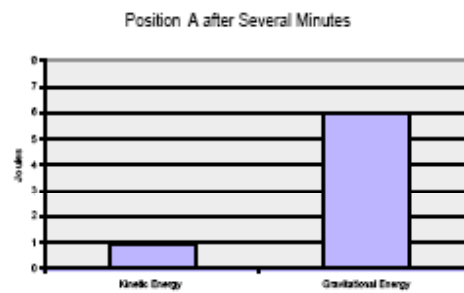
*Coding:*

<i>Student Response</i>	<i>Code</i>	<i>Points</i>
<i>Correct response (a bar that goes EQUAL TO OR higher than 6 joules)</i>	<i>CR</i>	<i>1</i>
<i>Incorrect response (a bar lower than 6 joules)</i>	<i>IR</i>	<i>-1</i>
<i>No response.</i>	<i>NR</i>	<i>0</i>

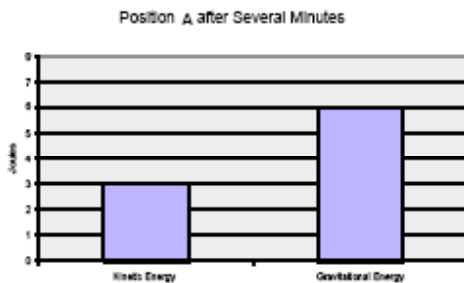
d. After swinging back and forth for several minutes the pendulum once again moves through position A. Which one of the following graphs correctly shows the kinetic and gravitational energies the pendulum has after several minutes? Circle the letter of the correct graph.



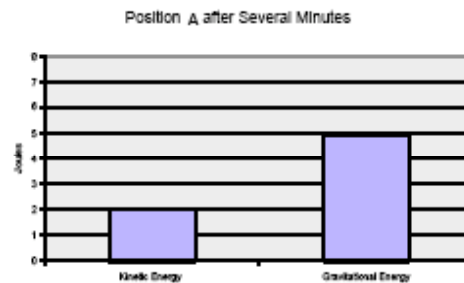
A



B



C



D

Correct response: B (1 point)

*Coding:*

<i>Student Response</i>	<i>Code</i>	<i>Points</i>
<i>Student chooses option A.</i>	<i>A</i>	<i>-1</i>
<i>Student chooses option B. (Correct response)</i>	<i>CR</i>	<i>1</i>
<i>Student chooses option C</i>	<i>C</i>	<i>-1</i>
<i>Student chooses option D.</i>	<i>D</i>	<i>1</i>
<i>No response.</i>	<i>NR</i>	<i>0</i>

e. Explain why the graph you chose correctly shows the kinetic and gravitational energies of the pendulum at position A after a few minutes.

Sample correct response:

(1) It has the same gravitational energy since it is at the same height. (2) It's total energy is less because some energy has left the system as thermal energy. (3) So, there must be less kinetic energy than there was when it was at position A before. (2 points; 1 point for KE; and 1 point for PE).

Coding:

<i>Student Response</i>	<i>Code</i>	<i>Points</i>
<i>Student gives a correct response similar to the one given above.</i>	<i>CR</i>	<i>2</i>
<i>Student correctly explains the case with gravitational energy, but offers no explanation for kinetic energy, i.e. mentions sentence similar to 1, but not 2 and 3 (see sample response above).</i>	<i>G</i>	<i>1</i>
<i>Student correctly explains the case with kinetic energy, but offers no explanation for potential energy, i.e. mentions sentences similar to 2 and 3, but not 1 (see sample response above).</i>	<i>K</i>	<i>1</i>
<i>Student correctly explains the case with gravitational energy, but offers an incorrect explanation for kinetic energy.</i>	<i>G~K</i>	<i>1-1=0</i>
<i>Student correctly explains the case with kinetic energy, but offers incorrect explanation for gravitational energy.</i>	<i>~GK</i>	<i>1-1=0</i>
<i>Student mentions that gravitational energy remains the same and kinetic energy reduces without giving any reasons.</i>	<i>A</i>	<i>0</i>
<i>Student incorrectly explains the case with gravitational energy, and doesn't explain kinetic energy.</i>	<i>~G</i>	<i>-1</i>
<i>Student incorrectly explains the case with kinetic energy, and doesn't explain gravitational energy.</i>	<i>~K</i>	<i>-1</i>
<i>Student incorrectly explains the case with both kinetic and gravitational energy.</i>	<i>IR</i>	<i>-1-1=-2</i>
<i>Student justifies her choice in terms of energy of the pendulum running out/leaking/decreasing over time</i>	<i>E</i>	<i>0</i>
<i>Student incorrectly justifies her choice (a) by saying that since the position (a) is the same as occupied by the pendulum earlier, it's energy will be same too.</i>	<i>S</i>	<i>-1</i>
<i>Other incorrect response</i>	<i>OIR</i>	<i>-1 for each incorrect statement.</i>
<i>No response.</i>	<i>NR</i>	<i>0</i>

8. In order to move, your body uses chemical energy. Where does this energy come from?

- A) Gravity
- B) Light
- C) Air
- D) Water

Correct response: B (1 point).

*Coding:*

<i>Student Response</i>	<i>Code</i>	<i>Points</i>
<i>Student chooses option A.</i>	<i>A</i>	<i>-1</i>
<i>Student chooses option B. (Correct response)</i>	<i>CR</i>	<i>1</i>
<i>Student chooses option C</i>	<i>C</i>	<i>-1</i>
<i>Student chooses option D.</i>	<i>D</i>	<i>-1</i>
<i>Student chooses options C and D.</i>	<i>CD</i>	<i>-2</i>
<i>Student chooses options A and B.</i>	<i>AB</i>	<i>0</i>
<i>Student chooses options A and C.</i>	<i>AC</i>	<i>-2</i>
<i>Student chooses options B and C.</i>	<i>BC</i>	<i>0</i>
<i>No response.</i>	<i>NR</i>	<i>0</i>

9. Which of the following sets of energy resources are renewable?

- A) Natural gas, nuclear, wind
- B) Nuclear, wind, solar
- C) Wind, solar, hydroelectric
- D) Solar, hydroelectric, natural gas

Correct response: C (1 point).

*Coding:*

<i>Student Response</i>	<i>Code</i>	<i>Points</i>
<i>Student chooses option A.</i>	<i>A</i>	<i>-1</i>
<i>Student chooses option B.</i>	<i>B</i>	<i>-1</i>
<i>Student chooses option C. (Correct response)</i>	<i>CR</i>	<i>1</i>
<i>Student chooses option D.</i>	<i>D</i>	<i>1</i>
<i>No response.</i>	<i>NR</i>	<i>0</i>

10. Identify one energy resource that is not practical for use in Michigan and explain why.

Correct response:

Solar energy. Michigan has too many overcast days and is so far north that the light is not strong enough. (2 points – 1 point for a correct energy source; and 1 point for a reasonable justification)

*Coding:*

<i>Student Response</i>	<i>Code</i>	<i>Points</i>
<i>Student mentions a correct energy source and a reasonable justification. (Correct response)</i>	<i>CR</i>	<i>1+1=2</i>
<i>Student mentions a correct energy source, but offers not explanation.</i>	<i>A</i>	<i>1</i>
<i>Student mentions a correct energy source, but offers an incorrect explanation.</i>	<i>B</i>	<i>1-1=0</i>
<i>Student mentions an incorrect energy source, and offers an incorrect explanation.</i>	<i>C</i>	<i>-1-1=-2</i>
<i>Student mentions an incorrect energy source, but offers not explanation.</i>	<i>D</i>	<i>-1</i>
<i>Student mentions an incorrect energy source, and offers a FACTUALLY correct but irrelevant explanation.</i>	<i>E</i>	<i>-1</i>
<i>No response.</i>	<i>NR</i>	<i>0</i>

## APPENDIX G: INTERVIEW CODING RUBRIC

Framework	Requirements for classification	Examples
Anthropocentric	<p>ONE of these:</p> <ul style="list-style-type: none"> <li>• Student states that people/animals in a scenario have energy, and that the inanimate objects in a scenario do not represent energy</li> <li>• Student relates energy to a feeling of “being energetic”</li> <li>• Energy allows living things to act as causal agents, but not non-living things.</li> <li>• Living things have a sort of inherent energy by nature of being alive.</li> </ul>	<p>“It’s a form of energy, its made by a person, I guess...there’s different forms of energy I guess, and then, and one of them is physical, like made by the body or produced by the body.”</p>
Activity	<p>BOTH of these:</p> <ul style="list-style-type: none"> <li>• An obvious action or process demonstrates energy while it is happening.</li> <li>• When the action/process stops, the energy stops.</li> </ul> <p>Clarification:</p> <ul style="list-style-type: none"> <li>• In this framework, the action and the energy are the same thing.</li> </ul>	
Product	<p>BOTH of these:</p> <ul style="list-style-type: none"> <li>• Energy is produced/created when a process occurs.</li> <li>• The energy is gone (or quickly fades) when the process is over.</li> </ul> <p>Clarification:</p> <ul style="list-style-type: none"> <li>• In this framework, energy is produced by an action/process and is a distinct entity.</li> </ul>	
Deposit	<p>ONE of these:</p> <ul style="list-style-type: none"> <li>• Energy exists in various objects and can be released for use during certain processes.</li> <li>• Some objects <i>have</i> energy, while other objects <i>need</i> energy.</li> </ul> <p>Clarification:</p> <ul style="list-style-type: none"> <li>• Once energy is used in this framework, it is expended by the object that needs the energy. Students may indicate that energy is used up (e.g., no longer exists) or that it continues to exist in some non-usable form.</li> </ul>	
Cause (active deposit)	<p>ONE of these:</p> <ul style="list-style-type: none"> <li>• Energy (or an energy type) is responsible for some action, but no transformation need take place.</li> <li>• Indicates that the presence of energy is enough to make something happen – the energy need not undergo transformation.</li> </ul> <p>Clarification:</p> <ul style="list-style-type: none"> <li>• This is similar (in fact derived by Trumper from) the deposit framework, so while no transformation is required, energy can certainly be used up in this framework.</li> </ul>	<p>“The train is moving because it has kinetic energy.”</p> <p>“The train uses kinetic energy to move.”</p>
Ingredient	<p>ONE of these:</p> <ul style="list-style-type: none"> <li>• Energy becomes unlocked during a process and is usable thereafter.</li> <li>• Energy becomes usable during a process</li> <li>• Energy is created from some ingredients during a</li> </ul>	

	<p>process, and the energy then exists after the process is completed.</p> <p>Clarification:</p> <ul style="list-style-type: none"> <li>• This is distinct from the product framework because the energy was already present, but in some dormant/unusable form.</li> </ul>	
Functional	<p>ONE of these:</p> <ul style="list-style-type: none"> <li>• Energy is a general type of fuel that enables a technical device to perform some sort of work that is useful to humans</li> <li>• Energy is generally useful for doing things</li> </ul>	
Flow-transfer	<p>ONE of these:</p> <ul style="list-style-type: none"> <li>• Energy is a concrete physical entity</li> <li>• Energy is transported from one place to another as a sort of fluid</li> </ul>	<p>“The energy comes from the battery, flows through the wires to the light bulb, and then returns to the battery.”</p>
Transformation	<p>BOTH of these:</p> <ul style="list-style-type: none"> <li>• Energy types can transform into one another</li> <li>• These transformations are important to phenomenon depicted</li> </ul>	



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