Teacher Growth in Knowledge of Conservation of Energy and in Self-Efficacy

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TEACHER GROWTH IN KNOWLEDGE OF CONSERVATION OF ENERGY
AND IN SELF-EFFICACY

By

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B.S. University of Maine, 2012

A THESIS

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This study examines a conversation between a group of three in-service teachers during a professional development workshop. During the workshop, the teachers collaborated to answer a set of survey questions pertaining to energy concepts in physical science. The teachers began the survey expressing low self-efficacy in their knowledge of energy. Through this study, we were able to observe teachers as they learned new concepts. This study used a narrative analysis of their conversation. The analysis centers on changes in the teachers’ common content knowledge of conservation of energy and their expressed self-efficacy regarding that knowledge. Their knowledge was evaluated from a resources perspective, as many components of conservation of energy appeared in their conversation. We found that the teachers, in the course of one hour, developed an understanding of conservation of energy, and that they expressed greater self-efficacy regarding this knowledge. Further study may expand our understanding of this process.
DEDICATION

For Mom, who has encouraged me to be a teacher since I was a boy, and whose self-efficacy continues to grow.
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1. INTRODUCTION

In the modern day, perhaps more than ever before, there is a need for rigorous science education in primary and secondary level classrooms. Many problems confront our society that can only be understood and mitigated through science. We face the potentially catastrophic effects of climate change, grapple to deal with a global pandemic, and try to maintain food and infrastructure for an ever-growing human population. Facing these challenges will mean pushing our collective limits of resourceful thinking to design scientifically sound solutions. This will require a collective of individuals who are well-educated in science disciplines. Not only must leading scientists forge solutions to the challenges we face as a species, but it is also crucial that the general populace have a degree of scientific literacy that will make them active and informed citizens. Perhaps the greatest illustration of this point is our failure as a species to respond in a prompt and serious manner to the threats of global warming and the COVID-19 pandemic. Thus, the current and future generations must be well prepared to face the world with a holistic scientific perspective. Students in the modern age must be scientifically literate, so that they are prepared to understand and take part in the modern scientific world.

Despite the need for rigorous science education, the United States has experienced a profound shortage of qualified teachers, particularly in STEM fields. This shortcoming was acknowledged by President Obama in 2011, launching the 100Kin10 Project, which strove to add 100,000 qualified STEM teachers to classrooms across the United States over the subsequent 10 years (100Kin10, n.d.). Optimistically, the 100Kin10 Project passed its 10-year milestone in November 2021 having surpassed its goal. Although this is promising progress, much work remains to be done to prepare STEM teachers in the United States to help students develop strong scientific thinking skills.
One way in which existing teachers can strengthen their teaching skills is through ongoing professional development. Teachers in the United States are required to attend a certain number of hours of professional development every year to maintain their teaching certification (Beavers, 2009). The intent of professional development is to expand teachers’ knowledge in order to prepare them to be more effective educators. Although professional development workshops may take on many different characters on a surface level, they serve to provide educational experiences to help their attendees grow as educators. In this sense, professional development can function as a classroom setting in which teachers assume the role of students. This gives the added benefit that teachers can develop empathy and understanding for their students as they experience what learning looks like from the stance of the learner and how the process can be made most effective.

It is often useful to observe teachers in the position of learners to better understand how learning takes place. Presumably, teachers learn in a manner similar to that of students. However, teachers may be in a better position to reflect on their own learning. Unlike classroom students, teachers are familiar with pedagogical practices, and are used to observing others in the learning process in their own classrooms. They may be more metacognitive in their learning than students due to being accustomed to examining others’ learning in close detail. Thus, teachers may be able to provide a richer perspective about their own learning than grade-level students would be able to do. This can provide insight as to how students themselves learn. This improved insight can lead to more effective and positive classroom instruction. Ultimately, understanding how to better the learning process can lead to progress in overcoming the shortage of effective STEM teachers by improving the efficacy of those already in the profession.
In order to ensure that students in classrooms across the United States are becoming proficient in the most ubiquitous science skills, learning standards that teachers are expected to teach and students expected to master have been put forth by national committees. The leading set of learning standards in science in the present day is the Next Generation Science Standards (NGSS), which identifies a variety of core science topics and concepts that are considered essential for robust and holistic scientific thinking. One topic prioritized by the NGSS is energy. The topic of energy appears in many Disciplinary Core Ideas of the NGSS, indicating that energy is central to many specific scientific disciplines (Gray et al., 2019). Furthermore, the NGSS considers many aspects of energy to be Crosscutting Concepts due to the topic’s applicability across all fields of science (Gray et al., 2019). Because of its importance to science, students need to have a good grasp on the concept of energy to become versatile scientific thinkers.

The fact that energy is ubiquitous across disciplines means that a teacher may find themselves having to teach energy in a context outside of their field. For example, a biology teacher may understand energy well in the context of how living organisms and ecosystems require complex energy interactions for sustenance, but struggle to understand energy from a physics standpoint, such as what happens to the energy of a moving object as friction slows it down. This makes teaching the topic of energy complex, as teachers may be unprepared to understand and therefore teach energy in a context relevant to the subject they teach. Because teachers are often required to teach out of field, it is important that these teachers have a solid understanding of the new content. For a teacher, along with learning a new subject comes a sense of uncertainty of how well they understand the new subject matter. It can be daunting for anyone to acquire new knowledge, but having to teach that knowledge to others adds a new level of
anxiety. It is best when teachers are able to learn new material and, at the same time, have confidence in their knowledge so that they may teach most effectively.

Because there are many aspects of good teaching, it is useful for these aspects to be clearly defined. The Interstate Teacher Assessment and Support Consortium (InTASC) has attempted to summarize the skills that all successful teachers require. The result is the InTASC Model Core Teaching Standards (Council of Chief State School Officers, 2011), intended to parallel the idea of student learning standards. Like learning standards for students, the InTASC standards are intended to be a measure of whether teachers have met various objectives needed for their professional success. Included among these standards is Content Knowledge (Standard #4), which includes an understanding of “the central concepts, tools of inquiry, and structures of the discipline(s) he or she teaches” (Council of Chief State School Officers, 2011, p. 13). It is not only the requisite knowledge itself, but also the teacher’s belief in the extent of their understanding of the subject that will govern whether or not this knowledge is applied effectively to classroom practice.

In the interest of exploring essential teaching skills, this thesis examines both teacher knowledge and perception of that knowledge through the following research questions:

1. How can teachers construct an understanding of the law of conservation of energy during a professional development activity without it being explicitly taught to them?
2. In what ways does teachers’ self-efficacy change in a professional development setting as learning takes place?

Chapter 2 is a review of the literature. The chapter begins by discussing types of teacher knowledge and how they are important to teaching. Then, a resource model of knowledge is introduced. Next, several important properties of energy are explored, with a focus on how these
properties are important for learners and how learners typically conceptualize them. Finally, self-efficacy is defined, and its relevance to teacher knowledge is discussed.

Chapter 3 contains an overview of the methods that were used to conduct this study. Initially, the context of the professional development workshop which provided the data for this study is summarized. Next, a brief description of the research subjects’ backgrounds is given. After this, the process that was used to develop the written transcript from the audio data used for this study is described. This is followed by a description of the process by which the transcript was analyzed to address the research questions.

Chapter 4 contains the findings from the analysis process described in Chapter 3. First, the chapter summarizes why conservation of energy and self-efficacy were chosen as relevant topics in the transcript. Then, sections of the transcript that are relevant to these topics are analyzed. This analysis examines the research subjects as they develop an understanding of energy from a physics standpoint, and as they express a shift in self-efficacy surrounding this knowledge.

Chapter 5 contains a discussion of the results from the previous chapter and provides concluding remarks. First, the method of answering the research questions is summarized. Next, concepts from the research framework are used to interpret the findings. Limitations of the study are then discussed. After this, suggestions for follow-up research are proposed. The chapter ends with concluding remarks.
2. REVIEW OF THE LITERATURE

This thesis is a narrative analysis that examines the common content knowledge of a group of teachers regarding energy concepts in physical science. First, this chapter will give a background of what is called common content knowledge and its role in teaching. It is the common content knowledge of the research subjects that is being analyzed. The theory being applied for the subjects’ knowledge is Resource Theory, which is outlined in the subsequent section. Resource Theory provides a framework for how the subjects created a theory of energy based on their existing knowledge. The next section details aspects of energy relevant to secondary physical science, focused on the particular concepts being analyzed in this study, which the subjects use to develop their theory. Finally, the role of self-efficacy is discussed, as the subjects demonstrated indicators of a shift in self-efficacy as they developed their theory of energy.

2.1 What is common content knowledge?

In order to teach effectively, teachers require many types of discipline-specific knowledge. Deborah Ball et al. (Ball et al., 2008) referred to this knowledge in the context of mathematics as mathematical knowledge for teaching; Figure 1 illustrates the components of mathematical knowledge for teaching as defined by Ball et al. (Ball et al., 2008). Others have broadened the idea of mathematical knowledge for teaching to the field of teaching in general, calling it content knowledge for teaching (CKT) (Etkina et al., 2018). CKT has been used to refer to, among other subjects, the topic of energy, abbreviated CKT-E (Etkina et al., 2018). Much of teacher education and professional development involves building on teachers’ CKT in order to make them better educators (Ball et al., 2008).
Ball et al. (Ball et al., 2008) divided mathematical knowledge for teaching into 2 domains: subject matter knowledge and pedagogical content knowledge. Subject matter knowledge is any knowledge required for teaching that pertains to the subject being learned, but not to the learning process; it includes the subdomains of common content knowledge, horizon content knowledge, and specialized content knowledge (Ball et al., 2008). The second domain, pedagogical content knowledge, refers to teacher knowledge that pertains to both the subject matter and to the teaching process; it is comprised of the subdomains of knowledge of content and students, knowledge of content and teaching, and knowledge of content and curriculum (Ball et al., 2008).

Of particular relevance to this thesis is the subdomain of common content knowledge. Common content knowledge (CCK) refers to a teacher’s understanding of the specific material that their students will encounter in instruction, without regard to any related concepts or form of pedagogical knowledge (Ball et al., 2008; Lucy, 2013). Because it is unrelated to pedagogy,
CCK is a type of knowledge possessed by any practitioner in a relevant field, not just in teaching (Ball et al., 2008). In order to develop CCK, a teacher must acquire and understand the essential background knowledge of the topic (Ball et al., 2008). CCK requires that a teacher be able to perform tasks such as finding a correct solution to a problem, recognizing a student’s wrong answer, and using correct terms and notation (Ball et al., 2008). Ultimately, the goal of teaching is that the students will show understanding of the CCK being taught (Lucy, 2013).

Related to but distinct from CCK is the subdomain of specialized content knowledge (SCK). Both CCK and SCK are subdomains of subject matter knowledge, but unlike CCK, specialized content knowledge is subject matter knowledge that is unique to the field of teaching (Ball et al., 2008). Lucy (Lucy, 2013, pp. 25–26) compared CCK and SCK in the context of mathematics: “During teaching, teachers need to know what mathematical answers are right or wrong (common content knowledge), but they also need to know if an answer is wrong why it is wrong so they can explain it to a student. They also need to know other ways of solving the same problem, to recognize them in student work.” (Lucy, 2013, pp. 25–26) The concept of SCK has also been applied to the topic of energy in physical science (Etkina et al., 2018; Lucy, 2013). While important, SCK will not be the focus of this analysis; rather, CCK alone and its importance to teaching will be examined further, as described in the next section.

2.2 The importance of common content knowledge to teaching

It seems intuitive that teachers must have a solid understanding of the content that they teach. Because students are expected to show an understanding of the relevant common content knowledge after instruction, teachers must also understand these concepts thoroughly to instruct effectively. For these reasons, CCK is generally thought to be a requirement for effective
teaching (Ball et al., 2008; Halim & Meerah, 2002; Lucy, 2013; Palmer, 2006). As Deborah Ball put it, “Because teaching involves showing students how to solve problems, answering students’ questions, and checking students’ work, it demands an understanding of the content of the school curriculum.” (Ball et al., 2008, p. 395). Furthermore, Ball observed that teachers who demonstrated a lack of sufficient CCK in the classroom delivered less effective lessons (Ball et al., 2008). Based on videotaped classroom observations, Ball asserted that: “When we analyzed videos of teaching, it was obvious that [CCK] is essential.” (Ball et al., 2008, p. 399).

According to the model presented in Figure 2.1, Ball et al. (Ball et al., 2008) considered both CCK and SCK to be fundamental components of teacher knowledge. Halim and Meerah (Halim & Meerah, 2002) took an even broader perspective by claiming that the types of teaching knowledge necessary for effective instruction are built upon subject matter knowledge, which includes both CCK and SCK. According to this perspective, teachers first require subject matter knowledge upon which to develop other types of teacher knowledge.

Common content knowledge is not a binary construct; that is, there are varying levels of CCK that a teacher may have (Ball et al., 2008; Lucy, 2013). Thus, measuring a teacher’s CCK is not simply a matter of whether or not they have it, but to what extent, and in what areas.

Several methods have been suggested for measuring a teacher’s CCK. Early studies looked at the amount of coursework teachers had taken in their field as an indicator of their CCK (Begle & Geeslin, 1972), although this method is now considered outdated (Nilsson & van Driel, 2011). More recent studies have used observation of classroom instruction (Ball et al., 2008), observation of professional development workshops (Nilsson & van Driel, 2011), written questionnaires (Nilsson & van Driel, 2011), and interviews (Nilsson & van Driel, 2011) as indicators of CCK. What is unclear from these discussions of content knowledge for teaching is
the nature and structure of that knowledge. For that, we focus on other perspectives, in this case, Resource Theory.

2.3 Knowledge is comprised of resources

Many theories have been developed pertaining to the structure and function of knowledge (Hammer, 2000; Sayre & Wittmann, 2008; Wittmann, 2006). One theory, Resource Theory, considers knowledge to be made up of smaller, broadly-applicable units known as resources (Hammer, 2000; Sayre & Wittmann, 2008; Wittmann, 2006). Resources are like tools in that they are basic and versatile enough to be applied to a variety of problems and scenarios (Hammer, 2000; Sayre & Wittmann, 2008; Wittmann, 2006). They often take the form of abstract generalizations; for example, the idea that phenomena (such as the ringing of a bell or a bouncing ball) tend to die away over time is an example of a resource (diSessa, 1993).

Learners carry resources with them that they have developed from previous learning experiences (Hammer, 2000). These resources can be put to use in a variety of scenarios, both familiar and unfamiliar (Hammer, 2000; Sayre & Wittmann, 2008; Wittmann, 2006). Depending on the problem or scenario at hand, certain resources are activated, meaning that the learner brings them to the forefront of their mind to be used in the context of the relevant scenario (Hammer, 2000; Sayre & Wittmann, 2008; Wittmann, 2006). A single resource on its own is insufficient to solve a problem; resources are activated in combination with other resources, forming a resource network specific to the problem at hand (Hammer, 2000; Sayre & Wittmann, 2008; Wittmann, 2006). In a resource network, resources that are associated with one another in the context of the problem or scenario are considered to be linked together (Sayre & Wittmann,
2008; Wittmann, 2006). Figure 2 shows an example of a resource network used to analyze the motion of a rolling and bouncing ball that slowly comes to rest (Wittmann, 2006).

![Resource Network Example](image)

Figure 2: Example of a resource network. Resources are shown in circles; lines between circles show connections between resources (Wittmann, 2006).

According to Resource Theory, learning occurs when novel resource networks are constructed (Sayre & Wittmann, 2008; Wittmann, 2006). These new networks typically originate from existing networks, and the changes may take the form of introducing new resources to a network, removing an existing resource from the network, or adding or removing links between resources in the network (Sayre & Wittmann, 2008; Wittmann, 2006). Wittmann (2006) demonstrated ways in which various types of conceptual change could be represented by changes in resource networks. Sayre & Wittmann (2008) further developed the theory of resource network construction by proposing that each resource has a “plasticity”; more plastic resources are those which are still being formed and less likely to be incorporated into networks than more solid resources. Newly developed resources begin as highly plastic and become more solid the more they are activated and incorporated into networks (Sayre & Wittmann, 2008).
2.4 What should students know about energy?

It is widely recognized that energy is an important concept in secondary classrooms (Brewe, 2011; Daane et al., 2015; Gray et al., 2019; Lucy, 2013). Energy is a major focus and appears in many crosscutting concepts across domains of science in the Next Generation Science Standards (Gray et al., 2019). Therefore, it is important that students develop a solid understanding of the nature of energy, and that teachers are able to teach the concept of energy effectively. As discussed in previous sections, teachers’ common content knowledge (CCK) is critical for effective teaching, so their knowledge of energy concepts is critical when teaching energy.

Energy is an abstract concept, and there are many aspects of its nature that are important to understand. This section provides an overview of some of the core concepts surrounding energy, and some methods by which these abstract concepts can be understood. When combined, these concepts lead to an understanding of the law of conservation of energy, an important principle across science disciplines.

2.4.1 Energy can change form

Energy can appear in various forms, such as kinetic, gravitational potential, thermal, and so on. Various physical interactions allow energy to be transformed from one type to another; for example, kinetic energy can be transformed to thermal energy through the force of kinetic friction. To understand energy, it is important to recognize different types of energy and understand how energy can be transformed between forms. Research has shed light on student understanding regarding energy forms and transformation (Brewe, 2011).

Eric Brewe (Brewe, 2011) proposed a fluid model of energy for physics students. Inherent in this model are analogies that encompass many properties of energy (Brewe, 2011).
One such property is the existence of various forms of energy and the ability of energy to be transformed between these forms (Brewe, 2011). In Brewe’s model, the nature of the fluid itself does not change based on the form of energy present; rather, the location of fluid within a system represents the type of energy that fluid represents (Brewe, 2011). Brewe (Brewe, 2011) referred to these locations as “containers,” with each container corresponding to a specific type of energy and corresponding physical process. Energy transformation is shown by the movement of fluid between containers (Brewe, 2011). The choice of representing energy transformation as movement between containers instead of a change in the energy “fluid” itself was to emphasize that energy maintains its identity as energy, no matter what its form or “container” might be (Brewe, 2011).

Brewe provided evidence that a curriculum consistent with the fluid model of energy results in productive discussion between students regarding energy concepts (Brewe, 2011). In one such discussion, taken from a university introductory physics course taught by Brewe himself, a group of students were asked to analyze the scenario of an object being tossed up in the air and subsequently falling back down (Brewe, 2011). The students defaulted to the use of forces to explain the object’s motion and one student applied the common misconception that the object would retain an upward impetus force as it continued to move upward, after being released from the toss, although several other students disagreed (Brewe, 2011). The student claimed that it was this impetus force that would cause the object to continue moving upward after being tossed, slowly dying away until the object began to descend (Brewe, 2011). They eventually resolved this disagreement by shifting their perspective from forces to energy (Brewe, 2011). By using the perspective of energy transformation, the students were able to see that the object’s initial kinetic energy was being transformed to gravitational potential energy by the
force of gravity as the object moved upward; thus the object did not need to retain any upward impetus force (Brewe, 2011). In another class discussion surrounding a different problem, a group of students used the idea of energy transformation to find the acceleration of a block sliding down a ramp, based on the change in velocity resulting from transformation of gravitational potential energy into kinetic energy (Brewe, 2011). In both cases, the energy transformation taking place can be thought of in terms of the fluid model of energy (Brewe, 2011).

2.4.2 Energy can move between objects and change location

In addition to energy transformation, in which energy changes form, energy can also be transferred between physical locations. Energy transfer is considered to be an important subject in national educational standards (Scherr, Close, Close, et al., 2012; Scherr, Close, McKagan, et al., 2012). Transfer is an important property of energy because it illustrates that the location of a particular energy is not fixed; it is free to move around between objects and location. Energy transfer can be observed in certain physical processes such as spontaneous heat flow between two objects of different temperatures, in which thermal energy is transferred between objects despite retaining its form as thermal energy. The idea of energy transfer is another important concept necessary for understanding the law of conservation of energy.

Similar to Brewe’s fluid model of energy (Brewe, 2011), Rachel Scherr and colleagues (Scherr, Close, Close, et al., 2012; Scherr, Close, McKagan, et al., 2012) proposed a substance ontology for energy that suggests the nature of energy is analogous to a physical substance in many ways. Like Brewe (Brewe, 2011), Scherr and colleagues (Scherr, Close, Close, et al., 2012; Scherr, Close, McKagan, et al., 2012) used the analogy of a fluid to describe the nature of
energy. Comparing energy to a physical form, with which learners have personal experience, makes the nature of energy more palpable (Scherr, Close, Close, et al., 2012; Scherr, Close, McKagan, et al., 2012). Like a physical substance, energy is not fixed in location; it can be transferred from place to place (Scherr, Close, Close, et al., 2012; Scherr, Close, McKagan, et al., 2012). Scherr et al. likened energy transfer to the flow of this fluid: just as a fluid can smoothly move between locations, so also can energy move smoothly between objects (Scherr, Close, McKagan, et al., 2012).

Some researchers have expressed concern that the substance metaphor for energy is confusing for learners, as energy does not possess many of the properties of a material substance such as mass (Scherr, Close, McKagan, et al., 2012). In response to this criticism, Scherr et al. (Scherr, Close, McKagan, et al., 2012) referred to energy as being like a “quasimaterial substance,” which retains certain properties of a material substance but also has important differences. Scherr et al. (Scherr, Close, McKagan, et al., 2012) contended that learners are able to understand the subtleties of the metaphor, recognizing that just because energy behaves as a material substance in certain ways does not mean it possesses all the properties of a material substance. Thus, Scherr and colleagues (Scherr, Close, Close, et al., 2012; Scherr, Close, McKagan, et al., 2012) stood by their assertion that a substance metaphor is a productive learning model when introducing concepts such as energy transfer.

When dealing with the transfer of energy, energy tracking is an important concept. Tracking refers to the process of following or accounting for energy as it changes location (Scherr, Close, Close, et al., 2012; Scherr, Close, McKagan, et al., 2012). There are many useful ways to represent energy transfer to assist in tracking energy, such as energy theater and energy cubes, both of which involve representing energy as discrete units in the form of objects that can
be moved around (Scherr, Close, Close, et al., 2012). When dealing with the law of conservation of energy, energy tracking becomes an important concept in light of the fact that all energy must come from previously existing energy.

### 2.4.3 Energy cannot be created nor destroyed

Two fundamental and related properties of energy state that i) energy can only come from existing energy, and ii) energy cannot be destroyed. Taken together, this paper will refer to these properties as “constant energy,” which implies that the total amount of existing energy must remain the same over time. Researchers often use the term “conservation of energy” instead of “constant energy.” However, the author of this thesis prefers the term “constant energy” to distinguish it from the law of conservation of energy, which will be discussed in Section 2.4.5.

Research has shown that understanding constant energy proves difficult for students (Brewe, 2011; Daane et al., 2015). One cause of this difficulty might be the fact that dissipative processes (such as friction) often cause energy to become less perceptible to human senses (Daane et al., 2015). For example, it may be easier to observe the kinetic energy of a moving object than to feel the thermal energy generated by friction after that object has stopped moving (Daane et al., 2015). This could give a learner the mistaken impression that some of the object’s initial kinetic energy is being “used up” or “destroyed.” Daane and colleagues (Daane et al., 2015) gave evidence that for many examples of dissipative scenarios, learners reject the idea that thermal energy comparable to the system’s initial energy has been produced.

To deal with student difficulties, pedagogical analogies have been proposed to help students conceptualize constant energy (Brewe, 2011; Daane et al., 2015; Gray et al., 2019; Scherr, Close, Close, et al., 2012; Scherr, Close, McKagan, et al., 2012). In response to the
supposed paradox that energy has decreased because its perceptibility has decreased, Daane and colleagues (Daane et al., 2015) proposed the use of exaggeration techniques which examine a related but more extreme example in which the production of a significant amount of heat is more obvious. For example, a group of teachers in a professional development workshop made sense of the thermal energy produced by a basketball rolling to a stop by comparing it with how a space shuttle heats up as it reenters the atmosphere (Daane et al., 2015).

Another pedagogical tool to help learners conceptualize constant energy is by thinking of energy as a substance-like quantity (Brewe, 2011; Gray et al., 2019; Scherr, Close, Close, et al., 2012; Scherr, Close, McKagan, et al., 2012). As with energy transformation and transfer, the comparison of energy to a physical fluid is often used to illustrate constant energy (Brewe, 2011; Scherr, Close, Close, et al., 2012; Scherr, Close, McKagan, et al., 2012). Similar to energy, a physical substance such as a fluid cannot be created nor destroyed due to conservation of mass (Brewe, 2011; Scherr, Close, Close, et al., 2012; Scherr, Close, McKagan, et al., 2012). Although this fluid may change location, or change type (e.g., ice, liquid, steam), the total amount of fluid will not change (Brewe, 2011; Scherr, Close, Close, et al., 2012; Scherr, Close, McKagan, et al., 2012). The same is true for energy (Brewe, 2011; Scherr, Close, Close, et al., 2012; Scherr, Close, McKagan, et al., 2012). The comparison of energy to a more familiar entity, matter, allows the idea of constant energy to be more accessible to learners (Brewe, 2011; Scherr, Close, Close, et al., 2012; Scherr, Close, McKagan, et al., 2012) and may even be a necessary stepping stone to understanding the constancy of a more abstract entity like energy (Scherr, Close, McKagan, et al., 2012).

The concept of constant energy can be supported by representations that describe energy as discrete, countable units. Energy can be represented in ways that emphasize that it can be
counted (Brewe, 2011; Gray et al., 2019; Scherr, Close, Close, et al., 2012). Various representations can be used. Some papers (Brewe, 2011; Scherr, Close, McKagan, et al., 2012) look at mathematical and graphical representations such as bar graphs, pie charts, and Sankey diagrams. Others (Gray et al., 2019; Scherr, Close, Close, et al., 2012) describe learner-generated diagrams in which energy is shown to be constant. In all of these cases, the use of countable units of energy plays an important role.

### 2.4.4 Systems can be defined to track energy

Despite the fact that energy cannot be created nor destroyed, it is often useful to define systems of objects for which the internal energy may or may not be constant. A system describes any object or group of objects for the purpose of energy accounting. Energy transformation and transfer may happen within this system and/or between the system and its surroundings. The concept of systems is an important component of energy analysis.

In a given context, systems are not predetermined; that is, they can be defined in ways that are most useful to the problem at hand (Lindsey et al., 2012). Many scenarios can be effectively analyzed from more than one systems standpoint (Lindsey et al., 2012). For example, a swinging pendulum’s motion is affected by the force of gravity from the Earth. The pendulum and the Earth can be defined as one system, or the pendulum could be defined as its own system, separate from the Earth (Lindsey et al., 2012). In the former case, the system comprised of the pendulum and the Earth undergoes a transformation from potential to kinetic energy as the pendulum swings down toward the Earth and a transformation from kinetic to potential as the pendulum swings up away from the Earth (Lindsey et al., 2012). In the latter case, where the system contains only the pendulum, the Earth performs positive work on the system as the
pendulum swings downward, thereby increasing its total energy, and negative work on the 
system as the pendulum swings upward, decreasing its total energy (Lindsey et al., 2012). This 
change in the system’s energy is possible because the system is defined such that energy will 
cross the system boundaries (Lindsey et al., 2012). These two choices of systems in the 
pendulum scenario lead to different conclusions about the energy in these systems, both equally 
valid (Lindsey et al., 2012).

Lindsey et al. (Lindsey et al., 2012) determined that there are several common 
misconceptions held by students pertaining to systems. One such misconception is that the 
internal energy of any system must remain constant over time (Lindsey et al., 2012). In reality, 
this is true if and only if no energy crosses the system boundary (the definition of a closed 
ystem). Usually, a student will justify this misconception by referring to “conservation of 
ergy” (Lindsey et al., 2012, p. 158), which in reality is a scientific law that is independent of 
one’s choice of systems in a given context.

2.4.5 Law of conservation of energy

Connecting together all of the properties of energy discussed in Sections 2.4.1 through 2.4.4 is 
the law of conservation of energy, which states that the total energy within any closed system 
will remain constant over time, no matter what physical processes take place within that system. 
Because it is applicable in any scenario involving energy, the law of conservation of energy 
(hereinafter referred to also as “conservation of energy” or “CoE”) is vital to the understanding 
of essentially any physical process across all domains of science. From an education standpoint, 
aspects of CoE appear in many Disciplinary Core Ideas and Crosscutting Concepts of the Next
Generation Science Standards (NGSS) (Gray et al., 2019). CoE has wide-ranging applications that make it crucial in the understanding of energy as a whole.

The law of conservation of energy cannot be properly formulated without an understanding of energy transformation, energy transfer, constant energy, and systems. Inherent in the idea of conservation is the idea that energy will change in some manner, and transformation and transfer are two forms that these changes may take: either the energy within a system will change form, or it will change its place within the system. Constant energy prohibits the creation or destruction of energy, either of which would invalidate CoE by allowing for an overall increase or decrease of existing energy. Finally, an understanding of systems gives accountability to energy tracking: if a closed system can be identified (for which no energy can enter or leave), then the energy contained within is guaranteed to be constant over time. Along with the law of conservation of energy, all of energy transformation, energy transfer, constant energy, and systems are considered constituent ideas in NGSS (Gray et al., 2019).

2.5 What is self-efficacy?

Common content knowledge, including that regarding energy, is clearly crucial to teaching and learning. What governs how a teacher perceives and uses this common content knowledge? The construct of self-efficacy sheds light on how individuals become motivated to accomplish a task.

Self-efficacy (SE) has been explored as a model by researchers for many years (e.g. Bandura, 1978). It is now defined by a well-developed framework. SE is governed by the idea that an individual’s behavior is determined by their long-term conception of its effectiveness based on their personal experience with related situations (Bandura, 1978). This is in contrast to the previous perspective that behavior is based primarily on stimuli, without much regard to
long-term patterns or the individual performing the behavior (Bandura, 1978). Bandura (1978) posited that the motivation concerning a behavior must also be rooted in these long-term conceptions.

Self-efficacy refers to an individual’s belief that they can successfully carry out a task or enact a behavior intended to produce a particular outcome (Bandura, 1978, 1982; Nissen, 2016). “Perceived self-efficacy is concerned with judgments of how well one can execute courses of action required to deal with prospective situations.” (Bandura, 1982, p. 122) The word “prospective” is important to note, as it implies that SE concerns beliefs in oneself even when the relevant situation is not immediately present. According to Bandura:

“Judgments of self-efficacy also determine how much effort people will expend and how long they will persist in the face of obstacles or aversive experiences. When beset with difficulties people who entertain serious doubts about their capabilities slacken their efforts or give up altogether, whereas those who have a strong sense of efficacy exert greater effort to master the challenges.” (Bandura, 1982, p. 123). Depending on a person’s level of SE, challenging situations can either turn them away or spur them on (Bandura, 1982). A person with low SE is more prone to giving up on a task, whereas a person with high SE is more likely to persist until they succeed, due in both cases to the person’s perception of whether persistence at the task will pay off (Bandura, 1982; Palmer, 2006).

A person’s self-efficacy can be shaped in a variety of ways, which include but are not limited to past instances of success or failure (Bandura, 1978, 1982); how an individual interprets their performance is also a key factor (Bandura, 1982). Internal perception and outside influence both play a role in shaping a person’s self-efficacy as well (Bandura, 1978, 1982). According to Bandura (1982), the most powerful method of shaping one’s SE is through enactive performance, so although outside factors can play a role, a person’s SE is determined foremost
by the outcomes of their own actions. Indeed, research shows a correlation between an individual’s SE regarding a particular activity and their successful completion of that activity (Bandura, 1978, 1982), which Bandura suggested functions as a positive feedback loop, both SE and performance adequacy reinforcing one another (Bandura, 1978, 1982).

Because certain people view certain tasks as threatening, not because they are inherently dangerous but because they perceive themselves as incapable of doing them, SE also applies to these tasks (Bandura, 1978). Bandura (1978, 1982) investigated SE as an explanation for behavior surrounding phobias. Bandura (1978)’s SE theory states that the situation itself is less influential to behavior than a person’s own perception of how they will handle that situation. A person’s SE level regarding a particular task will change in the long run based on the amount of success they have with that task. It is continual, repeated positive outcomes, not one-time scenarios that ultimately lead to improvement in a person’s SE (Bandura, 1978).

Measuring SE can be a challenging task (Bandura, 1982). Often, researchers will rely on their subjects’ own perceptions of their SE level as a means of measuring it (Bandura, 1978, 1982; Bandura et al., 1996; Nissen, 2016; Palmer, 2006), making it difficult to verify what the participants’ actual SE might be. Bandura (Bandura, 1978, 1982; Bandura et al., 1996) relied upon his study subjects’ perceptions of their SE as a measure of their actual SE. In other studies (Nissen, 2016; Palmer, 2006), formal surveys were used to attempt to measure student teachers’ SE. The reliability of these survey instruments is largely dependent on participants’ awareness of their own SE states and their willingness to express these feelings honestly. Thus, observing an individual’s SE is helpful if they are personally aware of their level of SE and are able and willing to express it.
SE, unlike self-confidence, is linked to capability in a particular activity; it is action-specific. It is completely feasible for a person to have high SE regarding one task and low SE regarding another.

2.6 How does self-efficacy relate to common content knowledge and physical science?
Common content knowledge is defined by many tasks that teachers must be able to carry out, all rooted in having a thorough understanding of the content that students are expected to master. Therefore, it is reasonable to expect that teachers have a level of self-efficacy regarding the understanding required by CCK. In order to teach effectively, a teacher’s self-efficacy surrounding this knowledge should be strong; that is, they should believe in their ability to understand and use the content to at least the extent of a student who has mastered it. This section explains the nature of self-efficacy regarding teachers’ use of common content knowledge, both inside and outside of the classroom.

Teacher self-efficacy has been defined as “[a] teacher’s belief or conviction that they can influence how well students learn, even those who may be difficult or unmotivated” (Deehan et al., 2017, p. 2551). For teachers to assess the impact of their teaching on their students, teachers require a reasonable level of SE regarding their ability to teach these students effectively (Deehan et al., 2017). Studies have shown that teachers with high SE make a more positive impact on their students than those with low SE (Deehan et al., 2017). A teacher who lacks SE regarding their teaching practice can have a negative impact on their students’ learning (Palmer, 2006).

Many studies have examined the self-efficacy of teachers or future teachers within the realm of physical science (Deehan et al., 2017; Nilsson & van Driel, 2011; Nissen, 2016; Palmer,
Science is often a daunting subject to elementary or prospective teachers (Deehan et al., 2017; Nilsson & van Driel, 2011; Palmer, 2006), which implies that these teachers’ SE regarding their ability to teach science is low (Deehan et al., 2017; Nilsson & van Driel, 2011; Nissen, 2016; Palmer, 2006). Deehan (2017) asserted that “Many teachers do not feel confident in their ability to teach science because of their inadequate science content knowledge.” Conversely, there is evidence that teachers with a strong understanding of science content have better SE with respect to their content knowledge than those who do not (Palmer, 2006).

Albert Bandura recognized that several factors can change a person’s level of SE (Bandura, 1978, 1982; Palmer, 2006). Palmer (2006) proposed that there also exist factors specific to teaching that can affect a teacher’s SE surrounding their content knowledge. What Palmer referred to as “cognitive content mastery” (Palmer, 2006, p. 339) is a teacher’s successful performance in demonstrating (often to themselves) that they understand the CCK required to teach in their field. Palmer (2006) identified the act of understanding as the action behind this mastery: “This type of mastery experience is distinct from enactive mastery because it involves success in understanding something rather than success in doing something.” (Palmer, 2006, p. 339). Due to the role of successful performance in enhancing SE, cognitive content mastery is presumed to have a positive effect on a teacher’s SE with respect to their CCK (Palmer, 2006), an assumption that was corroborated by the results of Palmer’s study (Palmer, 2006). Professional development programs are one way that teachers can improve their content knowledge and SE surrounding that knowledge (Deehan et al., 2017). Collaborative learning environments have been shown to improve teacher SE (Deehan et al., 2017). Aside from cognitive content mastery, Palmer (Palmer, 2006) also identified other pedagogical factors that may boost a teacher’s SE.
Self-efficacy is also closely linked to student performance (Nissen, 2016). Various authors have examined the role of SE for students in physical science courses (Nissen, 2016; Palmer, 2006). Some have found that female students are especially prone to lack SE with respect to their understanding of physical science principles (Nissen, 2016). It could be inferred that female teachers might have the same struggles in physical science as their student counterparts.

Because SE regards an action or behavior, so must SE regarding CCK be linked to the set of actions that defines CCK, such as finding a correct solution to a problem, recognizing a student’s wrong answer, and using correct terms and notation (Ball et al., 2008). Common content knowledge is a necessary component of teacher knowledge, so it could be said that SE regarding CCK must be a necessary component of SE regarding teaching at large.
3. METHODS

This chapter describes the way in which the data for this study were collected and analyzed. First, the professional development setting from which the data originate is described, including the workshop’s origin and purpose, the educational material that was used, and the means by which data were recorded. Second, a brief description of the study subjects is given, explaining their backgrounds and why they were chosen as the focus of this study. Next, the process by which the original audio data were translated into a written transcript is explained. Finally, the analysis methods that were used are described, including examples of how this analysis was carried out.

3.1 PD Setting

The professional development (PD) session from which the data for this thesis arise was part of a series of workshops conducted by Michael Wittmann, PhD. and Maine PSP Resource Coordinator Jason Baker, both of the University of Maine. The workshops were designed for secondary physical science teachers, and built on the research of Levi Lucy, a former student from the Master of Science in Teaching program at the RiSE Center at the University of Maine. Three such workshops were held in three separate locations in the greater Bangor, Maine area, all within the course of a month. The data for this thesis are taken from one of these workshops, held on April 9, 2013 in Ellsworth, Maine. This section provides a background of the research that inspired the PD session, and the goals for the series of workshops of which this session was a part.
3.1.1 History of the PD setting: Levi Lucy’s masters thesis

The PD workshops were conducted as a follow up to the research conducted by a former Master of Science in Teaching student, Levi Lucy, as the subject of his thesis. Lucy compiled and administered a survey to several middle school physical science teachers in Maine and to their students (Lucy, 2013). The survey was designed to test teacher and student knowledge of energy concepts in physical science, including teacher knowledge of student ideas, and to look for correlations between the knowledge of teachers and of their students. The teachers who completed the survey for Lucy’s thesis were asked to answer each question in two ways: first, to select their choice for the correct answer, and second, to predict which incorrect answer students most commonly pick, along with an explanation of student thinking for this answer. It was Lucy’s claim that these two methods of answering measure common content knowledge (CCK) and knowledge of content and students (KCS), respectively (Lucy, 2013). The students who completed the survey were only asked to give the correct answer to each question. To assess what students had learned in the classroom, the assessment was given to the students before the relevant concepts were taught, and again after they were taught, and the results were compared.

The data collected by Lucy suggest that there is a positive correlation between teachers’ KCS on the survey questions and the improvement of their students on the same survey. This finding suggests that KCS possessed by teachers has a significant impact on student learning. The correlation between teacher CCK and student performance could not be assessed, as no incorrect answers were given for any of the questions by the teachers who took the survey.
3.1.2 Nature of the survey

The energy survey which was administered to teachers and students as part of Levi Lucy’s thesis was comprised of eight multiple-choice items and one free-response item. The multiple-choice items were taken from the American Association for the Advancement of Science (AAAS) website (Assessment Resources | American Association for the Advancement of Science, n.d.). The free response question, which was the last item on the survey, was written by Lucy. The survey was designed to take a teacher 5 – 10 minutes to complete.

The answer choices for the multiple-choice items were chosen such that incorrect answers were based on common student misconceptions; therefore, each incorrect answer choice might indicate the nature of the misconception held by a teacher or student. This method of selecting answer choices is advantageous for assessing teacher KCS, as incorrect answers are intended to correspond closely to common student misconceptions. Each of the multiple-choice questions addressed one or more core energy concepts in secondary physical science; some of these concepts appeared in more than one question on the survey, and some questions required more than one concept to arrive at a correct answer. These concepts include, but are not limited to: different forms of energy (such as kinetic and heat), energy transformation, energy transfer, conservation of energy, open and closed systems, energy dissipation through friction, and energy dissipation through heat transfer.

Each of the concepts mentioned above plays a significant role in the understanding of energy. In the case of open and closed systems, each problem specifies whether the system is open or closed. The terms “open system” or “closed system” never appear in the survey; rather, the nature of the system can be deduced based on the question’s wording. For example, question 4 states: “Assume that no energy is transferred to or from the surroundings,” implying a closed
system. Each problem defines the relevant system carefully; either the question explicitly identifies which objects are part of the system, or the system can be assumed based on the object or objects that are being analyzed. For example, question 1 asks: “What happens to the energy of the box as it slides across the floor…?,” implying that the system consists of the box only.

A closed system is a helpful concept for understanding the law of conservation of energy: Because no energy can cross the boundary of a closed system, all the initial energy in the system must remain in that system. This means that if a question on the survey asks how the amount of final energy in a closed system relates to the amount of initial energy, the correct answer will always be that they are the same. This naturally leads into the portion of the law of conservation of energy that states that energy can neither be created nor destroyed. In the case of an open system, energy can leave or enter the system, which makes the comparison of the amount of initial and final energy less obvious.

Friction is another important component of the survey questions. In the survey, the word “friction” is not mentioned by name until the last question (question 9—the free-response question). Rather, in all of the questions that involve friction, a statement is made from which the reader can infer that there is friction in the system. For example, question 1 states: “As the box slides across the floor, the box slows down and both the box and the floor get a little warmer.” This simultaneous decrease in kinetic energy and increase in heat energy implies that there is friction in this system. Question 4 also emphasizes that the objects in the system get warmer.

Friction is an important component of the survey questions because it may appear to change the amount of energy in a system by converting kinetic energy to thermal energy. In some scenarios, because friction is a non-conservative force, thermal energy generated by friction cannot be transformed back into kinetic or potential energy, leading to the impression
that this energy is ‘lost.’ Or it may appear that the total energy of the system increases due to the increase in thermal energy. These are common misconceptions among students (Daane et al., 2015). Understanding the nature of friction is useful in understanding the law of conservation of energy, both because friction causes a transformation of energy, and because the increase in heat energy is equal to the decrease in kinetic energy.

3.1.3 Purpose of the PD

Because the results of Lucy’s thesis were noteworthy, Dr. Michael Wittmann decided to use the same survey and the data gathered by Lucy for teacher professional development. The teachers who attended the PD sessions worked in small groups to complete the survey; they were asked to provide the correct answer as well as the most common incorrect student answer, along with the student’s hypothetical line of reasoning, in the same manner as the teachers who participated in Lucy’s research. The teachers were encouraged to confer with their group members and to discuss the reasoning behind their answers. After the teachers had completed the survey, Dr. Wittmann held a full-room discussion encouraging participants in the PD to share their thoughts about the activity. Additionally, the findings of Lucy’s research were discussed, and teachers were encouraged to give their interpretations of the results.

The PD session was intended to further teachers’ understanding of how their own knowledge of content and students affects their students’ learning. The teachers who attended were encouraged to think creatively about the assessment questions, with the hope that they would become more conscious of the types of reasoning that might lead students to arrive at different conclusions. By sharing their ideas with the other attendees, and by examining the findings of Lucy’s thesis, they might be better prepared to teach energy concepts in the future.
Additionally, Wittmann sought teacher input on the findings from Lucy’s thesis. However, the teachers spent much more time completing the survey than originally intended, leaving limited time for discussion focused on the workshop’s intentions.

3.1.4 Nature of the data

Each group of teachers at the PD workshops was audio-recorded for the duration of the session. Each audio recording includes the group members’ discussion as they complete the survey and the ensuing discussion with the larger group of attendees.

The data used in this thesis come from an audio recording of the teachers in one of the groups from one of the PD workshops. Occasionally, conversations taking place in other small groups can be heard in the background of the recording. The survey itself is also used as data for this thesis, which comes directly from the Appendix of Lucy’s thesis (Lucy, 2013). It is included in this thesis as Appendix B.

3.2 Research Subjects

The group that is the focus of this thesis was made up of three teachers: Alice, Betty, and Cindy (pseudonyms). They worked together in a small group to complete the survey, then participated in the subsequent full-room discussion with all of the workshop attendees.

3.2.1 Subjects’ backgrounds

All three of the teachers being analyzed taught at schools in central Maine. Two of the teachers in this group, Betty and Cindy, were middle school physical science teachers; the third, Alice, was an elementary school special education teacher. Because of the grade level and subject they
taught, both Betty and Cindy were familiar with the Maine PSP physical science curriculum for middle school students. Alice had also encountered the curriculum through some of the students she had supported in the special ed program.

### 3.2.2 Why choose this group?

When it comes to studying learning, students are often the focus of study, but it is valuable to observe teachers in positions of learners as well. Analyzing what happens during professional development sessions provides the opportunity to do so, as these sessions provide a setting in which teachers function as learners. When learning is studied, the student’s (or in this case, teacher’s) growth as a learner can be evaluated.

The conversation among Alice, Betty, and Cindy was noteworthy because it demonstrated growth in two ways: in their common content knowledge pertaining to energy, and in their self-efficacy regarding this knowledge. Although all three group members began the survey with claims that they did not understand the relevant content and were therefore incapable of effectively completing the survey, they successfully navigated all of the survey questions, and as they did so, expressed improved self-efficacy regarding their ability to understand concepts on this topic. In essence, their conversation provides deep insight into the learning process, in both the dimension of knowledge and of perceived ability to apply that knowledge. The purpose of analyzing the teachers’ conversation, which will be discussed in Chapter 4, is to examine this learning process in detail.
3.3 Development of the transcript

The original audio recording of the group consisting of Alice, Betty, and Cindy was transcribed by the author of this thesis. The transcript is included as Appendix A. The original audio is 1 hour and 29 minutes long. Most of the audio recording was transcribed, but certain sections were omitted because they contained no relevant content or were otherwise off-topic. These omitted sections are noted in the transcript as they occur.

The transcript is organized into sections labeled by topic; in earlier parts of the recording, each section title refers to the survey question that the teachers were discussing, and in later parts, the section titles refer to another aspect of the PD activities (for example, “Revisiting questions for KCS”). This was done to summarize for the reader what the teachers were discussing during each part of their conversation and to make specific points in their conversation easier to locate in the full transcript.

The author decided to assign sequential line numbers, rather than timestamps, to each line of the transcript. Recording the timestamp for each line proved to be too time consuming and unnecessary. Instead, timestamps are given at the beginning of each section and for the parts of the audio that were omitted, as a reference to the reader. The use of line numbers makes it easier to refer to particular details in the teachers’ conversation than if timestamps were used. Each line of the transcript contains a single turn of talk, or a nonverbal note, such as a pause in the conversation. (A turn of talk refers to one person’s contribution to the dialogue, in between contributions made by the others.) Because the conversation involves many instances of more than one person speaking at a time, the notation “[crosstalk]” is often used to indicate that one person is speaking over another, with the interjection found in the subsequent line(s). Similarly, “[simult]” refers to more than one person speaking simultaneously.
Several people aside from Alice, Betty, and Cindy occasionally participated in their conversation. More often than any other, Michael Wittmann joined the three teachers’ conversation to check in with them. In the transcript, he is referenced as “Michael,” because he and Alice, Betty, and Cindy were on a first name basis. Even though Michael represented an authority figure when it came to physics content knowledge, his relationship with these teachers was nevertheless informal. Aside from Michael, other teachers who participated in the workshop are referred to anonymously as Man 1/Woman 1 and so forth. Any instance in which a speaker with the same name appears more than once (e.g. “Man 1” appears multiple times at different points throughout the transcript) indicates that this is the same person speaking.

3.4 Analysis

The analysis of the transcript focuses on the research questions that were defined for this study:

1. How can teachers construct an understanding of the law of conservation of energy during a professional development activity without it being explicitly taught to them?

2. In what ways does teachers’ self-efficacy change in a professional development setting as learning takes place?

Many examples throughout the transcript address these research questions; these are discussed and analyzed in the order that they occur in the transcript.

3.4.1 Approach

This thesis uses a narrative analysis research design, as it is described in the literature (Butina, 2015; Creswell & Poth, 2017). Narrative analysis (also called narrative research or narrative inquiry) can be generally defined as the relaying of an individual’s or small group’s personal
experience through the retelling of a story of that experience (Butina, 2015; Creswell & Poth, 2017). In this case, the story is that of Alice, Betty, and Cindy as they complete the survey, with their discussion serving as the data. Defining procedures of narrative analysis are “Analyzing data for stories, ‘restorying’ stories, and developing themes, often using a chronology” (Creswell & Poth, 2017, p. 105). Indeed, the analysis in this thesis aims to create a story of the events that took place with this group of teachers, in a way that highlights conceptually important details in chronological order, and extract general themes from these details. This is accomplished by using methods such as “restorying, theorizing, and [creating] narrative segments” (Creswell & Poth, 2017, p. 106). Examples of this process are given in the following sections.

The teachers’ conversation was analyzed to make inferences about their understanding of energy concepts and their level of self-efficacy pertaining to that understanding. Alice, Betty, and Cindy often articulated their understanding of energy concepts as they pertained to the survey. Likewise, they made explicit statements about their self-efficacy regarding this knowledge. Because their thoughts surrounding energy content and self-efficacy were often clearly stated, the analysis contained in this paper is solely based on the teachers’ words and does not attempt to analyze any type of non-lingual cues, such as pace, inflection, and pauses. For consistency, a method had to be established to analyze the teachers’ use of language. The process by which inferences were made from the language that the teachers used is described below.

3.4.2 Analysis of statements regarding energy

The conversation among Alice, Betty, and Cindy centered primarily around developing an understanding of energy concepts as they pertained to the survey questions. Thus, analysis of the teachers’ conversation was primarily concerned with their understanding of energy. This
includes the ideas about energy that the teachers discussed and what conclusions about energy they came to throughout the discussion process.

Two main types of verbal evidence were used to support claims about the teachers’ understanding of energy: evidence based on what they said directly, and evidence based on what was implied by their wording. In general, the energy concepts themselves that the teachers discussed could be inferred from what they stated directly. Alice, Betty, or Cindy would often overtly articulate a particular concept, such as the idea that new energy cannot be created from nothing. Despite sometimes lacking the specific vocabulary to refer to their ideas, they typically expressed scientific concepts with clarity.

In contrast, when it came to the process by which the teachers reasoned through these ideas and ultimately decided if they were credible or not, more subtle conversational cues had to be interpreted. These subtle cues could take a variety of forms. Often, a connection is made between what the teachers were saying in a particular moment and something similar they had discussed earlier in their conversation. Sometimes the teachers upheld their earlier claims, and at other times, they showed evidence of changing their minds. Often, the teachers showed signs of general agreement with what one of the others had said. In some instances, the way one of the teachers phrased a particular idea is examined, sometimes in contrast to another way they might have worded the same idea.

An example of the use of both types of verbal evidence can be found in Cindy’s statement from line 377: “What happens to the total amount of energy?…It has to stay the same.” Cindy directly stated that the amount of energy under consideration would not change, and (reading aloud from question 7) that she was referring to the overall (total) amount of energy present in the system in question 7 when she said this. Furthermore, more subtle cues give more
information about the meaning behind Cindy’s statement. Her use of the phrase “has to stay the same” suggested a level of necessity that phrases like “will stay the same” or “is going to stay the same” would not have. This sense of necessity is taken to mean that Cindy viewed the idea that the energy in this system would stay the same as a general scientific law, independent of the context of question 7. In other words, according to Cindy, the system could not react in any other way. When analyzed in combination with some of the teachers’ prior dialogue, Cindy’s comment in line 377 is the first time that the teachers as a group had concluded that energy in any closed system must remain constant. Specific details on the reasons behind this conclusion are fleshed out in Chapter 4.

3.4.3 Analysis of statements regarding self-efficacy

When analyzing the teachers’ expressed level of self-efficacy (SE), only overt statements of SE were considered. In order for a statement made by one of the teachers to be considered overt, the language used by the teacher must refer specifically to her perceived ability to complete the survey and therefore understand energy, or follow directly in the context of the conversation. For example, Betty’s comments “[Cindy is] the only one who knows anything” (line 3) and “We’re lucky we got Cindy” (line 5) would both be considered statements of low self-efficacy: the first of these statements directly states that Betty did not know anything about the subject of energy, and the second statement implies that she was relying on someone else to carry her through the task of completing the survey. In contrast, Betty’s remark “I’m glad I’m not with a high school person” (line 73) is a statement that could be taken as an expression of low SE: it is likely, based on other remarks from the three teachers, that Betty would have been uncomfortable working with a group of high school teachers. Because she taught at the middle school level, a high
school teacher would presumably have had more knowledge of energy than Betty. By contrast, Betty might have felt insufficient compared to a high school teacher. Because this would have made her feel less capable, it might have caused her SE to be low. However, for the sake of this thesis, line 73 would not be counted as an indication of SE, because Betty did not explicitly mention her perceived ability to complete the survey.

When applied to the full transcript, the methods of analysis described above yielded a detailed story of the teachers’ experience in terms of both their energy content knowledge and their self-efficacy. The next chapter contains the findings from this analysis.
4. FINDINGS

This chapter contains the findings from analyzing the transcript of the conversation that Alice, Betty, and Cindy had during their participation in the professional development workshop. Before they had begun the survey, Alice, Betty, and Cindy all claimed to have no knowledge of energy concepts as they pertained to the survey questions. By the time they finished the survey, they had collectively constructed an accurate theory of conservation of energy, using only the content of the survey questions, the knowledge they had already possessed, and a few hints from other participants. Throughout the process of completing the survey, the three teachers expressed a change in self-efficacy pertaining to their common content knowledge in the subject matter, from a low level of self-efficacy at the start of the survey to a high level by the time they had finished.

As Alice, Betty, and Cindy completed the survey, they discussed a variety of energy concepts relevant to each question. As they began to go through the questions, all three of them were able to contribute ideas regarding energy. As they did so, various expressions of self-efficacy, either low or high, were observed. Their ideas developed into a theory: as they answered the survey questions, the teachers used various components of this theory to inform their answer choice to each question, and in turn, were able to further expand and refine their theory. Eventually, the teachers were ready to think of the theory as their own.

Alice, Betty, and Cindy explicitly referred to the theory as they developed it. Because they used the word ‘theory’ to describe the set of ideas that they were discovering, this thesis will also refer to it as a ‘theory.’ The teachers concisely stated what their theory consisted of multiple times. Revisions to and expansions of their theory can be identified based on concepts they
discussed, with indicators like general agreement as well as the use of the concept to answer a question as evidence that that concept had indeed been integrated into their theory.

Although it was Alice, Betty, and Cindy who showed growth over the course of the professional development session, other workshop participants played a role in the teachers’ discussion. It is important to consider Michael Wittmann’s role as a workshop facilitator when analyzing the teachers’ conversation. The setting of the workshop was informal, but nevertheless, the teachers saw Michael as an expert since he was in the position of the workshop leader. Michael circulated among groups, regularly checking in with Alice, Betty, and Cindy. Although he did not teach them any concepts directly, he served as a source of affirmation for their ideas. In many cases, the three teachers asked Michael to confirm or deny an idea they had constructed. Michael provided Alice, Betty, and Cindy with encouragement on their progress, an important consideration in light of the observations surrounding the teachers’ professed self-efficacy. Because of Michael’s influence on the group members, it must be recognized that he was an integral part of the three teachers’ growth during the workshop. It is possible that the teachers would not have had the same breakthrough in understanding without Michael’s help. They may not have expressed the same shift in their self-efficacy, nor taken the risk of applying their theory to novel situations to the same extent. As will be discussed, Alice, Betty, and Cindy took ownership of their ideas, but Michael might be considered to have co-constructed their understanding.

This chapter will first explore the importance of both conservation of energy and self-efficacy. Then, it will begin to analyze the teachers’ conversation, starting with their initial claims of lacking knowledge in energy. Next, it will show the process by which the teachers worked through several energy concepts, including that energy cannot be created or destroyed.
and can have various forms, and that systems can be defined to track changes in energy. Finally, examples will be shown of how the teachers applied what they had learned about energy first to novel scenarios involving energy and then to pedagogy. Throughout each section that analyzes the teachers’ conversation, indicators of self-efficacy, whether high or low, will be discussed as they occur.

4.1 Reasons for focusing on conservation of energy

The teachers discussed a variety of energy concepts, some of which came up regularly and others which were mentioned relatively few times, or only once. Although many other of the energy concepts that were discussed could potentially be analyzed in detail, this thesis will focus only on energy concepts which are fundamental to the law of conservation of energy (CoE). There are many reasons that CoE was chosen to be the focus of this thesis.

First, CoE is a prevalent theme among the survey questions. Although a complete understanding of CoE is not required to answer every question, such an understanding is useful in most, perhaps every question. Some of the questions require that ideas inherent to CoE be applied: for example, question 5 involves a quantitative approach to account for all of the energy in a system before and after an event (in this case, the release of a spring) has occurred. In order to answer the question correctly, it is necessary to understand that the energy in a closed system must remain constant over time, but that it can change form and/or be transferred between objects in that system.

Second, the teachers’ theory is, in essence, a restatement of the law of conservation of energy. As will be discussed, this became clear when the teachers stated their theory in its entirety. They restated their theory a few times, and each time, CoE was apparent within it.
Eventually, Alice, Betty, and Cindy were able to identify the phrase “conservation of energy” as the canonical scientific name for the theory that they called their own.

Finally, because CoE is a fundamental concept across all domains of science as evidenced by its prevalence in the Next Generation Science Standards (NGSS) (Gray et al., 2019), it seems worth choosing as a topic of analysis. Analyzing how CoE can be understood could be beneficial in developing curriculum and assessment pertaining to the topic of energy. Likewise, the successes and struggles that Alice, Betty, and Cindy may have had while learning about CoE may be very similar to those experienced by students, and could provide insight into students’ thinking processes and the nature of their knowledge.

Because this thesis focuses only on energy concepts relating to CoE, not all discussions involving energy from the transcript will be analyzed in this chapter. This is due to constraints in the scope of this study and is not meant to indicate that these topics are of less significance. Thus, some portions of the teachers’ conversations about energy will not be found in the following sections. Additionally, the dialogue surrounding survey questions 3 and 8 has been omitted entirely from the following analysis, because it does not contain discussion of any concepts that pertain to the fundamentals of CoE. The full transcript of the teachers’ conversation can be found in Appendix A.

4.2 Role of self-efficacy

As they completed the survey, Alice, Betty, and Cindy gained expertise in the topics included therein. It is expectable that as a person gains knowledge in a particular topic, their self-efficacy (SE) pertaining to that knowledge will increase. In the transcript of their conversation, there were many instances in which Alice, Betty, and/or Cindy gave overt statements pertaining to their
level of SE regarding their knowledge of energy concepts, particularly conservation of energy. These moments are considered to be an important part of the teachers’ conversation, as they show that not only was a change in knowledge taking place, but also a shift in their perceived ability to apply that knowledge.

The level of SE expressed by Alice, Betty, and Cindy, both high and low, coincided with their process of learning about energy and developing their theory. In general, as the teachers furthered their knowledge of energy and expanded their theory, their expressed level of SE improved. Several instances were identified in the transcript in which significant discoveries about energy coincided with improvements in one or more of the teachers’ SE. These instances will be discussed as they occur in the transcript. Although attempting to establish a causal connection between discoveries about energy concepts and moments of transition in SE is beyond the scope of this study, these moments are included because they enhance the narrative of the teachers’ collaborative learning and problem-solving process.

It is important to note that the shift observed in these teachers’ conversation is in their expression of self-efficacy, and not necessarily in their self-efficacy itself. It is not outside the realm of possibility that some of the statements that Alice, Betty, and/or Cindy made about their level of SE are exaggerated or false. Attempting to analyze whether or not the statements made by Alice, Betty, and Cindy are genuine is beyond the scope of this study.

This study focuses on expressions of SE pertaining to the teachers’ common content knowledge (CCK) of energy concepts as defined by (Ball et al., 2008). There are times that the teachers make a reference to their SE regarding aspects of teacher knowledge other than CCK. In some of these cases, these instances are still considered to be related to CCK in ways that will be discussed in this analysis as they occur.
4.3 Claims of no initial knowledge

At the beginning of the recording, Alice, Betty, and Cindy claimed that they had insufficient knowledge of energy to answer the questions on the survey. The teachers’ assertions that they lacked this initial knowledge of energy turned out to be inaccurate, as will be explained in the subsequent sections.

The following dialogue occurred between the three teachers:

3 Betty: [to Cindy] You’re the only one who knows anything.
4 Cindy: [stutters] Oh my gosh, you—
5 Betty: We’re lucky we got Cindy. [laughs]
6 Alice: Yes, we’re lucky to have…
7 Cindy: You might not be saying that, by the end of this.
8 [general laughter]
9 Cindy: Yes, ’cause I’m normally—
10 Alice: [to Cindy] We won’t know any different! [laughs]
11 Cindy: —I’m normally the one that goes, “Yeah, that sounds good.”
12 Betty: [laughs]

On line 3 of the transcript, Betty said to Cindy: “You’re the only one who knows anything.” This revealed Betty’s belief that she herself did not have any knowledge of energy concepts. Implicit in her statement is the assumption that Alice had no knowledge of energy concepts either, as Betty was identifying Cindy as the sole member of the group who had any knowledge on the subject. Betty reemphasized her point by saying, “We’re lucky we got Cindy.” (line 5), and Alice agreed (line 6). Thus Betty was exempting herself from having any initial knowledge of energy. Betty’s statement does not imply that Cindy had no knowledge of energy; in fact, it implies just the opposite. Furthermore, although Betty spoke on behalf of Alice, Alice herself may have felt differently. Her comment on line 6 expressed gratitude for Cindy, but Alice did not necessarily mean to imply that she herself had no knowledge.
However, Alice and Cindy soon professed their own ignorance on the subject of energy: Cindy replied to Alice’s and Betty’s comments on lines 3, 5, and 6 with, “You might not be saying that, by the end of this.” (line 7) This implies that Cindy was also claiming ignorance on the subject of energy: she rejected the others’ assertions that Cindy knew what she was doing. Alice replied to Cindy with, “We won’t know any different!” (line 10) By saying this, Alice implied that it wouldn’t matter if Cindy had no knowledge of energy, as neither she nor Betty had any of their own knowledge of the subject. In the first 10 lines of the transcript, all three teachers had asserted implicitly that they had no knowledge of energy concepts.

Each example of Alice, Betty, or Cindy claiming that they had no knowledge of energy also demonstrates that their level of self-efficacy with respect to these energy concepts was low. In order to have SE regarding the application of knowledge, one must possess that knowledge to begin with. A person cannot have SE if they believe they are totally unfamiliar with the subject to which that SE pertains. Thus, by claiming ignorance on the topic of energy, Alice, Betty, and Cindy were simultaneously expressing low SE pertaining to this subject. In later instances in their conversation, statements about energy were distinct from those about SE, as will be discussed.

Additionally, Cindy’s comment on line 11 is indicative of low SE, as she predicted what her role in the group might be. She refuted the compliment that Betty gave her in lines 3 and 5 by suggesting that Betty might change her mind once she had observed Cindy attempt to answer the survey questions. Cindy was suggesting that she did not possess a level of competence in the subject matter that deserved praise from her group members. When Cindy described herself as “the one that goes, ‘Yeah, that sounds good,’” she was most likely suggesting that she viewed herself as a passive member of many groups, and simply tended to go along with whatever her
group members thought. If Cindy had had a higher level of SE during group work in the past, she would have presumably been able to contribute more of her own ideas. Cindy’s comment suggests that she believed that her role in this group would be more or less the same as it had been in other groups.

Other lines from the transcript give further evidence that the teachers did not believe to have any understanding of energy: In line 28, Cindy said, “And I haven’t done energy yet,” to which Betty replied, “I don’t think they have at our school either.” (line 30) By saying this, Cindy suggested that she did not have an understanding of energy because she had not yet been required to teach it. Betty’s comment not only echoed this sentiment; it also revealed that she was not aware of the topic of energy’s place in the school curriculum. If Betty had been responsible for teaching energy, she would have known whether or not it had been taught at her school. Alice also expressed her lack of background in energy topics in the following conversation:

58 Alice: I haven’t seen my 8th graders—I have two 8th graders and sometimes we do some of their science stuff in my room.
59 Cindy: Yeah.
60 Alice: You know it’s part of their reading program, [crosstalk] or to support the math pieces.
61 Cindy: Right.
62 Alice: But I haven’t seen anything about the [inaudible]
63 Cindy: [finishes the thought] …energy.
64 Alice: Yeah.

Alice told the others that she had had experience working with her students on science assignments (line 58) but the topic of energy had never arisen (lines 62-64). By this point in the transcript, all three teachers had established that they had not taught or discussed energy in the classroom at any point in the recent past. Thus, they had not needed to understand energy theory for the purpose of teaching it. Such an understanding of energy would have been necessary to succeed on the survey. As with prior examples, these statements in which the teachers denied
that they had knowledge of energy concepts also show that they had low SE regarding these concepts.

One final expression of low SE is noteworthy in the following conversation between Alice, Betty, and Cindy and a teacher from a different small group (referred to as “Man 1”):

32 Man 1: You don’t have to share any of your answers.
33 Betty: Oh okay.
34 Alice: This is supposed to be collaborative.
35 Cindy: [to Man 1] Okay.
36 Alice: ’Cause we don’t know what we’re doing.
37 Man 1: No, I’m saying you don’t have to share any of your answers.
39 Betty: [also understands] Oh, oh—okay.
40 Man 1: So don’t feel self-conscious, just—
41 Cindy: [interrupts] So we just smile and nod when we’re going over everything.
42 Betty: [laughs]
43 Cindy: [jokingly, mocking] Yeah, that sounds good!

In this conversation, Alice made perhaps the most obvious statement of her lack of SE, directed at Man 1: “We don’t know what we’re doing.” (line 36) This is a clear statement that Alice did not believe that she had the skills necessary to complete the task at hand, which is the definition of low SE. In this instance, she was not only expressing her own self-inefficacy, but also speaking on behalf of all of her fellow group members, who by this time had all expressed their own self-inefficacy.

At this time, Cindy also spoke on behalf of the whole group. By commenting, “So we just smile and nod when we’re going over everything: ‘Yeah, that sounds good!’” (lines 41, 43), she reiterated her previously expressed self-image as a passive group member. In this case, however, she was suggesting that all three of them, not just herself, may have ended up playing passive group member roles when all of the workshop attendees were convening to share their answers. She said this after all three of them had expressed SE, and her comment had changed from an individual observation to an observation that applied to Alice and Betty as well.
Even as the teachers were constructing their theory, there were times when they referred back to having started with insufficient knowledge of energy. Such statements are useful, as they show that even as the teachers began to understand energy concepts, they were consistent in their assertions that they had started with no knowledge. These instances will be analyzed as they occur in the transcript.

The teachers’ assertion that they began the survey with insufficient knowledge of energy offers the unique opportunity to observe the development of their theory in its entirety. Because the teachers claimed to have no knowledge at the start, there were no concepts that the teachers would have taken to be obvious, and therefore not discussed as a group. Thus, it is assumed that every step in the development of the teachers’ theory was spoken out loud during the recording. This eliminates the possibility that the teachers’ theory was based partially on concepts which were not spoken during the recording. Thus, it is assumed that every statement that became a part of their theory can be found in the recording, and therefore in the transcript. This makes the teachers’ thinking process as they expanded their theory very clear, making the analysis more reliable.

4.4 Energy can neither be created nor destroyed and can have different forms

Alice, Betty, and Cindy began to make discoveries and deductions about energy concepts shortly after they began to answer the survey questions. The developments that they made to their theory while answering questions 1 and 2 centered mostly on energy existing in different forms, which allows energy to change form rather than being created from nothing or destroyed entirely. During these two questions, the teachers explored how instances where energy appears to be
created or destroyed are actually cases of energy transformation. While answering later questions, they would assert that energy can never be created or destroyed in any situation.

The first development was the realization that energy exists in several different forms. This occurred while answering question 1 (Figure 3).

The following conversation occurred as they were discussing the answer choices to question 1:

76 Alice: Well [answer choice] D can’t be right—“an object only has energy when it’s moving…”
77 [pause, ~15 sec]
78 Cindy: Yeah, it’s not D, ’cause I know there’s potential energy in everything;
79 Betty: Right.
80 Alice: Exactly.
81 Cindy: Everything has that potential energy [crosstalk] so we can cross that one off.

In line 76, Alice suggested that objects do not need to be in motion to have energy, indicating that types of energy other than motion energy exist. Cindy followed up on this idea in lines 78 and 81 by suggesting that objects have a potential energy that is a different type of energy than motion energy. She did not offer any specifics at this point as to what potential energy might be, but it is nevertheless an idea with which Betty and Cindy agreed without hesitation (lines 79 and 80). By introducing the idea and garnering agreement, Cindy opened up the possibility of
considering energy in many different forms. By identifying that energy can exist in more than one form, the teachers took the first step in setting the stage for the idea of transformation from one type of energy to another, which is one of the core concepts in CoE.

Shortly thereafter, the teachers used the idea of the existence of different types of energy to decide whether it was feasible for new energy to be created. The following excerpt shows how they incorporated the idea of potential energy into the discussion:

87 Cindy: Yeah, and what’s [answer choice] C?—“The motion energy of the box stays the same and its thermal energy increases because new energy in the form of the thermal energy is made.”
88 Betty: But there’s no new energy.
89 Alice: [interrupting] But the motion energy [crosstalk] can’t stay the same, because it’s stopped.
90 Cindy: But…[interrupting] Yeah, because it’s slowing down [crosstalk], so it has to be decreasing. [crosstalk] The motion energy has to be decreasing otherwise it would keep sliding across the floor.
91 Betty: Right.
92 Betty & Alice: Right.
93 Alice: [interrupting] And—and so this is what’s happening: it got a push—
94 Betty: [interrupting] And—the…the difference between these two questions [answer choices] too is that this one says “energy is converted into” and this one says “new energy is made.”
95 Cindy: Yeah.
96 Alice: Right.
97 Betty: So…you’re not gonna make new energy; it’s potential; it’s already there.
98 Cindy: Right.
99 Alice: Right.
100 Betty: It’s just changed into something—

In line 88, Betty rejected the idea that new energy would be created (as in answer choice C), and for the first time, identified the distinction between creating new energy and converting, in other words transforming existing energy (line 94) by referring to the difference in wording between answer choices A and C. Betty followed this up by offering a plausible explanation: that the energy that appeared to be new was actually already there in the form of potential energy (line 97) and that it had somehow been changed into something else (line 100). At this point in the discussion it was not clear what Betty may have meant by “changed,” but her idea elicited
general agreement from the others (lines 98 and 99). In terms of CoE, Betty’s assertions are the basis of the idea that energy can be transformed from one type to another, an idea which the teachers soon expounded on while answering the subsequent survey questions.

During the same discussion, Alice observed that the motion energy of an object that is slowing down must change (line 89). In this case, the box in question 1 is slowing down to a stop, so Alice reasoned that its energy cannot remain constant as its speed decreases. Cindy agreed with this point and clarified that an object that is slowing down must be losing motion energy (line 90). Alice and Betty agreed (lines 91-92). This was the first time that the teachers talked about a decrease in a particular type of energy—in this case, kinetic energy. Although none of them questioned whether that initial kinetic energy might go somewhere, or whether it is destroyed entirely, the teachers acknowledged the disappearance of one type of energy, which would soon lead them to question where, if anywhere, that energy goes. The teachers would address this conundrum as they worked on question 2.
Question 2, shown in Figure 4, involves a swinging pendulum that gradually stops swinging.

Figure 4: Question 2 on the survey.

Question 2 led Alice, Betty, and Cindy to expand their theory: in this question, they were required to account for energy that has ostensibly disappeared, or been used up. This is evident in the following excerpt:

116 Betty: Okay. So...my choice is B.
117 Alice: [inaudible] choice too.
118 Cindy: That’s the one I was thinking too, and I was trying to explain, like, thinking of why I thought that.
119 Betty: Well I think it’s because of the part where it’s—
120 Alice: [interrupting, confidently] Because the motion energy isn’t transferred anywhere else.
Betty: Its—it’s not really used up though, so that’s… [slowly and deliberately] “the motion energy is not used up”… now that I reread it.

Cindy: Yeah.

Alice: [very softly] “A little bit of the ball’s motion energy is used up…” [fades away]

Betty: C also says energy is used up. [implying that can’t be the answer]

In the conversation above, there was an abrupt change in the teachers’ opinion on whether or not the motion energy of the pendulum was transferred somewhere else. At first, all three teachers agreed that the energy of the swinging pendulum would not be transferred anywhere (lines 116, 118, 120). However, it was the phrase “used up” in answer choice B that led Betty to be skeptical of her assumption (line 121): it did not make sense to her that the motion energy of the pendulum could be used up. Cindy seemed to agree (line 122), while Alice appeared to be considering Betty’s idea (line 123). Betty applied her idea to reject answer choice C as well (line 124).

After the teachers had rejected the idea that energy of the pendulum could be “used up,” they were confronted with the problem of deciding what might happen to that energy as the pendulum slows down. This was their discussion:

Alice: But [the energy of the pendulum] also is transferred somewhere else, like the air.

Betty: Yeah, so this one says it’s not transferred; this one says it is transferred—

Cindy: —both of them say the energy is ‘used up.’

Betty: And then [answer choice] A says “is transferred somewhere else, like the air, as the ball swings from side to side,” so, in—when it goes swing to side to side, is that, like, the air means that the air is—will be moving, then? So is that where the motion is going? Is that what it means?

Cindy: [incredulously] I—I guess.

Alice: [contemplatively] “Why does the ball stop swinging?”

Betty: So it trans [inaudible] when it’s moving.

Alice: It [crosstalk] stops moving because the friction of the air is making it slow down.

Betty: It’s pushing the air, right?

Cindy: It’s pushing the air. [simultaneously with Alice] …slow down.

Alice: [simult with Cindy] Theoretically in a vacuum it would keep right on going.

In line 126, Alice indirectly rescinded her statement in line 120 by asserting that the pendulum’s energy would be transferred to the air around it. Betty responded to Alice with confusion about what it might mean for the energy to be transferred to the air (line 130). This is when the idea of
friction is first discussed; Alice summarized it succinctly: “[The pendulum] stops moving because the friction of the air is making it slow down.” (line 134) She expanded on this idea by contrasting the scenario in question 2 with a pendulum in a vacuum (line 137). Alice correctly identified that friction cannot rob the pendulum of energy in a vacuum, because there would be no air friction, so the pendulum would never stop.

By the time they had finished answering question 2, Alice, Betty, and Cindy had correctly identified an instance in which a transformation of energy appeared to produce new energy and one in which a transformation made energy appear to be used up. They went on to use these ideas to account for the amount of energy in a closed system in some of the following questions.

4.5 Energy of a closed system

Some of the survey questions, starting with question 4, require that the total amount of energy in a closed system be considered. These questions ask how the total amount of energy in a system compares before and after an event. In order to answer these questions correctly, it was necessary for the teachers to understand that the total amount of energy in a closed system must stay constant over time. This is implied by the nature of a closed system (by definition, no energy can enter or exit) and the fact that energy cannot be created or destroyed. While answering these questions, Alice, Betty, and Cindy applied their discoveries from questions 1 and 2 to account for the total energy of each system.
Question 4 is shown in Figure 5.

The teachers had the following discussion while answering question 4:

233 Alice: Okay, “the total energy of the ball and track system increases because new energy is—”
            [definitively] No. New energy is not formed.
234 Betty: It might be D this time. I decided to go from the bottom up.
235 Alice: “The total energy of the ball and track system decreases because the ball loses all of its energy and eventually stops rolling.” [continues to read through answer choices, then softer] “The total energy…”
236 Betty: It says “no energy is transferred to or from the surroundings.”
237 [pause, ~4 sec]
238 Betty: But new energy’s not made, right?
239 Alice: No.
240 Betty: Didn’t we determine—didn’t we decide that?
241 Cindy: I—I—I th[ink]—
242 Betty: Everything has potential energy, [crosstalk] it just has to be put in motion. Right?
243 Cindy: Right. [simult with Betty] Right.

Alice was quick to assert that no new energy is formed in this scenario (line 233), which was consistent with the ideas of new energy that the three teachers had developed while answering questions 1 and 2. She also seemed to realize the importance of the idea of total energy to the context of the question, as she purposefully repeated, “The total energy…” (line 235): this was a significant realization, because for the first time during the survey, the question required the teachers to account for an amount of energy, not just a transformation from one type to another. The concept of total energy also required that the teachers take into account energy in all of its possible forms. Alice, Betty, and Cindy had explored some of these different types of energy in the context of questions 1 and 2, and they were now being required in question 4 to think of these various types of energy as a single entity. Immediately after, Betty identified another aspect of the scenario that required all of the energy to be accounted for: the fact that no energy could enter or leave the system under consideration (line 236). This is the concept of a closed system: because no energy can enter or exit the system, none of the energy that was present initially can be accounted for by claiming that it left the system, nor can any of the final energy be accounted for by claiming that it entered the system.

When answering questions 1 and 2, Alice, Betty, and Cindy had used the idea that energy could not be created or destroyed, but they had not made it clear whether these rules applied only to the particular question, or to all scenarios. The discussion they had while answering question 4 settled this uncertainty. In line 238, Betty remarked, “But new energy’s not made, right?” Her wording seems to suggest that she was proposing this as a general rule that is true for all scenarios. If she had meant her rule only in the context of question 4, she might have said something like, “new energy won’t be made,” or, “new energy isn’t going to be made,” which
both imply context due to their wording. Alice agreed with Betty’s remark (line 239). Betty’s follow-up comment, “Didn’t we determine—didn’t we decide that?” (line 240) clarified her meaning: Since the teachers had not yet discussed whether or not new energy could be created in the context of question 4, Betty was presumably referring to their earlier discussions surrounding questions 1 and 2. The words “determine” and “decide” suggest that Betty assumed that their conclusions from questions 1 and 2 should apply to other scenarios. Because Betty was transferring her knowledge from previous questions to the present question, she was presenting the idea that new energy cannot be created as a general rule, independent of the context of the question.

Further evidence that Betty had begun to adopt the idea as applicable to all scenarios comes from her statement on line 242. Her statement offered a specific explanation of why new energy cannot be created, and it draws on an idea that the teachers had already accepted as being universal, that all objects have potential energy. Cindy had previously made this claim in lines 78 and 81, and Betty’s statement in line 242 applied it to the context of question 4. Because Betty claimed that “everything” has potential energy, she again framed the idea as being independent of context. She then used this claim to offer an alternative to the creation of new energy: that instead, it is potential energy that is “put in motion.” Cindy agreed with Betty’s claim (line 243). Much like her statements in lines 97 and 100, Betty suggested that potential energy would be transformed into something else instead of new energy being created. However, the phrase “has [emphasis added] to be put in motion” (line 242) suggests a level of necessity: if new energy appears, existing potential energy must have been transformed to have caused this change. In contrast, statements like those in lines 97 and 100 speak of context: the word “gonna” (“going to”) in the phrase “you’re not gonna make new energy” (line 97) implies that Betty was speaking
only in the context of question 1; otherwise she might have said, “you can’t make new energy.” Similarly, in “it’s potential; it’s already there” (line 97) and “It’s just changed” (line 100), “it” must refer to the potential energy specific to question 1, as the teachers had not yet encountered any other questions at that time. The fact that Betty made the claim in line 242 to follow up on her first clear assertions that energy can never be created from nothing (lines 238 and 240) strengthens the evidence that she was speaking in a general sense.

The teachers continued to expand their ideas about energy transformation and systems to select the answer for question 4:

247 Betty: I think it’s [answer choice] D.
248 Alice: “The total energy of the ball and [track] system does not change—”
249 Cindy: [continues reading] “[—because even though it’s [energy is] transferred…”
250 Alice: “…because even though energy is transferred between the ball and track—”
251 Cindy: [interrupting] “[—no energy was added to or released].”
252 Alice: “…no energy was added to or released from…”
253 Betty: Right.
254 Cindy: It’s just changing the type of energy.
255 Betty: Right.
256 Cindy: Yeah.
257 Betty: Because it seems [crosstalk] from “the ball and track system,” this is looking at this one as a whole system [crosstalk]—not individually as the ball and the track but the whole thing.
258 Cindy: I agree with that…Mmm hmm.
259 Alice: Yeah.
260 Cindy: Right.
261 Betty: So even though it does get warmer, nothing has left [crosstalk] and nothing’s added; it’s all still there, [crosstalk] just changed—
262 Alice: Right

In lines 247-252, Alice, Betty, and Cindy read through and considered answer choice D, which is the correct answer to question 4. Choice D includes important aspects of CoE: that energy can change through transfer between objects, that a system can be defined for which no energy enters or leaves, and that the total internal energy of such a system will be constant over time. The teachers picked up on these details as they discussed question 4. Cindy correctly identified that
the type of energy would change in this scenario (line 254). Her use of the word “type” may have been to emphasize that it is the type instead of the amount of energy that changes in question 4. Betty agreed with Cindy (line 255).

Betty’s next statements were a pivotal moment in the conversation. In line 257, she pointed out the concept of a system for the first time during the discussion. Although the teachers had previously read the word “system” from the survey, they had not said anything to indicate that they understood what a system refers to in this context. This changed when Betty referred to the wording of “ball and track system” used in the question as evidence that the ball and track should be thought of as a single unit. She furthered her point by contrasting the idea of a system with consideration of objects individually. This garnered agreement from Cindy and Alice (lines 258–260).

Once Betty had established that the ball and track were intended to be thought of as a system, she explained what this meant in terms of energy analysis. In line 261, Betty resolved the paradox that if something gets warmer then new energy must be created. Her use of the wording “even though” suggests that an object that gets warmer could be mistaken to have energy that was just created, but that this is not actually the case. Her follow-up comment, “nothing has left and nothing’s added” (line 261) parallels the wording of answer choice D, “no energy was added to or released from.” This wording does not refer to energy created or destroyed within the system, but rather that no energy would enter or exit, as the system is closed. When Betty said that the energy is “all still there” (line 261), she presumably meant that no energy would be created or destroyed—the word “all” implies that no energy is destroyed, because “all” of it remains (“still there”). Although “all still there” does not preclude the possibility that new energy is created, Betty seemed to imply this as well; as mentioned, her use of the words “even though”
(line 261) suggest that new energy appears to be created, but in reality it is not. Furthermore, Alice, Betty, and Cindy had already agreed that no new energy can ever be created, so it is unlikely that Betty would have changed her mind without explicitly saying so. Finally, Betty mentioned that the energy present in the ball and track system had “just changed” (line 261), implying that the cause of the temperature increase was actually a change in existing energy, not the introduction or creation of new energy. On the whole, Betty’s remarks from line 261 framed the process in question 4 as a change in energy within a system, where no energy leaves or enters, or is created or destroyed. Alice and Cindy expressed agreement (lines 262-263), and Cindy clarified that the change Betty was describing referred to the type of energy.

Taken together, Betty’s statements from lines 257 and 261 contain all of the elements of the law of conservation of energy: that the amount of energy in a system will not change (“nothing has left and nothing’s added; it’s all still there” -line 261), that the energy can change form (“just changed” -line 261), and that the system must be closed in order for this to happen (“this is looking at this one as a whole system—not individually as the ball and the track but the whole thing” -line 257). Although her statements were made in the context of question 4, it would later become clear that the teachers were applying these same rules to all scenarios. Unbeknownst to her, Betty had just stated an early version of what would become the teachers’ theory.

Although Alice, Betty, and Cindy decided that new energy can never be created as a universal rule while answering question 4, they did not specifically state that it is impossible for energy to be destroyed completely in any scenario as well. They had ruled out the idea of energy being used up in question 2, and Betty’s statements from lines 257 and 261 led the teachers to the same conclusion for question 4. Betty’s statement of “it’s all still there” (line 261), referring
to the energy in the system, sounds context-dependent. If she had meant that it is impossible for energy to be used up, she might have said instead, “it all \textit{has to be} still there” or “it \textit{must} all still be there,” which both imply necessity as a general rule. Nevertheless, the teachers had begun to treat the idea that energy can never be used up as a consistent rule, and they would continue to do so in question 5 and beyond.

The teachers were able to apply the ideas about energy conservation that they had developed while answering question 4 in order to answer question 5. Question 5 (Figure 6) involves a compressed spring that transfers energy to a cart as the spring is allowed to expand. The amount of initial energy of the spring is shown as a bar graph, with each answer choice showing a bar graph representing the energy of the spring and the cart after the spring is released.
A student compresses a spring and holds a cart next to the spring. The graph shows the amount of elastic energy the spring has when it is compressed and the amount of motion energy (kinetic energy) the cart has before it starts moving.

Before student lets go of the cart

After he lets go of the cart, the spring pushes the cart and the cart rolls across the floor.

Which of the following graphs represents the elastic energy of the spring and the motion energy (kinetic energy) of the cart when the cart is rolling across the floor and the spring is no longer in contact with the cart? (Assume that no energy is transferred between the spring and its surroundings and no energy is transferred between the cart and its surroundings.)

A.  

B.  

C.  

D.  

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Figure 6: Question 5 on the survey.
Like question 4, question 5 refers to a defined system in which no energy can enter or leave. Thus, the teachers were able to apply similar logic to question 5 as they did to question 4. The reasoning process they used to answer question 5 showed that they were able to transfer ideas from previous questions to the novel scenario presented in question 5.

Once Alice, Betty, and Cindy had read through the question, they began to make observations based on their developing theory. In line 274, Betty remarked, “So as soon as this spring is let go, it doesn’t have any more energy,” an important point because it indicates that the total energy of the spring must decrease to zero. Thus, the teachers again were faced with a scenario in which they needed to account for a decrease in a particular type of energy, in this case, the spring’s initial energy. They reasoned through it in the following conversation:

277 Cindy: [sighs] I feel like it has to be C.
278 Betty: Yeah…I agree with you.
279 Alice: It’s gotta be C.
280 Betty: Yuh, I agree with you, because this no longer has any—
281 Cindy: [interrupting] When it’s pushed in…
282 Alice: Right.
283 Cindy: I was listening to what [man from another group] was saying [crosstalk] this should be, like, here, like, it might still be bouncing a little bit, [crosstalk] but we don’t have that choice; there’s definitely more energy in the cart, [crosstalk] and it’s not the same at this point.
284 Alice: It has no more energy.
285 Betty: Right…Yeah, yup.
286 Alice: Uh-huh.
287 Betty: Because right now, this doesn’t have any more elastic energy.
288 Cindy: Right, it’s out.
289 Alice: Right, right, it’s only—
290 Betty: It now has kinetic energy, right?
291 Cindy: Right.
292 Alice: Right.
293 Cindy: Now we’re looking at the cart’s moving; it’s given its energy to the cart, [crosstalk] and pushed the cart.
294 Betty: Yup…Yup. I’d say C, too.
295 Alice: It’s gotta be C.
296 Cindy: Alright.

All three teachers initially agreed that choice C was the correct answer (lines 277-279). They seemed to have come to this conclusion independently, since none of them hesitated or had to be
persuaded into agreeing. Betty may have used process of elimination to arrive at her answer choice: after having asserted in line 274 that the spring would lose all of its energy after being released, she told Alice and Cindy that she agreed with them because, “this no longer has any” (line 280), where “this” presumably refers to the amount of energy shown on the graph for the spring after it had been released. Since choice C is the only answer choice for which the spring has no remaining energy, Betty may have reasoned by process of elimination that it must be the correct answer. Alice expressed her agreement (lines 282, 284) and reiterated in line 284 that, “[The spring] has no more energy.”

Because C was the only answer choice for which the spring did not retain any energy, Betty’s process of elimination would have been sufficient to determine the correct answer. However, the teachers continued to discuss what would happen to the spring’s initial energy in order to further justify their answer choice. In line 283, Cindy asserted that the cart would end up with most, if not all of the energy in the system. By “bouncing a little bit,” she likely meant that the spring might still have been moving slightly after it had been released, and therefore might have retained a small amount of energy. But as she pointed out immediately after, none of the answer choices showed the spring having only a small amount of energy remaining. Betty and Alice agreed with Cindy’s claims (lines 285-286). Cindy’s statement from line 283 was the first instance of one of the teachers alluding to a conversation that they had overheard from another group.

Betty and Cindy went on to articulate how the energy in the system changed form from elastic to kinetic and how it was transferred from the spring to the cart. In line 287, Betty used the information given in the question that the spring initially had elastic energy and that after being released, it would no longer have that elastic energy, with which Cindy and Alice agreed.
(lines 288-289). Consistent with their earlier discussion of transformation of energy from one type to another, Betty stated in line 290 that the energy present after the spring had pushed the cart would be kinetic energy, not elastic. Again, Cindy and Alice agreed with her (lines 291-292). Cindy clarified that the cart’s final kinetic energy was given to it by the initial energy of the compressed spring (line 293). The question did not explicitly state that the spring gave its energy to the cart, nor had the teachers previously stated that this was the source of the cart’s energy, so Cindy’s statement did not arise from the question itself. The transfer of energy from one object to another is a crucial idea of CoE, because it allows energy to move between objects in a system. Once all of this had been established, the three teachers were ready to agree on their answer choice for question 5 (lines 294-296).

Unlike the questions that precede it, question 5 offers a quantitative representation of the law of conservation of energy. Each of the bar graphs found in question 5 uses the vertical axis to represent the amount of energy in the spring and in the cart. The vertical scale has units that divide the graph into six segments, where each segment presumably represents a certain amount of energy. (See Figure 6.) The graph in the question’s introduction shows that the spring initially had 5 ‘units’ of energy. By CoE, this means that if no energy enters or leaves the system, the total energy of the system will remain at 5 units. Answer choice C, which is the correct answer and the answer that the teachers chose shows that after the cart has been pushed, the spring no longer contains any units of energy, and the cart contains all 5 units of energy in the system. The teachers did not acknowledge this quantitative relationship during their conversation surrounding question 5, but they recognized it when they referred back to question 5 later in their discussion, while answering question 7.
Question 6 (Figure 7) also required the teachers to think quantitatively, as they were presented with a scenario in which positions on a track are labeled on a numbered scale, with higher numbers corresponding to positions of greater height. The teachers were required to identify the relationship between the points on the track and the energy of a ball at those points.

![Image of a track with labeled positions](image)

**Figure 7: Question 6 on the survey.**

After reading through the question, the teachers had the following conversation:

320 Betty: Well it’s gonna go—isn’t it gonna go back up the same distance it goes down?
321 Alice: Hmmmm…
322 Betty: If it goes down to here, doesn’t it have the same energy to go back up?
323 Alice: [interrupting] If no energy is transferring, it should never stop, either.
324 [pause, ~4 sec]
325 Betty: [quickly] It doesn’t say it has to stop. It just says before it goes—[crosstalk] if it—once it goes up, how far will it go up before it goes back down—it doesn’t say it will necessarily stop.
Betty’s comment on line 320, in which she claims that the ball will go back up to its starting height (position 2), shows that the correct answer can sometimes be in the form of gut instinct—in this case, Betty was likely basing her prediction on real-life observations. Alice would later bring up a real-life example by making the comparison to a roller coaster (line 332). Betty clarified her point with her comment on line 322 by identifying the role of energy in this scenario: The ball possesses energy when it is at the bottom of the track, and that energy is what causes the ball to go back up the track. Betty’s use of the phrase “the same energy” implies that the amount of energy present in the ball when at the bottom of the track will remain in the ball as it goes back up the track, and it will determine how far back up the track the ball will go.

Because Betty used the evidence in line 322 to justify her claim that the ball will go back up to its original height, it can be inferred that by “same energy,” Betty meant same amount of energy, as that would explain why the ball would return to its original height. Thus, Betty was claiming that the energy of the ball is conserved as it moves back up the track.

Alice’s next comments resulted from confusion on semantics, but they were nevertheless an important observation about a system with the absence of friction. Question 6 refers to the ball “stopping and going back down the track,” which means that the ball would stop for an instant when its kinetic energy is zero and its potential energy is maximum, after which the ball would begin to travel back down the track again. In line 323, Alice expressed confusion that the ball was said to “stop,” making a reference to where the question stated that no energy would transfer out of the ball. Since the teachers had already established that energy cannot be destroyed, Alice knew that the amount of energy in the ball would not change over time, since
there would be nowhere for that energy to go. She also must have recognized that the speed of the ball indicates how much energy it has, and that a ball that had stopped would not have as much energy as one that was rolling. Therefore, Alice reasoned that the ball’s back-and-forth motion would continue forever; it would never stop and remain stopped. This is essentially the same idea that Alice expressed about a pendulum while answer question 2: “Theoretically in a vacuum [the pendulum] would keep right on going.” (line 137) In line 325, Betty expressed agreement with Alice that the ball would not stop, not recognizing the wording in the question that was confusing Alice. Betty mentioned the ball going up before coming back down, but she did not identify the transition between going up and coming down as the ball “stopping.” In line 326, Alice realized her mistake as she reread the wording of question 6. It was then that Betty recognized the significance of the word “stop” in the question as no longer going up (line 327). In line 328, Alice rephrased Betty’s observation in line 327, and Betty expressed agreement in line 329. Thus, the confusion on the question’s wording was resolved. Alice’s observation about the use of the word “stopping” was an important one, as it showed that she was accounting for all of the ball’s energy, and that the ball in this situation must remain in perpetual back-and-forth motion for its energy to be conserved.

The teachers continued to discuss the question:

330 Alice: No energy is transferred, it’s gonna keep right on going, but I think it’ll only go as far as [position] 2, but I can’t think of the rule because, does—can’t it not go higher than it started at?
331 Betty: Well, it depends on—
332 Alice: Isn’t that the whole premise of roller coasters?
333 Cindy: [interrupting] It doesn’t have any more energy, like, it’s…it’s…I don’t know…This is how much energy it started with, to get down to where it has to go back up, so it can’t have more energy than—to go up higher.
334 Betty: [interrupting, inaudible]
335 Alice: [interrupting] Right, so it can’t go past the 2.
336 [pause, ~4 sec]
337 Betty: Right?
In line 330, Alice first reiterated her conclusion from line 323: that because no energy is being transferred into or out of the ball, it would never stop rolling back and forth. She then continued to claim that the ball would not go up higher than its starting height. She demonstrated that the physics concepts underlying question 6 were intuitive to her—the ball should not be able to go higher than its starting position. Betty had showed in line 320 that she had a similar intuition, without having to understand the physics on a higher level. It is unclear what Betty might have been claiming it depended on in line 331, but Alice furthered her point in line 332 by making a comparison to the real-life scenario of a roller coaster: that by intuition, a roller coaster car cannot coast to greater heights than its starting height. Alice’s observation shows that she was taking the concepts inherent in CoE and examining them at work in a familiar scenario.

Cindy’s comment on line 333 shows that she was able to apply the previously agreed-upon rule that new energy cannot be created to the scenario in question 6. She referred to “[the amount of] energy [the ball] started with” as a certain quantity that would not increase. Cindy used the phrases “It doesn’t have any more energy” and “it can’t have more energy…to go up higher” to show that the energy would remain the same as the ball moved down and up the track. Inherent in the latter of these statements is the (correct) assumption that the height of the ball corresponds to the ball’s energy, and that the amount of energy that the ball started with would limit the maximum height of the ball. Alice expressed agreement with Cindy (line 335), and offered specificity that the ball could only reach position 2 when going back up the track. Betty and Cindy indicated agreement (lines 337-338).

In line 339, Betty showed evidence that her self-efficacy was beginning to improve. She responded to the idea that the ball couldn’t go higher than it started by saying, “That seems so
simple.” This is in contrast with her initial assertion that energy was a topic beyond her understanding (e.g. line 3). The fact that Betty expressed a level of ease with an energy topic demonstrates a clear shift from the level of self-doubt she had initially expressed: by suggesting that the concept was easy, she implied that it was a concept she was capable of understanding. Betty’s comment occurred shortly after Alice’s comparison of question 6 to a roller coaster (line 332). It is noteworthy that shortly after the teachers considered a real-life example (the roller coaster) pertaining to the problem, Betty began to express a sense of ease with the energy concept. Perhaps the comparison to something more familiar to her, like a roller coaster, precipitated this comment. Thus, she was no longer claiming to be incapable of understanding any aspect of energy, and this, by definition, means she was expressing a higher level of self-efficacy than she had earlier.

Later in the conversation, Alice reiterated her conclusion from line 330: “If no energy is being transferred [between the ball and track]… [the ball] should only be able to go up as high as it started from…” (line 347) However, unlike in line 330, where Alice used the fact that no energy would be transferred to conclude that the ball would never stop rolling back and forth, in line 347, Alice made a direct connection between no energy being transferred into or out of the ball and the conclusion that the ball would only go up the track to its starting height. This is in line with Cindy’s statement from line 333: that the ball would not have any additional energy to go higher than it started. However, Alice’s statement from line 347 gives a broader explanation: it is the fact that no energy is transferred into or out of the ball which means it must reach the same height as that at which it began. The fact that no energy is transferred implies that the ball does not gain or lose any energy. Again, Alice’s explanation implies that maximum height is an indicator of the energy of the ball. Cindy expressed agreement with Alice’s comment (line 348).
The teachers went on to further clarify their thinking:

352 Betty: [interrupting] But it seems like it would go [emphasis] fast then slow, and then slower.
353 Cindy: Then it slows down until it—
354 Alice: No, if it goes slower and slower then it’s going to be losing energy and it doesn’t lose energy.
355 Betty: It doesn’t say it goes slower and slower.
356 Alice: It’s gonna come down, and it’s gonna go up to a certain point, and then it’s gonna come back down and go back to this point.
357 Betty: Right.
358 Alice: What I’m saying, it can only go as high as it started from. It only builds up enough energy between here and here to go from here to here.
359 Cindy: But it has to slow down.
360 Betty: Mmm hmm.
361 Cindy: Yeah, that’s kinda what I was thinking too.
362 Betty: Mmm hmm.

More confusion on semantics is evident in the first few lines of the excerpt. In line 352, Betty described the ball as slowing down gradually. In the context of question six, the ball will be moving fastest at the bottom of the track and will slow down as it moves up the track, eventually coming to a standstill at its highest point for an instant before heading back down the track. This is presumably what Betty meant. The wording of the question mentions the ball “stopping and going back down the track,” but it does not describe the ball slowing down as it does so. Thus, Betty’s comment was of her own observation. In line 353, Cindy reiterated Betty’s comment, that the ball would slow down, adding “until it”—she was interrupted by Alice, but Cindy might have been about to mention that the ball would slow down until it reached its highest point. Alice misunderstood what Betty and Cindy were referring to; in line 354, she said that a ball that is slowing down would be losing energy, which would be true if the ball’s maximum speed decreased over time. Through her statement, Alice correctly identified the correlation between the speed of an object and its (kinetic) energy—specifically that as an object slows down, it loses kinetic energy. She had already expressed her understanding that the ball could not be losing energy, because the question stated that no energy would be transferred into or out of
the ball. Alice’s statement from line 354 is similar to the confusion that she expressed in line 323, when she said that the ball would never stop because that would mean that it would be losing energy.

In line 355, Betty seemingly contradicted her statement from line 352, by claiming that the ball would not slow down. She may have been influenced by Alice’s reasoning from line 354 and shifted her definition of “slow down” to match Alice’s. Alice responded by explaining that the ball would go up to its maximum height, move back down again, and eventually reach its original height (line 356). Betty agreed with this statement (line 357).

In lines 358-362 of the excerpt, the teachers discussed the process of transformation between gravitational potential energy and kinetic energy. In line 358, Alice first reiterated that the ball would not reach a greater height than that at which it started. (She presumably meant that it would go exactly to its starting height, as evidenced by the teachers’ eventual selection of position 2 as their answer.) She then described the ball “build[ing] up…energy” (line 358) as it moves down the track, and described the energy that it builds up as the energy expended to move the ball up the other side of the track. She said that it would only build up enough energy to go back up to its starting height. Although she did not identify it as such, the building up of energy that Alice was describing referred to the transformation from potential energy to kinetic energy as the ball moved down the track, and the expending of energy referred to the transformation back from kinetic energy to potential energy as the ball rolled back up the track. Thus in line 358, Alice identified two instances of the transformation of energy from one type to another. Cindy added that the ball would slow down as it moved up the track (line 359). Betty and Cindy expressed agreement with this analysis (lines 360-362).
Question 7 (Figure 8) also required the teachers to account for the total energy in a closed system. Similar to question 5, question 7 involves the transformation of stored energy in a rubber band into kinetic energy in a toy car. Question 7 specifies explicitly that the system is comprised of the car and rubber band and that no energy will enter or leave this system.

![Figure 8: Question 7 on the survey.](image)

After examining the question, Alice, Betty, and Cindy had the following conversation:

376 Alice: [interrupting] “Imagine that no…” Okay: “What happens to the total amount of energy in the system when the car is moving across the floor and no contact…” [fades to a mumble]

377 Cindy: [interrupting] “What happens to the total amount of energy?” [confidently] It has to stay the same.

378 Betty: Yeah, because this [energy in Q5] stayed the same.
379  [pages flipping]
380  Cindy:  [laughs] If we go with that theory.
381  Betty:  [interrupting] [counting the bars on Q5] One, two, three, four, five; one, two, three, four, five—So if we chose this [answer choice C on Q5], this…elastic energy of the spring was—the total amount of that energy was transferred to the total amount of motion energy of the cart.
382  Cindy:  Right…
383  Betty:  And that’s what the—isn’t that the premise we’ve been using all along, [crosstalk] is the energy is never goes, and is never made, [crosstalk] it just changes?
384  Cindy:  Yeah… It’s just different—[laughs] That is the theory we’ve been going on.
385  Alice:  Okay, so what’s the answer?
386  Betty & Cindy:  [laughing]
387  Cindy:  Let’s stick with it. It’s been working!

In line 377, Cindy stated that the energy in the system in question 7 has to stay the same. Her wording suggests a level of necessity; she did not say “will stay the same” or “is going to stay the same,” but rather “has to stay the same.” Whereas the former two phrasings would suggest a conclusion valid for the context of the question, the language of “has to” implies a more universal law. The idea that the total energy in a closed system must remain constant is an important conclusion that can be drawn from CoE. Cindy’s statement on line 377 is the first time during the teachers’ discussion that one of the teachers said that by necessity, the amount of energy in a closed system must remain constant. Betty responded to Cindy with agreement, and made a comparison to question 5 (line 378); the fact that Betty was referring to question 5 is evident in the subsequent discussion, which is discussed below. Cindy’s reply, “If we go with that theory,” (line 380), suggests that she was basing her analysis on the conclusions that the teachers had drawn while answering question 5.

Cindy’s response (line 380) was the first instance of the word “theory” in the teachers’ conversation. The framing of the teachers’ thinking as a theory was an important development in their conceptualization of energy; because Alice, Betty, and Cindy had claimed to have no understanding of energy at the beginning of the survey, their discussion was comprised of a series of ideas about energy that applied to each particular scenario. Eventually, they decided that
many of these ideas were universal, and were able to apply them to multiple questions. Cindy’s use of the word theory showed a recognition that the ideas the teachers had been working with were related and consistently applicable across the survey questions. Calling their ideas a theory soon allowed the teachers to recognize the process they had gone through to go from professed inefficacy in energy concepts to a set of consistent rules. Cindy first used the phrasing “that theory” (line 380), which did not show ownership of the theory, but all three teachers would soon switch to the phrasing “our theory,” which shows a recognition that they were the ones who had developed it. Initially, the theory Cindy was referring to was specifically regarding the total energy in a closed system. However, their theory would soon take on a broader definition to become the law of conservation of energy. Like a tool, the teachers would go on to use their theory as a basis to analyze every scenario.

In line 381, Betty demonstrated a quantitative approach to this newly recognized theory: she counted the number of “units” of energy shown in the bar graphs in question 5. She counted to 5 twice, presumably counting the number of units of energy contained by the spring in the initial graph, and then the corresponding units of energy contained in the cart in answer choice C, their chosen answer. Her next statement suggests that she was counting so as to compare the amount of initial energy in the spring in question 5 to the amount of final energy in the cart. Her wording, “elastic energy of the spring was—the total amount of that energy was transferred to the total amount of motion energy of the cart” (line 381) gives evidence that Betty recognized the relationship between the 5 units of energy in each of the two graphs. She acknowledged that the spring had energy that, through a process of energy transfer, was given to the cart. Her use of the word “total” suggests that she was accounting for the energy in each object in its entirety, and that all of the spring’s energy was transferred to the cart. It was apparent that Betty was referring
back to question 5, both because her counting to 5 represented the units of energy in the two graphs, and because question 5 is the only question that refers to a spring and a cart.

With the phrasing “So if we chose this [answer choice C on Q5]” (line 381), Betty demonstrated a connection between the teachers’ reasoning on question 5 and question 7, suggesting that the same reasoning (now called a “theory”) could be applied to both. This statement was a follow up to her statement “Yeah, because this [energy in Q5] stayed the same.” (line 378), by which she was arguing that their reasoning for question 5 could support their answer choice for question 7. Like question 7, question 5 requires the understanding that the total energy in a closed system must remain constant over time. Betty’s statement in line 381 shows the transfer of knowledge between these two questions. Cindy indicated agreement with Betty (line 382).

Quantitative reasoning, such as that used by Betty when counting the units of energy in question 5 (line 381), is an important application of CoE. Assigning a value for the amount of energy contained in a system is the basis for the use of energy calculations within that system. It serves as a numerical representation of equality between the initial and final energy within a system. The fact that Betty recognized the importance of considering energy as numerical units strengthens the evidence that she understood that all of the energy in a system must be accounted for. By counting the units of energy in question 5, she was confirming that the quantity of these units remained constant before and after an event, which is implied by CoE. This quantitative reasoning represents another significant development in the teachers’ thinking.

The next statements by Betty and Cindy were pivotal in their conversation. Betty’s comment in line 383 contained the first succinct summary of the teachers’ theory: “…the energy is [sic] never goes, and is never made… it just changes.” All of the fundamentals of CoE are
encompassed in this statement: that energy cannot be destroyed ("never goes"), energy cannot be created ("is never made"), and can only change form or location ("it just changes"). Cindy reiterated the last of these premises with, "It’s just different" (line 384). The teachers had already established all of these premises, as was discussed, but this was the first time that they were presented together as a theoretical framework. The teachers would continue to state their theory a few more times during the course of the audio recording, each time worded somewhat differently, but always keeping to the theme of CoE.

Betty also resolved some ambiguity in her statement in line 383 with the query to the others: “…isn’t that the premise we’ve been using all along…?” Until this point in the conversation, analysis of the teachers’ use of energy concepts to answer questions had relied solely on their discussion surrounding the relevant question(s). In line 383, Betty had a metacognitive realization that she and the others had been using the same “premise” to answer all of the survey questions. Betty’s use of the phrase “all along” suggested that she meant throughout the entire survey, starting with question 1. Although Betty posed this as a question, Cindy affirmed it in line 384, stating, “That is the theory we’ve been going on.”

In terms of the analysis of their conversation, the fact that the teachers revealed that they had been using this theory consistently since beginning the survey helps to validate claims made earlier in this chapter. Many inferences had to be drawn from the teachers’ conversation to suggest that they were applying CoE to answer the survey questions; lines 383 and 384 serve to validate these assumptions. Although the teachers did not discover all of these premises at the same time (e.g. they decided that energy could not be created before they decided that it couldn’t be destroyed), the statements from lines 383 and 384 suggest that the teachers had been using each of the premises consistently whenever the relevant question required them. Alice expressed
agreement with Betty and Cindy (line 385). Cindy expressed her intention to continue to use the same theory to answer the remaining survey questions and tried to motivate the others to use it as well (line 387); this gives evidence that the teachers’ thinking continued to be consistent with their theory while answering the subsequent survey questions.

Alice, Betty, and Cindy concluded their discussion of question 7 by identifying and agreeing upon the correct answer:

395 Betty: [mumbles from one of the answer choices] [answer choice] D…I think.
396 Alice: [continues reading] “…The total amount of energy in the system will decrease…[mumbling]…remain the same…” Yes. It has to remain the same.
397 Cindy: [simult] I’m—then I’m going with it.
399 Betty: [simult] Uh-huh.
400 Alice: Hey—we’re GOOD.

Alice was able to draw a conclusion as she read aloud from the latter 2 answer choices (line 396). Alice recognized that the energy in the overall system presented in question 7 (the car and rubber band) would stay the same; her use of the wording “has to” implies that this is necessary according to a set rule; this rule may have been their theory. Alice’s conclusion would be implied by their theory because it states that energy can neither be created nor destroyed, and the question wording requires that no energy can move into or out of the system. Thus, Alice correctly reasoned that the amount of energy in the system would remain constant. Betty and Cindy expressed agreement with Alice on her choice of correct answer (lines 395, 397, 399).

Alice’s statement on line 400 is another instance in which one of the teachers expressed high self-efficacy. Just as the teachers had all agreed on the answer to question 7, Alice made a very assertive statement of SE: “Hey—we’re GOOD.” This was a shift for Alice from her earlier claim that none of them knew what they were doing (line 36). Alice spoke on behalf of all three of them that they were excelling at the survey. To excel at a task requires a high level of capability in that task, and awareness of this capability is the definition of self-efficacy. When
Alice said that she and her group members were *good*, she was expressing a new level of confidence in the ability of all three of them to complete the task. The moment in which Alice expressed this high level of SE may have been precipitated by several events leading up to it. For one, the fact that Cindy first summarized the group’s theory (line 377) and first identified it as a “theory” (line 380) represents an important development in the teachers’ thinking, as explained above. Likewise, the transfer of knowledge from question 5 to question 7 used by Betty (line 381) is an important milestone. Because improvement on a task is thought to foster higher SE pertaining to that task, it is feasible that these moments of success led Alice to her expression of high SE on line 400. Additionally, the fact that the three teachers were able to agree on the correct answer so quickly (lines 395-397, 399) may have led Alice to her belief that the three of them were working effectively and efficiently, another measure of success that can lead to high SE.

**4.6 Application and ownership of the teachers’ theory**

By the time they had finished answering question 7 of the survey, Alice, Betty, and Cindy had deduced enough about energy to formulate a theory, which is commonly known as the law of conservation of energy (CoE). The three teachers first referred to their theory in its entirety while answering question 7 of the survey (lines 383-384). While answering question 9, and in the follow-up discussions, they would make use of this theory to make inferences about energy, ultimately expanding their understanding of energy even further. The teachers stated their theory a few more times throughout the course of the discussion. Although they initially referred to it as “the theory” (line 384), they would eventually change their wording to “our theory,” highlighting
that the idea had originally been of their own devising. The following is an account of how the teachers applied their theory and claimed it as their own.

Question 9, which involves a block which is at first stationary, then begins to slide down a ramp, is shown in Figure 9. It requires that the answerer consider energy changing form and multiple types of energy existing concurrently. It is an open-ended (constructed response) question, so the teachers had to demonstrate their understanding without having preselected answers to choose from.
Important to question 9 is the statement that there is friction between the block and ramp; it is the first and only question on the survey to mention friction by name. Questions 1 and 4 implied the presence of friction by mentioning that the objects in the scenario “get a little
“Although the teachers had previously discussed friction and thermal energy independently, they had not yet linked the two entities together. The following conversation, which the teachers had while answering question 9, centered around the relationship between friction and thermal energy:

432 Cindy: What’s the friction energy called though, like is—what’s the energy that’s gonna slow it down?
433 Alice: Friction.
434 Cindy: Is that a…is that…
435 Alice: Friction slows it down. Does it have another name?
436 Cindy: I don’t know. [laughing]
437 Alice: Oh.
438 Betty: I’m looking. There’s a—elastic energy is from the spring, we have Connecticut—kinet—[amused] “Connecticut…”—kinetic [laughs] [crosstalk], potential, motion energy, which is kinetic energy… [crosstalk] thermal energy—so is that the friction: thermal energy?
439 Cindy: [laughs]
440 [voice clicking]
441 Cindy: [answering Betty] No that’s heat. Thermal is the heat.
442 Alice: [simult with Betty] But it’s going to create heat by sliding things.
443 Betty: [simult with Alice] Is—the friction causes the heat.
444 Cindy: Thermal…
445 Betty: Right?
446 Cindy: Thermal energy, sure; let’s go with that. Right: if there’s friction, it’s gonna make heat.
447 Betty: Right, like this. [sound of rubbing hands together]
448 Cindy: Okay.
449 Betty: Because when you rub your hands together, you’ve got thermal—

Through her comment in line 432, Cindy expressed doubt that friction could be considered to be a type of energy; because she asked what “friction energy” is called, she seemed to suggest that the word “friction” itself is insufficient to represent a type of energy. Alice responded to her question in line 435 when she asked Cindy if there was another name for the type of energy she was referring to, which suggests that she too understood Cindy to be asking if it was appropriate to refer to friction as a type of energy that slows down an object.

In line 438, Betty made the link between friction and thermal energy; she looked through the previous questions to find the various types of energy that appeared in the questions, and correctly identified that thermal energy would be associated with friction. This was the first time...
during their conversation that one of the teachers made the link between friction and thermal energy. Although previous questions mention thermal energy by name, question 9 does not, nor do any of the prior questions mention friction, so it is assumed that Betty came to this conclusion on her own. In line 441, Cindy pointed out that thermal energy is heat, to which Alice replied that friction would “create heat.” Her use of the word “create” left some ambiguity as to whether she meant that the heat would be created from nothing, but Betty clarified her point by saying that friction “causes the heat” (line 443). In line 446, Cindy agreed and stated that the friction would “make heat”; her choice of the word “make” also lacked some clarity in meaning. Whereas “create,” or “make” in the literal sense would have contradicted the teachers’ theory that energy cannot be created from nothing, Betty’s restatement using the word “cause” (line 443) indicates that this idea is not in conflict with their theory.

In line 447, Betty made the connection to a familiar example of heat caused by friction: rubbing hands together to warm them up. (She acknowledged that that was what she was doing in line 449.) Cindy indicated agreement (line 448), and Betty began to explain the phenomenon using the idea of thermal energy (line 449).

However, Betty’s comment was cut short by an exclamation of high self-efficacy from Cindy:

450 Cindy: [interrupting] I think maybe I can—Maybe I can teach this.
451 Alice: Yes you can!
452 Cindy: [sighs loudly with relief]
453 Alice: Sure you can!
454 Betty: Of course you can!
455 Cindy: [laughs with exasperation]
456 Betty: It’s like anything else, you know, that you haven’t taught before.
457 Cindy: I know.

In Cindy’s statement, “I think maybe I can—Maybe I can teach this” (line 450), her use of the word “maybe” implies some level of uncertainty, but she was nevertheless expressing some
increase in SE. If she had said instead, “Maybe I can’t teach this,” she would have been implying that she had thought earlier that she could and was now less certain. Cindy was making known to Alice and Betty that her attitude toward the topic had begun to change. Although it is unknown what exactly caused Cindy to change her attitude, as she did not articulate it, it is noteworthy that her statement came shortly after she and her groupmates explored the real-life example of rubbing one’s hands together to generate heat through friction (lines 446-449). As with Betty’s expression of improved SE in line 339, making a comparison to a more familiar scenario involving energy may have made the abstract concepts in the survey questions more palpable to the teachers.

As discussed in Chapter 2, effective teaching requires several different kinds of discipline-specific knowledge for teaching. One such type of knowledge is common content knowledge (CCK). As was discussed in Chapter 2, in order for effective teaching to take place, the instructor must have a sufficient level of CCK pertaining to their subject. This study focuses on the teachers’ SE as it pertains to their CCK surrounding energy. In the case of line 450, Cindy would not have expressed her belief that she could teach about energy unless she also had an underlying understanding of how energy works. Cindy’s assertion that she could teach energy gives evidence of her belief that she was beginning to understand energy better than she had when starting the survey. Her emphasis on the word “can” shows a clear contrast from her attitude of “cannot” at the beginning of the workshop; perhaps she was expressing surprise that her perspective had changed so greatly in such a small amount of time.

Alice and Betty responded to Cindy’s comment with words of encouragement: “Yes you can! Sure you can!” (lines 451, 453), and, “Of course you can!... It’s like anything else, you know, that you haven’t taught before.” (lines 454, 456) These comments by Alice and Betty did
not directly address their own level of SE, as they referred to Cindy’s level of efficacy. In a way, these are similar to the statements they had made early in the recording (line 3, 5, 6) in that Alice and Betty were expressing their faith in Cindy; however, in these earlier statements, Alice and Betty implied that Cindy was the only member of the group who understood energy concepts, and that they would have to rely on her to carry them through. In the case of lines 451, 453, 454, and 456, Alice and Betty made no implication that they themselves were incapable of teaching energy. In fact, Betty implied that energy concepts are inherently understandable: By stating, “It’s like anything else, you know, that you haven’t taught before,” she framed energy concepts as being on par with any other subject they may had had to learn about before teaching, which they eventually mastered. This statement of efficacy was not exclusive to Cindy, but could be applied to the abilities of all three teachers in the group. Evidence follows that all three teachers had begun to improve their SE.

Soon afterwards, the teachers began to refer to the theory they had developed as their own. This happened when Michael came by to check in with the three teachers. Alice, Betty, and Cindy shared their theory with Michael; it was the first time that they shared their theory with someone outside of their group. Michael and the teachers had the following conversation:

461  Michael:  Are you feeling more secure than you were when you started doing the survey?
462  Betty:  Well, if we’re right. [laughs]
463  Cindy:  Yeah: [crosstalk] can’t wait to see how our thinking—
464  Alice:  Of course we’re right.
465  Betty:  [interrupting] We went with one theory.
466  Michael:  Yeah?
467  Cindy:  We stuck with it, the whole time.
468  Betty:  We all decided on—we stuck to the one theory.
469  Michael:  What is your theory?

Michael’s comment in line 461 referred back to the beginning of the survey, when Alice, Betty, and Cindy had expressed to him that they had no knowledge on the topic of energy. In line 461, Michael suggested that they might be feeling more “secure” than they did when they started,
thereby implying that the teachers still felt that they had started the survey with insufficient knowledge of energy. The lack of “security” that Michael referred to was caused by the teachers’ initial impression that they did not have any knowledge about energy. Thus any reply that Alice, Betty, or Cindy made to Michael’s question about feeling more secure would also address their perceived understanding of energy. Michael’s comment invited a rebuttal; the teachers might have disagreed with the idea that they had started off feeling less than confident in their understanding. Had they changed their minds, they might have responded to Michael’s comment by denying that they had not felt secure at the beginning of the survey, or by saying they had realized that they had known what they were doing all along. Instead, Betty’s reply, “Well, if we’re right,” (line 462) did not offer any resistance to the idea that she and her groupmates had started the survey feeling uncertain of their knowledge. If Betty had disagreed with this idea, or changed her mind, she might have said instead, “We didn’t feel insecure,” or “We actually knew what we were doing all along.” But by dismissing the opportunity to correct Michael’s presumption, all three teachers implicitly showed that they agreed with Michael; they still acknowledged that they did not feel secure when they began the survey. This reinforces the idea that the teachers began the survey believing that they had no knowledge in energy concepts and were consistent in that belief even after they began to develop their theory.

An important aspect of the conversation is that it shows that the teachers had a sense that their theory was objectively right or wrong. This is in fact a correct assumption, as conservation of energy is considered to be a universal scientific law; it always holds true. In line 462, Betty’s comment “if we’re right” showed her belief in the objective nature of the theory she and her groupmates had been using. A number of other phrases Betty might have used would have indicated that she thought the theory was subjective, such as “if you agree,” “if that makes
sense,” or “if we have a good idea.” Betty’s use of the word “right,” in another word, “correct” frames the theory she and the others had been using as able to be confirmed correct or not. Alice implicitly expressed her agreement regarding the objective nature of the teachers’ theory in line 464. By asserting, even jokingly, that she and her groupmates were correct, she was confirming her belief that the theory they had been using could be considered either correct or incorrect. Although neither Cindy nor Michael commented on whether or not the theory could be considered right or wrong at this point in the conversation, neither objected, suggesting that they may have agreed with this notion.

Not only did Michael’s comment in line 461 refer to the fact that the teachers had claimed to have started the survey with no knowledge of energy, it also served as a reference to the low level of SE which they expressed when they began. In the case of line 461, “feeling more secure” can be interpreted as “having higher self-efficacy”; the security that Michael spoke of is presumed to mean security in completing the survey. As with the teachers’ comments early in the transcript, claims of ignorance on the subject pertaining to the task by definition show a low level of SE. Thus if “secure” is presumed to mean perceiving to lack knowledge of energy, in this context it must also indicate low SE. Through his comment on line 461, Michael was implicitly asking Alice, Betty, and Cindy if their SE had improved. Betty’s response to Michael on line 462 vindicates the presumption that Michael was speaking in terms of SE. She predicated her response to Michael’s question on whether or not her and her groupmates’ thinking process was right or wrong. By framing the theory she and the others had been using as objectively right or wrong, she implied that answering the survey questions could be done correctly or incorrectly, and that she was uncertain of her group’s level of correctness. Performing a task correctly is at the center of SE, as it refers to a person’s belief that they can carry out a particular task. That fact
that Betty gave such a conditional answer to Michael’s inquiry about SE suggests that she was closely relating her SE regarding the task and her agency surrounding that task. This gives evidence that Betty was attempting to establish her level of SE regarding completing the survey.

The teachers continued to elaborate on their performance. In line 463, Cindy used the phrase “our thinking” to refer to the process of reasoning undergone by the three teachers to decide on answers to the survey questions. The teachers had already mentioned that they were using a “theory” to answer the questions, but Cindy’s choice of the phrase “our thinking” was especially metacognitive. This study is based on the idea that the teachers developed a theory of energy through a process of collective reasoning, exploring different ideas to see what made sense and what did not. That this process occurred is relatively self-evident based on their conversation, but the teachers did not often articulate it. Cindy’s choice of phrasing indicated that she recognized that she and the others had undergone a cognitive process that had led them to develop their theory. Her choice of the word “our” in “our thinking” is also significant, as it indicates that it took the effort of and interchange between all three teachers to develop their theory. If Cindy had instead said “my thinking,” she would have framed the thought process as her own, perhaps unspoken, but her use of the word “our” implies that it was the conversation amongst the teachers that defined their thinking process. This strengthens the idea that all components of their reasoning were spoken aloud, because in order for the teachers’ reasoning process to be collective, they would have to share their thinking out loud with each other. Soon after Cindy recognized this collective thinking, she and the other teachers began to refer to the theory as their own.

In line 465, Betty again confirmed that she and her groupmates had been using a single theory to answer all of the survey questions. This is comparable to the discussion on lines 383-
384, in which Betty and Cindy confirmed that they had been using the same theory to answer all of the questions. This once again shows consistency in the teachers’ thinking throughout the entire survey. Cindy further clarified that this was the case with her comment on line 467: “We stuck with it, the whole time.” The phrase “stuck with it” indicates that the teachers had been using the theory consistently, and “the whole time” indicates that this was the case since they had begun the survey. Betty’s follow-up comment on line 468 added group consensus to the claims that she and Cindy made on lines 465 and 467: because she started off her comment with “We all decided on,” she suggested that the group’s use of that theory was a unanimous decision.

Furthermore, Betty indicated that she and the others had “stuck to” the theory (line 468), which similarly to Cindy’s use of the phrase “stuck with it” (line 467) indicated that the teachers had used the theory consistently. Again, Betty referred to the “one theory” (line 468) that she, Alice, and Cindy had been using throughout.

Michael’s reply in line 469 might have had some influence on the teachers’ referring to the theory as their own; the fact that he referred to it as “your theory” might have given the teachers the impetus to start referring to it as “our theory.” Soon afterwards in the conversation, Alice, Betty, and Cindy began to refer to the theory as their own as they explained it to Michael:

476  Cindy: Okay, here’s our theory: [crosstalk] The amount of energy doesn’t change; [crosstalk] it just transfers to different types of energy.
477  Michael: Yeah… Right… Sure!
478  Cindy: Is that right?
479  Michael: Yeah!
480  Cindy: Okay.
481  Alice: Yeah.
482  Betty: Alright!!
483  Alice: That was our theory.
484  Michael: That’s the right theory.

Cindy’s comment in line 476 was the first time that any of the teachers had referred to the theory as “our theory.” This change of phrasing indicates that Cindy was ready to recognize the theory
as something that she and the other teachers had put together. By stressing that the theory she
and her groupmates had been using was of their own devising, Cindy implied that the teachers
had taken a sense of ownership over their own learning. Instead of using a set of ideas that they
were fed from an outside source, they were instead active members in formulating those ideas
and developing them into a coherent theory. Cindy’s comment represents a turning point in the
conversation, as the teachers would continue to call the theory their own, without exception,
from that point on.

In line 476, Cindy reiterated the group’s full theory: “The amount of energy doesn’t
change; it just transfers to different types of energy.” Like the first time that Betty explained their
theory (line 383), Cindy’s statement from line 476 contains all the elements of the law of
conservation of energy: that energy cannot be created or destroyed (“The amount of energy
doesn’t change”), and can only change form or location (“it just transfers to different types of
energy”). Thus, Cindy’s statement of the teachers’ theory from line 476 was a reworded version
of Betty’s statement from line 383. This shows consistency in what the teachers considered to be
their theory, strengthening the claim that their thinking was consistent throughout the survey.

Although Alice, Betty, and Cindy had used their theory consistently as they answered the
survey questions, they did not receive confirmation from another individual that their theory was
correct until line 477. In lines 477-484, Michael confirmed that the teachers’ theory was
accurate. While Cindy was sharing the theory in line 476, Michael made the comments “Yeah,”
“Right,” and “Sure!” (line 477) to indicate that Cindy’s thinking was correct. In line 478, Cindy
asked Michael directly if their theory was correct, to which Michael replied “Yeah!” (line 479).
Betty expressed excitement for this confirmation in line 482 with her comment “Alright!!” In
line 483, Alice confirmed Cindy’s expression of their theory from line 476 by affirming, “That
was our theory.” Michael again confirmed that it was correct with his reply, “That’s the right theory.” (line 484)

This conversation also supported the teachers’ idea that their theory was objectively right or wrong. Alice and Betty had previously framed the theory in terms of right or wrong; in the excerpt above, Cindy showed alignment with this framing, and Michael affirmed it. In line 478, Cindy asked if their theory was right, implying that the theory’s correctness was objective. Michael confirmed its correctness in lines 479 and 484, and by doing so, confirmed that the teachers’ theory could be considered objectively right. Michael’s emphasis on the word “right” (line 484) showed that the theory was accepted as correct when applied to the survey questions and emphasized the fact that it was indeed a theory that is objectively correct.

It should be acknowledged that, in response to Cindy’s statement of the teachers’ theory from line 476, Alice mentioned an additional component of their theory in line 486: “That and the fact that there’s no such thing as cold.” This pertained to discussions that the teachers had had while answering questions 3 and 8, in which they recognized that “coldness” is not itself a form of energy, but rather a lack of thermal energy. These discussions are not analyzed in this thesis as they are not considered to be relevant to the fundamental ideas of the law of conservation of energy. Nevertheless, because Alice included it as an official part of the teachers’ theory, it is worth mentioning. Alice’s comment did not negate Cindy’s statement from line 476; her use of the words “That and” (line 486) implied that her comment was simply an additional part of their theory. In fact, the teachers restated their theory a few times during the session, and the nonexistence of coldness was never included in it again.

Further confirmation that Alice, Betty, and Cindy had been using their theory consistently throughout the survey is found in line 497, when Michael prompted, “So, you guys have been
answering the questions using that theory,” to which Betty and Cindy definitively replied, “Yes.” (line 498) The teachers went on to elaborate how they used their theory using process of elimination as a primary means of selecting an answer to the survey questions:

502  Betty:  —we got rid of answers—
503  Cindy:  We talked about it.
504  Michael:  Oh yeah.
505  Betty:  —we decided which ones [crosstalk] didn’t work.
506  Alice:  Yeah.
507  Michael:  Okay.
508  Alice:  Yeah [crosstalk] and we talked through what didn’t work.
509  Cindy:  [inaudible] narrowed it down.
510  Michael:  Yeah.
511  Betty:  Yup, so when we saw [crosstalk] that it increased or decreased the amount of energy in the system, we got rid of those.
512  Michael:  Okay… Okay.
513  Betty:  Right? Isn’t that what we did?
514  Alice:  Yeah.
515  Cindy:  Yeah.
516  Michael:  So you’re using your model also to get rid of some of the answers?
517  Betty:  Yes.
518  Alice:  Yes.

The teachers explained to Michael that they eliminated certain answer choices to arrive at the correct answer—phrases like “got rid of” (lines 502, 511), “didn’t work” (lines 505, 508), and “narrowed it down” (line 509) suggest that the teachers were using process of elimination. It is also clear from the conversation that Alice, Betty, and Cindy used this process of elimination collaboratively. In line 503, Cindy said “We talked about it” to indicate that all three of them participated in discussions of which choices to eliminate. (Many examples of such discussions have already been analyzed.) Similarly, Alice asserted that she and the others discussed their choices of answers to eliminate (line 508). The answers they eliminated were based on what Betty and Alice described as answers that “didn’t work” (lines 505, 508), which begs the question of what criteria the teachers had been using to eliminate these answer choices. They expressed to Michael that they had been eliminating wrong answers on the basis of their theory.
Betty indicated in line 511 that if an answer choice indicated that the amount of energy [in a closed system] would increase or decrease, they eliminated it, the same idea expressed in their theory. Betty followed up by asking the other group members to confirm that these were the criteria they had been using to eliminate answers (line 513), which Alice and Cindy confirmed (lines 514-515). Finally, Michael summarized that the teachers had been using their model (theory) to eliminate answers (line 516), which Betty and Alice affirmed (lines 517-518).

After Michael had left Alice, Betty, and Cindy to continue working on the survey, the teachers continued to answer question 9. They began to discuss the third part of question 9, which asks to compare the amount of each type of energy between picture 1 and picture 2. Picture 1 shows the block and ramp before the block begins to slide down the ramp, and picture 2 shows the block and ramp after the block begins to slide. This is where question 9 introduces the conundrum of whether each type of energy must be conserved. The teachers had previously decided what types of energy were present in the two pictures, and they went on to apply their theory to draw conclusions about the amount of each type of energy in each picture. The following is the beginning of their conversation to answer this question:

<table>
<thead>
<tr>
<th>Line</th>
<th>Speaker</th>
<th>Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>570</td>
<td>Alice</td>
<td>[interrupting] Okay, so “for each type of energy identified in picture 2, say whether there is more than, less than, or the same amount [as] in picture 1.” So for kinetic energy, in the picture 1, it’s going to be the same as number 2; it’s still got the same kinetic energy.</td>
</tr>
<tr>
<td>571</td>
<td>Betty</td>
<td>Kinetic energy is motion energy.</td>
</tr>
<tr>
<td>572</td>
<td>Alice</td>
<td>[interrupting] I mean potential—sorry.</td>
</tr>
<tr>
<td>573</td>
<td>Betty</td>
<td>Yeah. Potential.</td>
</tr>
<tr>
<td>574</td>
<td>Alice</td>
<td>Potential energy.</td>
</tr>
<tr>
<td>575</td>
<td>Betty</td>
<td>Yeah…Yup.</td>
</tr>
<tr>
<td>576</td>
<td>Alice</td>
<td>They both have the same potential energy.</td>
</tr>
</tbody>
</table>

In line 570, Alice read the question out loud. She claimed that the block would have the same potential energy before and after the block began to slide. (She initially called this “kinetic” energy in line 570, but corrected herself in line 572.) The teachers had previously decided, correctly, that there would be kinetic energy in picture 2 but not in picture 1 (lines 415-427), so it
was clear that Alice did not actually mean to say that the kinetic energy would be the same in both pictures. Once Alice had corrected herself that she meant potential energy, Betty expressed agreement that the potential energy would be the same in both pictures (lines 573, 575). In line 576, Alice reiterated her conclusion: that the potential energy in each picture would be the same. This was an erroneous conclusion, which the teachers would go on to correct shortly thereafter.

The teachers briefly paused their discussion of question 9 when Cindy again referred to the fact that they had started the survey with no experience in teaching energy, which echoed claims that the three of them had made in lines 28, 30, and 58-64. Referring to the teachers in another group, Cindy stated, “Those guys both taught this; that’s not fair; they can have a conversation.” (line 581) Cindy contrasted the members of her group with the members of the other group, saying that they had taught energy concepts and implying that she, Alice, and Betty had not. She then mentioned the other group’s ability to have a conversation about energy, implying that they each had more than a layperson’s knowledge on the subject. Again, this is a contrast with Alice, Betty, and Cindy, whose conversation had to rely on the discoveries they had made while developing their theory. Betty expressed agreement with Cindy (line 582). Despite having developed a universally applicable theory that had been confirmed to be correct, Cindy and Betty were nevertheless consistent at different points in their conversation that they had begun the survey with insufficient knowledge of energy.

The conclusion that the potential energy in picture 1 would be the same as that in picture 2 turned out to be incorrect, and Cindy identified this error:

583  Alice: [interrupting] Okay. So for thermal energy, there’s more thermal energy in [picture] 2…
584  Cindy: [confidently] So there has to be less potential: there’s less potential, more kinetic and more thermal. Because that’s all there is in number 1. So if you have the same amount you can’t have the same amount of potential; that would be making more of the other two.
585  Betty: Right.
586  Cindy: So there has to be less potential
In line 583, Alice recognized that a particular type of energy, namely thermal energy, would increase from picture 1 to picture 2. As the teachers had previously discussed (lines 438-449), the increase in thermal energy would be caused by friction between the block and the ramp.

Cindy’s follow-up comment (line 584) applied the teachers’ theory to Alice’s comment from line 583. Cindy claimed that the potential energy in picture 2 must be less than the potential energy in picture 1. This was in direct contradiction to Alice’s and Betty’s conclusion that the potential energy would be the same in both pictures (lines 570-576). Cindy went on to explain her reasoning in line 584: she pointed out that the teachers had already decided that potential energy was the only type of energy found in picture 1, whereas picture 2 contained potential, kinetic, and thermal energy (lines 415-446). In line 584, Cindy’s comment “if you have the same amount” refers to the component of the teachers’ theory that energy cannot be created nor destroyed. She reasoned that if the total amount of energy must be the same in both pictures, then new types of energy can only appear if there is a decrease in a previously existing type of energy. In this case, potential energy must decrease in order for kinetic and thermal energy to appear. Cindy showed by contradiction that if the potential energy remained the same in both pictures, but picture 2 also had additional types of energy, then the total energy in picture 2 would be more than that in picture 1 (line 584), which was impossible according to their theory. Betty expressed agreement with this reasoning (line 585). In line 586, Cindy reiterated her conclusion that the potential energy in picture 2 would be less than that in picture 1.

The teachers’ theory also contained the component that energy can change form, which the teachers went on to emphasize for the scenario in question 9:

590 Cindy: Potential energy was all you had in number 1, [crosstalk] so that’s—you’re getting less of that because you’re giving some away to make thermal and kinetic energy. So it doesn’t have as much potential energy anymore. Because it’s using that energy to move and create friction.
In line 590, Cindy reiterated her reasoning from line 584 with a specific emphasis on the transformation of energy from picture 1 to picture 2. In her phrasing, “you’re giving some away to make thermal and kinetic energy” (line 590), “giving some away” refers to the transformation of some of the initial potential energy to kinetic and thermal energy. Similarly, “it’s using that energy to move and create friction” illustrates that the initial potential energy is getting “used” to “move” (create kinetic energy) and “create friction” (create thermal energy). This reasoning led Cindy to the same conclusion: that the potential energy must have decreased from picture 1 to picture 2. Alice accepted Cindy’s argument (line 591). Betty repeated the idea that energy was transformed through her phrasing, “transferred into another form” (line 592), language which was affirmed by Cindy (line 593). Alice challenged the idea that the potential energy would decrease (line 594) pointing out that the block in picture 2 still had the potential to move, to which Betty agreed (line 595). But Cindy pointed out that this potential to move would be lessened (line 596), and Betty completed her thought by reiterating that some of the initial potential energy had been transformed to other types of energy (line 597).

In earlier survey questions, Alice, Betty, and Cindy had to consider what happened to a particular type of energy as that energy disappeared. In these instances, a certain type of energy decreased to zero. Alice’s remark in line 594 shows that she recognized that potential energy would not be totally absent in picture 2, because the block could continue to move faster down the ramp. However, it was Cindy who clarified that the potential energy could decrease without being totally absent when she responded, “not as much” (line 596). This interchange signified the
understanding that the increase or decrease in a particular type of energy need not be complete; different types of energy may simply increase or decrease proportionally.

Once the teachers had agreed that some of the potential energy from picture 1 was being transformed to other types of energy in picture 2, they continued with the next part of question 9, which asked them to explain these transformations. The teachers quickly and efficiently identified the transformations that take place:

604 Betty: So, potential to kinetic to thermal? Is that right?
605 Alice: [softly] Sure.
606 [pause, ~4 sec]
607 Alice: [quietly] I think…[inaudible]…[normal volume] “Describe the transformation??”
608 Betty: I didn’t do that part, I just did this. I made a little line.
609 Alice: Okay: kinetic creates heat.
610 [pause, ~5 sec]
611 Alice: [mumbles the words she is writing] “…moves…friction…causes…heat…”
612 Cindy: [whispers to herself] …the total energy increase…
613 Betty: Everything else is gonna be the same, right?
614 Cindy: Yeah. I’m trying to…
615 Alice: But it would stay the same, right?
616 Betty: Right.

In line 604, Betty identified that the potential energy that disappeared from picture 1 to picture 2 would be transformed first to kinetic energy, which would then be transformed to thermal energy. As the teachers had previously discussed, the latter of these transformations would occur due to friction between the block and the ramp. Alice expressed agreement with this conclusion (line 605). Again, in line 609, Alice specified that kinetic energy would create heat (be transformed into thermal energy). In line 613, Betty mentioned that “everything else [would stay] the same”; it is unclear what she meant by “everything else.” Because the three teachers had just been discussing the amounts of different forms of energy and the transformations between them, Betty may have been referring to types of energy other than potential, kinetic, and thermal, which would not have changed between the two pictures, although these other types of energy were never identified. Regardless of Betty’s meaning, Cindy indicated that she agreed
In line 615, Alice repeated that “it” would stay the same, without specifying what “it” was, and again was met with agreement (line 616).

As previously mentioned, the teachers’ theory was in essence a restatement of the law of conservation of energy, but they did not recognize this canonical name until they were nearly finished with the survey. The following dialogue illustrates how they discovered the phrase “conservation of energy”:

644  [pause, ~11 sec, Michael is heard talking to another group in the background]
645  Betty: “Conservation of energy,” that’s what that’s called.
646  Cindy: What?
647  Alice: What’s that?
648  Betty: Conservation of energy, where nothing is gained or lost; it’s just transferred.
649  Alice: Yes! I’ve heard that before. Couldn’t have come up with it, but I’ve heard it.
651  Cindy: Oh!
652  Betty: I knew it.

In line 644, Michael was heard talking to another group in the background during a pause in the three teachers’ conversation. Betty broke the silence by revealing the phrase “conservation of energy” (line 645). After Cindy and Alice questioned her on what she had said (lines 646-647), Betty clarified what conservation of energy is (line 648), using similar language to that which the teachers had used when explaining their theory to Michael (line 476). Alice told the others that she recognized the name (line 649), and Betty told her that she had just overheard Michael use the phrase (650). She and Cindy reacted with excitement (lines 651-652) and Betty suggested that the phrase was also familiar to her (line 652).

4.7 Pedagogical applications of the theory

Once Alice, Betty, and Cindy were finished answering the survey questions, they were asked to revisit the questions and analyze the energy concepts from a student’s point of view. During this portion of the session, the three teachers revealed more about their own understanding of energy
by comparing and contrasting their theory with the conceptions that students might have when answering the survey questions. This reveals the teachers’ thinking in further depth, as they examined ideas about energy that are specific to particular survey questions and revealed their own conceptions as they strove to understand student conceptions of the same topic.

At one point during the session, all of the teachers present at the workshop were asked to examine student scores and analyze why the scores improved more on certain problems than on others. While they were considering why student scores improved more on questions 1, 5, and 8 than on others, Alice, Betty, and Cindy had the following conversation:

In line 738, Cindy compared a component of CoE with a possible student misconception: that the total energy of a system could change. The teachers had already established that the total energy of a closed system cannot change, and Cindy again referred to it as “our theory” (line 738). Cindy was suggesting that the students who took the survey may not have understood that aspect of energy. She was most likely referring to the students’ understanding for the pre-test scores, before they learned about energy in class; her change of phrase from “they think” to “they
thought before” (line 738) suggests that she wanted to specify that she was referring to their understanding pre-instruction. Betty expressed agreement (line 739). Cindy continued her thought in line 740 by proposing that a student may have thought that the energy of an object changed proportional to its motion. (It is unclear whether she was talking about the context of a particular survey question, multiple questions, or more generally in energy problems.) Through her statement in line 740, Cindy indirectly restated the teachers’ theory by explaining how a student might have overcome their misconception; whereas the student might have originally thought that the total amount of energy would vary with speed, they would have learned that it was actually the type of energy that was changing and that the total amount of energy would remain the same. Betty and Alice agreed with Cindy’s conjecture (lines 741-743).

Betty made another conjecture about student understanding starting on line 743. When she mentioned “two balls hitting each other,” she was presumably referring to question 2, the question involving a pendulum with a ball at the end. (The illustration for question 2 appears as though there are 2 balls on 2 different pendulums, and that they will collide with one another.) Betty recognized that there was only one ball and pendulum in the situation but proposed that students might have done better on the problem if there were in fact 2 separate pendulums. She went on to explain her thinking in line 745, where she contrasted the situation from question 2 with the scenario in question 5, where one object (the spring) transferred energy to another object (the cart) through direct contact. (Her words, “this is pushing this” refer to the spring pushing the cart.) In contrast, Betty mentioned that “When you just have the air [in question 2] …Where is that energy going? How does it hit the air?” (line 745). Cindy expressed agreement with this contrast (line 746). In line 745, Betty referred back to when the teachers were answering question 2 and she had been confused by this same concept. Betty expressed her belief that the
students may have also been confused about how energy could be transferred from a single object like the ball on the end of a pendulum to a more abstract substance like the air, even if they understood that the total energy in the system must remain constant. Alice expressed agreement with this idea (line 747).

Not only does the dialogue from line 738 through line 747 highlight some similarities between the teachers’ thinking and possible student thinking, it also potentially shows that Alice, Betty, and Cindy had attained a higher level of understanding of energy concepts by the fact that they were applying the theory that they had developed to analyze the content of the questions themselves and of student thinking regarding those questions. In her comments on lines 738 and 740, Cindy began by mentioning the teachers’ theory and then contrasted the theory with student thinking. Thus, she started with a conclusion that she and the other teachers had already made and applied that conclusion to a novel scenario. She then described a student going through a similar learning process to that which she, Alice, and Betty went through, learning that the total energy will not change, but simply change form. This could be a metacognitive reflection on Cindy’s part, as it parallels the process that she and the other teachers had just experienced. In lines 743 and 745, Betty showed similar metacognitive thinking as she reflected on how she and the others had struggled to understand how energy could be transferred from an object to the air. When she said, “just like me” (line 745), she acknowledged that she had originally had the same misconception that she was describing a student having. This was another example of one of the teachers consistently acknowledging that they had begun the survey with limited knowledge of energy concepts. Additionally, when Betty said, “Where is the energy going? How does it hit the air?” (line 745), she shifted her perspective from trying to answer a question about energy to posing a question about energy. In contrast to most of the survey, when the teachers were trying
to answer questions that the survey asked, Betty was beginning to analyze student thinking by identifying which questions about energy were most useful in analyzing it. Both Cindy’s and Betty’s analyses show that the teachers were shifting from being learners who were discovering rules about energy to pedagogical thinkers who felt comfortable enough with their understanding of energy to apply it to the analysis of student thinking. This is considered to be a significant advancement in Alice’s, Betty’s, and Cindy’s understanding of energy concepts.

Along with a higher understanding of energy came another notable moment of high self-efficacy. In line 748, Cindy remarked, “I’m kind of excited to teach this next year; maybe I’ll actually understand it.” The fact that Cindy used the word “excited” to describe her attitude toward teaching the topic of energy is considered an indicator of high SE. One is seldom excited to be unable to complete a task, so Cindy’s excitement strongly suggests that she believed she could teach the topic effectively. As with her comment on line 450, Cindy’s expression of high SE in teaching energy is considered by necessity to imply high SE in understanding energy, due to the vital role of CCK in effective teaching. Additionally, Cindy explicitly referred to her understanding of energy with her comment “maybe I’ll actually understand it.” Although, as with line 450, her use of the word “maybe” implies some uncertainty, this statement was nevertheless a significant shift from Cindy’s initial claims of ignorance on the topic. Taken together, Cindy’s enthusiasm for teaching the topic of energy and her optimism that she could understand it are considered to be an expression of high SE regarding her understanding of energy.

Cindy claimed she was “excited” to teach a topic that she had shortly before claimed she did not understand. When compared with some of her earlier statements, Cindy was showing evidence of a gradual shift from low to high self-efficacy in her understanding of energy: at the
At the beginning of the survey, she had claimed to have no knowledge on the subject (e.g. lines 7, 9, 11), then later on, she showed signs that she was changing her mind (line 450), and finally she expressed enthusiasm for a task (teaching) that naturally requires a solid understanding of the content (line 748).

4.8 Full room discussion

In the later parts of the PD session, Michael led all of the attending teachers in a discussion of the survey and student results. This gave Alice, Betty, and Cindy the opportunity to receive confirmation of the correctness of their theory from members of other groups and to share their theory with the room at large.

The first of these instances occurred when a man from another group of teachers (here labeled as “Man 2”) was explaining to all of the PD participants how difficult it was to lead students to an understanding that energy is conserved:

779  Man 2 (from another group): …As many times as we’ve said, “the amount of energy stays the same,” [crosstalk] and done and proven [crosstalk] [crosstalk] that the amount of energy stays the same, [crosstalk] still about 50% of the kids say that it’s—it’s not the same.
780  Michael: Mmm hmm.
781  Cindy: [whispering] Yesss!
782  Betty: [whispering] Hey, we were right!

In line 779, Man 2 explained that many of his students, despite repeated emphasis, would never learn that the amount of energy does not change. Implied in this statement, according to CoE, is that Man 2 was referring to the total amount of energy in a closed system. Michael’s response in line 780 shows that he agreed with Man 2, as he did not offer any disagreement with Man 2’s claim. This caused excitement from Cindy and Betty (lines 781-782), with Betty specifically stating that Man 2’s explanation indicated that she, Alice, and Cindy had been correct in their theory (line 782).
Alice, Betty, and Cindy had the opportunity to share their theory with all of the participants in the PD session. This was their conversation:

791  Michael:  You guys [Alice, Betty, Cindy] decided, we’re gonna answer all these questions [crosstalk] based on the theory—how did you guys describe it? Energy—?
792  Cindy & Betty:  [laugh anxiously]
793  Betty:  It never…it just stays. It never leaves.
794  Michael:  Energy stays the same, [crosstalk] and you just change the kind of energy that it is and where it is, but, you know…So you guys, like, set up the rule: It is conservation of energy—BAM.
795  Alice:  Yeah.
796  Cindy:  We stuck with our theory.
797  Michael:  And that got you through the whole test, right?
798  Cindy:  Yeah.

Michael began by giving the three teachers the opportunity to share their thinking with the room, inviting them to share their phrasing of their theory and acknowledging that they had used the theory consistently (line 791). Cindy’s and Betty’s response (line 792) suggested that they felt anxious about sharing, but Betty went ahead and shared their theory (line 793). Her statement, “It never…it just stays. It never leaves,” (line 793) meant that the total amount of energy in a system is conserved, where “it” refers to the total energy, and “stays” and “leaves” refer to conservation and disappearance of this energy, respectively. Michael reworded Betty’s statement adding that the form and location of the energy is what changes (line 794). Alice indicated agreement (line 795). Michael praised the teachers for coming up with their theory and called it by its canonical name, conservation of energy (line 794). In line 796, Cindy confirmed that she and her group members had used their theory consistently. Michael asked for confirmation that they applied their theory to every test question (line 797), which Cindy gave him (line 798).

4.9 Conclusion

During the course of the survey, Alice, Betty, and Cindy went from a state of proclaimed self-ignorance regarding the topic of energy to an accurate understanding of the energy concepts
necessary to succeed on the survey. They formulated the law of conservation of energy through a process of discussion and logical reasoning as they collaborated to answer the survey questions. All three teachers contributed to the discussion, sharing initial doubt about their knowledge of energy, contributing ideas, and ultimately, expressing their conclusions. It was their final understanding of energy concepts, synonymous with the law of conservation of energy, that they called their theory.

The teachers referred to their conclusion, which was in essence the law of conservation of energy, as their “theory.” Consistent with the teachers’ language, this analysis also refers to what the teachers called their theory using the word “theory.” This was primarily for consistency with the teachers’ language when analyzing the transcript, but there are other reasons that the teachers’ conclusion could aptly be called a theory. One aspect of a scientific theory is that it has predictive value; that is, it can be applied to situations different from those from which it was developed and produce accurate predictions of the outcomes. This attribute was seen in the teachers’ theory. The first time that the teachers expressed their theory in full was while they were answering question 7 (line 383). They were then able to apply this theory to question 9, which they had not yet encountered, and use their theory to provide correct answers to the question, which included making novel discoveries during the process. The teachers again used their theory to analyze student thinking, identifying components of the survey questions pertaining to their theory and predicting how students might respond to these ideas.

Concurrently with the formulation of their theory, Alice, Betty, and Cindy made many statements which pertained explicitly to their level of self-efficacy at various points in time throughout the process of completing the survey. Their initial statements claiming that they had no knowledge of energy concepts also served as indicators of low self-efficacy. As their theory
began to develop, the teachers began to express high self-efficacy; these statements were often made in conjunction with significant developments in their theory. Such statements of self-efficacy, whether high or low, shed light on how Alice, Betty, and Cindy, in the position of learners, viewed their ability to complete the survey questions successfully.
5. DISCUSSION AND CONCLUSIONS

This thesis analyzed the conversation between research subjects Alice, Betty, and Cindy to address the research questions given in Chapter 1:

1. How can teachers construct an understanding of the law of conservation of energy during a professional development activity without it being explicitly taught to them?
2. In what ways does teachers’ self-efficacy change in a professional development setting as learning takes place?

Both of these questions were answered by applying narrative analysis to the teachers’ conversation as they collaborated to complete the survey provided at the professional development workshop. Here is a summary of how each of these questions was answered:

To answer research question 1, the teachers’ discussion of energy concepts pertaining to the survey was analyzed. Because the teachers were so vocal and forthright in their thinking process, they provided a great deal of insight into how their understanding of energy developed over time. Because conservation of energy (CoE) could be used to answer most of the survey questions, the teachers’ discussion seems to have led them to an understanding of CoE. Alice, Betty, and Cindy articulated their conception of CoE in what they referred to as their theory. The fact that all three of them claimed not to understand CoE to begin with and ended the survey with a concise summary of CoE strongly suggests that the teachers learned the concept as a result of their discussion surrounding the survey, not because it was explicitly taught to them. The fact that they referred to their theory as if it were their own gives further evidence that their learning process occurred independently of explicit instruction by an authority. The result was that this theory, synonymous with the scientifically accepted law of conservation of energy, led Alice,
Betty, and Cindy to answer every question correctly, despite their initial claims of no knowledge on the subject.

To answer research question 2, statements given by the teachers of their level of self-efficacy (SE) were analyzed. Only explicit statements of SE were considered, as there were many such explicit statements throughout the teachers’ conversation. The teachers made these SE statements before beginning the survey, and later at various points throughout their process of completing the survey. The result of this analysis was that Alice, Betty, and Cindy showed evidence of a shift from low to high SE in conjunction with the development of their understanding of energy. The teachers initially expressed that they had a low level of SE by professing their ignorance on the topic of energy. As their understanding of energy improved, they gave various statements of high SE, in contrast to their initial expressions of low SE. Often, the explicit expression by one of the teachers of their SE coincided with an important development in their understanding of CoE.

5.1 Connections to the Research Framework

In Chapter 2, many constructs from the literature were identified, namely common content knowledge, Resource Theory, energy pedagogy, and self-efficacy. This section examines briefly how each of these constructs applies to the findings discussed in Chapter 4.

Common content knowledge (CCK) is a type of teacher knowledge synonymous with the material that the students are expected to learn (Ball et al., 2008; Lucy, 2013). In the case of this study, CCK regarding conservation of energy was analyzed. Alice, Betty, and Cindy demonstrated aspects of CCK during their discussion: they were able to answer questions correctly, identify and correct a wrong answer (such as the false assertion that the potential
energy in question 9 would not decrease), and refine the use of their terminology regarding energy concepts. CCK is considered to be a necessary component of effective teaching (Ball et al., 2008; Halim & Meerah, 2002), so Cindy’s improved outlook on teaching energy indicated that she believed herself to possess this knowledge.

The teachers’ conversation showed their thinking process in great detail. It was evident that their understanding began as discrete ideas surrounding particular questions which they pieced together into a larger framework over time, consistent with the Resource Theory conception of learning. When they started the survey, the teachers claimed to have no knowledge of energy. However, Resource Theory suggests that people derive their resources from prior learning experiences (Hammer, 2000), which suggests that Alice, Betty, and Cindy likely already had the ideas surrounding energy that they used to piece together their theory. It is possible that these preexisting resources had not been activated for a long time, which caused the teachers some difficulty in activating them. It is unclear whether the teachers’ theory, which can be described as a framework of their resources, was preexisting, or if the teachers truly pieced it together for the first time during the workshop. Because learners use existing resource networks to piece together new networks (Sayre & Wittmann, 2008; Wittmann, 2006), it may have been some combination of the two.

The teachers examined all of the energy concepts summarized in Section 2.4, namely energy transformation, energy transfer, constant energy, open and closed system, and conservation of energy. All of these concepts contributed toward their overall understanding of energy. The teachers identified what is commonly known as the law of conservation of energy as their theory, which they used to answer all of the survey questions. The fact that Alice, Betty, and Cindy showed growth in their understanding of energy is important, as energy is a crucial
concept in physical science classrooms and indeed across many disciplines inside and outside of the classroom.

Along with their growth in understanding of energy came what the teachers expressed as an increase in their self-efficacy (SE) related to this understanding. Their comments were taken to refer to their SE regarding their knowledge because they addressed their perceived ability to understand the energy content. Their SE was shaped by what Bandura considered the most powerful method, enactive performance (Bandura, 1982); the teachers improved their SE regarding their knowledge by actively applying that knowledge. Self-efficacy theory predicts that as a person’s SE increases, so does their level of persistence; Alice, Betty, and Cindy demonstrated their persistence through their willingness to complete a survey that they had claimed to be incapable of completing when they began.

5.2 Limitations
This study applied narrative analysis to a pre-recorded dialogue among the research subjects in a specific setting, which limited the scope of the study. Although the data give a wealth of insight into the subjects’ collective thinking process, these limitations should nevertheless be recognized. Some of the most pertinent of these limitations are discussed below.

One limitation was the incomplete nature of the data: because there was no video of the session available, the analysis had to rely solely on the audio recording of the subjects. A video recording could have provided more evidence for the claims given in this thesis because certain types of nonverbal communication such as gestures and body positioning could have been observed. Without a video of the subjects, the audio recording was the only dataset available for analysis.
Furthermore, the scope of analysis of this study was limited. Only certain aspects of the audio recording were analyzed. This thesis focused only on the language that the teachers used and did not attempt to analyze any form of spoken inflection such as tone, pauses, or pacing. Analyzing such inflection might have provided more nuanced insight into the teachers’ thoughts and emotions, but attempting to perform this analysis was beyond the scope of this study.

Furthermore, not all topics within the teachers’ conversation were analyzed. As mentioned, the teachers discussed energy topics aside from conservation of energy (e.g., the nonexistence of “coldness” as its own entity) but these were not analyzed in this study. Additionally, the teachers made many statements throughout the course of their conversation that could be considered implicit indications of their level of self-efficacy, but this study only considered statements which referred to their SE directly. In short, there are many aspects of the conversation that have yet to be examined.

Another limitation on this study comes from the fact that the data were not collected for the sake of the study. The professional development workshop occurred years before the start of this thesis, and the objectives of the workshop were different than the objectives of this study. Thus, the research questions for this study were based on the conversation of the group of teachers that was chosen, instead of the other way around. The timeframe of the data collection also limited the opportunity for any follow-up data collection: by the time this thesis had begun, it is likely that the research subjects would not be able to recall any subtle meaning behind their words should a follow-up interview be desired.

Yet another limitation of this study is evident when attempting to apply the findings to a larger population of teachers. It is unlikely that Alice, Betty, and Cindy were a representative group of teachers for the sake of this analysis. Other teachers, perhaps most other teachers would
not have experienced such a profound self-directed learning experience or increase in SE in such a short period of time. Indeed, this group was chosen for their uniqueness, which implies by definition that they were not a typical group of teachers.

Many of the limitations described above indicate that changes could have been made to the research process used in this study. Instead, implications for future research can be explored that could shed light on uncertainties resulting from the limitations of this study and expand on the foundation laid by this work.

5.3 Future research

Although this thesis gives insight into how teachers are able to learn and improve their self-efficacy during a professional development (PD) workshop, there are many ways in which greater understanding is needed concerning how such an experience is connected to education overall. Ultimately, the experience of Alice, Betty, and Cindy should help to inform better teaching practices in the classroom. Future research questions include:

1. Do teachers who gain common content knowledge in a professional development workshop retain what they learned?
2. Does learning in professional development lead to successful teaching of the content in class?
3. Assuming that teachers can gain self-efficacy by participating in professional development, do they retain this self-efficacy long enough to bring it back to their classrooms?
4. What influence does a teacher’s self-efficacy of content knowledge have in the classroom?
Understanding the ways in which teachers retain their knowledge would influence the design of future professional development workshops in which they participate. Likewise, understanding how teachers develop and maintain self-efficacy in their knowledge would facilitate the design of professional development opportunities to help them develop such self-efficacy. Furthermore, it is useful to understand how both content knowledge and self-efficacy affect student learning. In what ways does increased teacher knowledge lead to changes in the classroom? Similarly, how does improved teacher self-efficacy affect the classroom experience? Addressing such questions may help to inform classroom practice.

5.4 Conclusions

Teaching is not easy, but it is crucial. Having effective educators in schools nationwide will prepare learners to face a future in which a solid understanding of science is increasingly necessary. It is vital that we continue to push for effective STEM teachers in this country. Part of this push will continue to involve frequent and effective professional development for all in-service teachers. These professional development sessions place teachers in the position of learners, and to be effective, they must promote growth and learning for the teachers who attend them. The hope is that the growth and learning experienced by teachers will be passed on to their students in the classroom.

This thesis showed how teachers can use ideas in the form of resources to develop an understanding of unfamiliar concepts and that that process can be largely self-directed. Topics such as the law of conservation of energy are ubiquitous across many energy-related concepts, so many resources are available to help teachers piece together an understanding of conservation of energy. The ability of teachers to apply what they have learned about conservation of energy to
novel situations strengthens the evidence that such an understanding has been developed. In conjunction with this learning process, the teachers in this study expressed an increase in their self-efficacy surrounding their knowledge.

   Professional development provides unique learning opportunities to teachers. This thesis has shown that learning can indeed take place among teachers in this environment, and that teachers can be more confident of their knowledge as a result. If learning in the classroom could be so successful, students would enjoy a fulfilling education.
WORKS CITED


APPENDIX A: FULL TRANSCRIPT

Introduction [00:00]

1 Cindy: Yeah.
2 Alice: [laughing] So this will be really good! [laughs]
3 Betty: [to Cindy] You’re the only one who knows anything.
4 Cindy: [stutters] Oh my gosh, you—
5 Betty: We’re lucky we got Cindy. [laughs]
6 Alice: Yes, we’re lucky to have…
7 Cindy: You might not be saying that, by the end of this.
8 [general laughter]
9 Cindy: Yes, ’cause I’m normally—
10 Alice: [to Cindy] We won’t know any different! [laughs]
11 Cindy: —I’m normally the one that goes, “Yeah, that sounds good.”
12 Betty: [laughs]
13 Cindy: We go “haha”… [nervous laughter]
14 Betty: Well this gives you a chance to be the leader.
15 Alice: [laughs]
16 Michael Wittmann: Or it gives you guys—’cause there’s no—this isn’t about, like, right and wrong and all that stuff; this is really about, just, what kinds of thinking lead to the different kinds of answers.
17 Betty: Mmm hmm.
18 Michael: And if it’s your thinking for answer B (whatever answer B might be)—fine.
19 Betty: Mmm hmm.
20 Michael: Just—you know…think about it.
21 Betty: So, if I don’t do well you’re not gonna kick me out ’cause I haven’t [inaudible] [laughs]
22 Cindy: So we’re talking about it as we go.
23 Michael: [whispering to Betty] There’s no doing badly!
25 [Michael and Alice laugh]
26 Betty: Being new is hard.
27 Alice: [to Michael’s comment] That’s ’cause it’s inquiry-based.
28 Cindy: [whispering] And I haven’t done energy yet. [We] don’t do physical science until [inaudible].
29 Man 1 (from another group): [interrupting] You don’t—you don’t have to share any of your answers.
30 Betty: [to Cindy] I don’t think they have at our school either.
31 Betty & Cindy: [to Man 1] What?
32 Man 1: You don’t have to share any of your answers.
33 Betty: Oh okay.
34 Alice: This is supposed to be collaborative.
35 Cindy: [to Man 1] Okay.
36 Alice: ’Cause we don’t know what we’re doing.
37 Man 1: No, I’m saying you don’t have to share any of your answers.
39 Betty: [also understands] Oh, oh—okay.
40 Man 1: So don’t feel self-conscious, just—
41 Cindy: [interrupts] So we just smile and nod when we’re going over everything.
42 Betty: [laughs]
43 Cindy: [jokingly, mocking] Yeah, that sounds good!
Betty: Alright.

Cindy: Okay.

Betty: So—

Alice: So this is being done by Miss Susie Q…

Betty: Ha, Miss Susie Q!

Cindy: There you go.

[Pause, ~2 seconds]

Cindy: [Quietly reads Question 1 aloud] “A student shoves a”…

Betty: So this is from…What grade would this be from? Si—seventh? Sixth?

Cindy: This is from the 8th grade does the PBIS, yup.

Alice: [Talking over Cindy] I was gonna say, I think this is 8th grade.

Cindy: Next year [crosstalk] it’ll be my 7th and 8th grade are going to do it.

Alice: I don’t—

Betty: Okay.

Alice: I haven’t seen my 8th graders—I have two 8th graders and sometimes we do some of their science stuff in my room.

Cindy: Yeah.

Alice: You know it’s part of their reading program, [crosstalk] or to support the math pieces.

Cindy: Right.

Alice: But I haven’t seen anything about the [inaudible]

Cindy: [Finishes the thought] …energy.

Alice: Yeah.

Cindy: Yeah.

Betty: Okay. So we’re supposed to go through and answer these questions [crosstalk] and talk about what we think?
Cindy: Mmm hmm. I think—I think talk about...[crosstalk]...what—what answer we think. [crosstalk] As we go.

Betty: Okay.

Alice: Okay.

**Question 1** [01:48]

Alice: [reading Question 1] “A student shoves a box; it slides across the floor. As the box slides across the floor, the box slows down, and both the box and the floor get a little warmer. What happens to the energy of the box as it slides across the floor and comes to a stop and why?”

Betty: Okay.

Alice: [reading answer choices] “The motion energy decreases and thermal energy stays the same...” That doesn’t sound right. “The motion energy of the box stays the same and its thermal energy increases...”

Betty: Okay.

Cindy: Yeah, it’s not D, ’cause I know there’s potential energy in everything;

Betty: Right.

Alice: Exactly.

Cindy: Everything has that potential energy [crosstalk] so we can cross that one off.

Alice: Gotcha.

Betty: Mmm hmm.

Cindy: And I also crossed off B [crosstalk] ’cause I didn’t think that it...was that.

Betty: I did too. Nope. I—
Alice: That one—yeah, that one just didn’t sound right. I’m going with A: “The motion energy of the box decreases and its thermal energy increases because the motion energy is converted into thermal energy.”

Cindy: Yeah, and what’s C?—“The motion energy of the box stays the same and its thermal energy increases because new energy in the form of the thermal energy is made.”

Betty: But there’s no new energy.

Alice: [interrupting] But the motion energy [crosstalk] can’t stay the same, because it’s stopped.

Cindy: But… [interrupting] Yeah, because it’s slowing down [crosstalk], so it has to be decreasing. [crosstalk] The motion energy has to be decreasing otherwise it would keep sliding across the floor.

Betty: Right.

Betty & Alice: Right.

Alice: [interrupting] And—and so this is what’s happening: it got a push—

Betty: [interrupting] And—the… the difference between these two questions [answer choices] too is that this one says “energy is converted into” and this one says “new energy is made.”

Cindy: Yeah.

Alice: Right.

Betty: So… you’re not gonna make new energy; it’s potential; it’s already there.

Cindy: Right.

Alice: Right.

Betty: It’s just changed into something—

Cindy: [interrupting] So it has to… [crosstalk] be A.

Alice: Has to be A.

Betty: It’s gotta be—

Cindy: In our thought process that sounds…

Alice: Yup.
Cindy: ...sounds good.

Betty: Sounds good to me too. Alright.

**Question 2** [03:59]

Alice: “A student is playing with a pendulum, a ball attached to the end of a string. He gives the ball a push and watches the ball as it swings from side to side. After a while the ball stops swinging. Why does the ball stop swinging?” [continues to read through the answer choices]

Cindy: [mutters something from one of the answer choices]

Betty: [to the group] Well it’s not going to be D [crosstalk] because a person doesn’t have to make something move, right?

Alice: I don’t think so.

Cindy: “An object only has motion energy when a person makes it move and the student is no—” Yeah, [crosstalk] ’cause it’s still moving after you’re pushing it.

Betty: It’s not gonna be D. [faintly] Yuh.

Cindy: [contemplatively] “Energy is transferred somewhere else and some motion energy is used up…”

Betty: [pause, ~7 sec]

Alice: [inaudible] choice too.

Cindy: That’s the one I was thinking too, and I was trying to explain, like, thinking of why I thought that.

Betty: Well I think it’s because of the part where it’s—

Alice: [interrupting, confidently] Because the motion energy isn’t transferred anywhere else.

Betty: Its—it’s not really used up though, so that’s… [slowly and deliberately] “the motion energy is not used up”… now that I reread it.

Cindy: Yeah.

Alice: [very softly] “A little bit of the ball’s motion energy is used up…” [fades away]

Betty: C also says energy is used up. [implying that can’t be the answer]
Alice: But it also is transferred somewhere else, like the air.

Betty: Yeah, so this one says it’s not transferred; this one says it is transferred—

Cindy: This one says ‘some.’

Betty: —both of them say the energy is ‘used up.’

Betty: And then [answer choice] A says “is transferred somewhere else, like the air, as the ball swings from side to side,” so, in—when it goes swing to side to side, is that, like, the air means that the air is—will be moving, then? So is that where the motion is going? Is that what it means?

Cindy: [incredulously] I—I guess.

Alice: [contemplatively] “Why does the ball stop swinging?”

Betty: So it trans [inaudible] when it’s moving.

Alice: It [crosstalk] stops moving because the friction of the air is making it slow down.

Betty: It’s pushing the air, right?

Cindy: It’s pushing the air. [simultaneously with Alice] …slow down.

Alice: [simult with Cindy] Theoretically in a vacuum it would keep right on going.

Betty: Yeah. If we keep choosing A over and over again then we’ll know… [laughs]

Alice: I would choose A.

Cindy: I’m going with A.

Betty: Me too.

Cindy: [softly] Wow, this is…

Betty: [mock whining] How long is this thing?!

Cindy: [exasperated groan, then laughs in an exasperated manner]
**Question 3 [06:41]**

148 Betty: Next…

149 Alice: Okay…

150 Cindy: [sighs in exasperation]

151 Alice: “A cook uses an iron frying pan to cook a meal. After cooking he places the hot frying pan on the counter. After a while, the frying pan, the counter, and the air in the room will be at the same temperature. Why?”

152 Cindy: I don’t know.

153 Alice: First of all, he’s burned the heck out of the countertop.

154 Betty: [laughs, then reads] “Because coldness will be transferred from the counter to the frying pan and from the air to the frying pan.” [confidently] No, ’cause some of the heat has to move out, doesn’t it? I don’t think it’s B. [inaudible]

155 [pause, ~8 sec]

156 Betty: “Because thermal energy will be transferred from the frying pan to the counter [crosstalk] and from the frying pan to…”

157 Cindy: “To the counter…”

158 Alice: [interrupting] Well that can’t be right because there’s no such thing as cold.

159 Michael: [laughs]

160 Alice: My husband told me that; he was an engineer. There’s no such thing as cold: thermometers don’t measure cold; they measure heat—[crosstalk] or lack thereof. So there is no such thing as cold.

161 Michael: Okay.

162 Cindy: Okay, so cross off B.

163 Michael: [interrupting] Except—

164 Alice: [interrupting] I told him when it was 30 below—don’t tell me that!

165 Michael: Yeah, exactly, see, there’s—there’s—there’s perhaps a science way of talking about it, and then there’s every day.

166 Cindy: Uh-huh.
Michael: When I open up a window, I don’t worry about the heat of my house escaping out the window—

Cindy: Mmm hmm.

Michael: —it feels freakin’ cold, and cold is coming in! Right?

Betty: [laughs]

Alice: [interrupting] But there is no such thing as cold. [laughs]

Betty: [to Michael] Right.

Michael: So...yeah.

Cindy: [begins to mumble the answers aloud, and trails off]

Alice: [reads aloud as Betty and Cindy continue talking] Okay—“because thermal energy will be transferred from the frying pan to the counter and from the frying pan to the air.” Alright, so that’s possible. “Because coldness will be transferred from the counter to the frying pan and from the air to the frying pan”—no. “Because thermal energy will be transferred from the frying pan to the counter, from the frying pan to the air; coldness will be transferred from the...Because thermal energy will be transferred from the frying pan to the air, but thermal energy will not be transferred from the frying—”

Betty: [while Alice is reading] Well you know the counter’s gonna feel hot. If you put a frying pan on a counter, and you pick it up, [inaudible]

Cindy: [inaudible]—right. So, it transferred from the pan to the counter.

Betty: So it can’t be D.

[pause, ~4 sec]

Cindy: “...thermal [energy will] not be transferred...” no, ’cause the counter would be hot, as well. Alright, so, my reasoning: it has to be A again, if there’s no such thing as coldness.

[pause, ~3 sec]

Betty: ’Cause the air will feel warm? The air will feel warm, but—

Cindy: [interrupting] I mean if you—yeah, if you put your hand above it.

Alice: [interrupting Betty and Cindy] Okay, it’s not D. There’s no way it’s D.

Betty: Nope—we crossed off D also. And you’re saying there’s no coldness, then—but didn’t he say A, and then they made him...Oh I don’t know.
Scientifically, there’s no such thing as cold; there’s only heat or lack of heat.

Alright.

Thermometers don’t measure cold.

They measure the amount of heat.

The amount of heat or lack—

[interrupting] Yeah, I get that. But if the—

But this is for an 8th grade kid who’s not gonna get that concept.

But I don’t think the cold’s gonna, I don’t know, when you put, when you—in my house though, the heat rises, right?

Right.

So…

“Because the thermal energy will be transferred from the frying pan to the counter and from the frying”—I think it’s A. Because thermal energy that’s in that frying pan is going to be transferred to the counter and to the air until they all reach an equilibrium.

’Cause they’re gonna replace—

[interrupting] Coldness isn’t being transferred from the counter to the frying pan, and from the air to the frying pan; the heat is dissipating from the frying pan.

So when you take, like, say you’re making something hot and you take it and you put it in the snowbank.

Mmm hmm.

The heat is dissipating into the snow.

Into the snow.

Right.

[pause, ~2 sec]

But it will get really cold.

Yup. Because the heat is dissipating.
Betty: But the colder the thing it’s in, the colder the pan will get.

Alice: That’s because all of the heat is being dissipated.

[pause, ~6 sec]

Alice: It’s not B. I know it’s not B.

Betty: Well then it can’t be C either because there’s no such thing as coldness.

Alice: [interrupting] “Because thermal energy will be transferred from the frying pan to the counter, and from the frying pan to the air, and coldness will be transferred from the counter to the frying pan and from the air to the frying pan”—no.

Betty: It must be A again then.

Alice: It’s gotta be A.

Cindy: Alright.

[pause, ~2 sec]

Alice: Then he’s [Michael’s] gonna stand up there and go, “No, it was D, people.” [laughs]

Cindy: [chuckles]

**Question 4 [10:37]**

Alice: “A ball, starting from rest at Position 1, rolls back and forth along a curved track and eventually stops rolling."

Cindy: More of this frickin’ heat.

Betty: [laughs]

Alice: “As the ball rolls along the curved track, the track and the ball get a little warmer.”

Betty: [repeating] “Frickin’ heat!”

Cindy: [laughs]

Alice: “How does the total energy of the ball and track system change as the ball rolls along the track?—Assume that no energy is transferred to or from the surroundings.”

[pause, ~3 sec]
Betty: [repeating] “The track and the ball get warmer…”

Alice: [joking] Well you see, as the ball and the track get warmer, those molecules are moving faster, and so the ball theoretically should go faster and faster, shouldn’t it?

Betty: [laughs prolongedly] You’re thinking like a kid now!

Alice: [laughs, then reads through the answer options]

Cindy: [mumbling] “Total energy of the ball and…”

Alice: Okay, “the total energy of the ball and track system increases because new energy is—” [definitively] No. New energy is not formed.

Betty: It might be D this time. I decided to go from the bottom up.

Alice: “The total energy of the ball and track system decreases because the ball loses all of its energy and eventually stops rolling.” [continues to read through answer choices, then softer] “The total energy…”

Betty: It says “no energy is transferred to or from the surroundings.”

[pause, ~4 sec]

Betty: But new energy’s not made, right?

Alice: No.

Betty: Didn’t we determine—didn’t we decide that?

Cindy: I—I—I th[ink]—

Betty: Everything has potential energy, [crosstalk] it just has to be put in motion. Right?

Cindy: Right. [simult with Betty] Right.

Betty: [simult with Cindy] Do I remember that right from…however many years ago I did this?

[pause, ~2 sec]

Alice: [considering answer choice C] “The total energy of the ball and track system increases as the speed of the ball increases, and decreases as the speed of the ball decreases.”

Betty: I think it’s D.
“The total energy of the ball and [track] system does not change—”

[continues reading] “—because even though it’s [energy is] transferred…”

“…because even though energy is transferred between the ball and track—”

[interrupting] “—no energy was added to or released.”

“…no energy was added to or released from…”

It’s just changing the type of energy.

Right.

Yeah.

Because it seems [crosstalk] from “the ball and track system,” this is looking at this one as a whole system [crosstalk]—not individually as the ball and the track but the whole thing.

I agree with that…Mmm hmm.

Yeah.

Right.

So even though it does get warmer, nothing has left [crosstalk] and nothing’s added; it’s all still there, [crosstalk] just changed—

Right

…still there. [interrupting] Just, different type.

[confidently] Right?

I think—I think you’re right.

[less certain] I—I’m—Sure.

Okay. Sounds good to me. [laughs]

“A student compresses a spring and holds a cart next to the spring. The graph shows the amount of elastic energy the spring has when it is compressed and the amount of motion energy (kinetic energy) the cart has before it starts moving. After he lets go of the cart, the spring pushes the cart and the cart rolls across the
floor. Which of the following graphs represent the elastic energy of the spring and the motion energy of the cart when the cart is rolling across the floor and the spring is no longer in contact with the cart? (Assume that no energy is transferred between the spring and its surroundings and no energy is transferred between the cart and its surroundings.)”

Betty: [inaudible]

Cindy: [mutters]

[pause, ~5 sec]

Betty: The spring has—it’s compressed…So this is what it has when it’s compressed…And he lets go, it no longer is compressed…

[pause, ~6 sec]

Betty: Okay. So as soon as this spring is let go, it doesn’t have any more energy, no more—

Cindy: [interrupting] When the cart is rolling across the floor, so no longer in contact.

Alice: So, “which of the following graphs represents the elastic energy of the spring...”

Cindy: [sighs] I feel like it has to be C.

Betty: Yeah…I agree with you.

Alice: It’s gotta be C.

Betty: Yuh, I agree with you, because this no longer has any—

Cindy: [interrupting] When it’s pushed in…

Alice: Right.

Cindy: I was listening to what [man from another group] was saying...this should be, like, here, like, it might still be bouncing a little bit, [crosstalk] but we don’t have that choice; there’s definitely more energy in the cart, [crosstalk] and it’s not the same at this point.

Alice: It has no more energy.

Betty: Right...Yeah, yup.

Alice: Uh-huh.
Betty: Because right now, this doesn’t have any more elastic energy.

Cindy: Right, it’s out.

Alice: Right, right, it’s only—

Betty: It now has kinetic energy, right?

Cindy: Right.

Alice: Right.

Cindy: Now we’re looking at the cart’s moving; it’s given its energy to the cart, [crosstalk] and pushed the cart.

Betty: Yup…Yup. I’d say C, too.

Alice: It’s gotta be C.

Cindy: Alright.

[pages flipping]

Betty: Okay.

Cindy: Oh no, there’s open-ended!

Alice: What?!

Betty: Oh no!

Alice: Where?

Betty: [laughs with exasperation, then play whining] Do we have to do that one??

Cindy: I’m like the kids: [mocking voice] “That’s an essay!”

Man 1: It’s not really essay.

Alice: Which one’s open-ended?

Man 1: It’s just a constructed response. Okay?

Betty: [to Man 1] [simult with Alice] That’s the same thing. That’s a teacher way of saying ‘essay.’

Alice: [simult with Betty] That’s ano—that’s a fancy word for…essay.

Man 1: [interrupting] And it doesn’t even have to be complete sentences.
Betty: Ohhhhh—okay.

Man 1: How’s that?

Betty: [laughs]

Alice: Slightly better.

Man 1: We’ll back off the literacy for just a little bit.

Betty: Ohh, thank you.

Alice: [laughs]

**Question 6 [15:37]**

Alice: “Imagine a ball on a track where no energy is transferred between the ball and the track or between the ball and the air around it. The ball starts from rest at the position labeled start, moves along the track toward positions 1, 2, and 3. What is the highest position the ball will reach before stopping and going back down the track? (Remember, no energy is transferred between the ball and the track or between the ball and the air around it.)”

Betty: Well it’s gonna go—isn’t it gonna go back up the same distance it goes down?

Alice: Hmmmm…

Betty: If it goes down to here, doesn’t it have the same energy to go back up?

Alice: [interrupting] If no energy is transferring, it should never stop, either.

Betty: [quickly] It doesn’t say it has to stop. It just says before it goes— [crosstalk] if it—once it goes up, how far will it go up before it goes back down—it doesn’t say it will necessarily stop.

Alice: “No energy is trans—”…It says, “what is the highest position the ball will reach before stop—” oh, I see:

Betty: [interrupting] Stop—up—going up.

Alice: “…before stopping and going back down the track?”

Betty: Yup…
330 Alice: No energy is transferred, it’s gonna keep right on going, but I think it’ll only go as far as [position] 2, but I can’t think of the rule because, does—can’t it not go higher than it started at?

331 Betty: Well, it depends on—

332 Alice: Isn’t that the whole premise of roller coasters?

333 Cindy: [interrupting] It doesn’t have any more energy, like, it’s…it’s…I don’t know…This is how much energy it started with, to get down to where it has to go back up, so it can’t have more energy than—to go up higher.

334 Betty: [interrupting, inaudible]

335 Alice: [interrupting] Right, so it can’t go past the 2.

336 [pause, ~4 sec]

337 Betty: Right?

338 Cindy: R—uh. Right.

339 Betty: [chuckles] That seems so simple.

340 Alice: I’m a special ed teacher.

341 Cindy: [laughs]

342 Alice: [laughs] I don’t always think in logic.

343 Betty: [laughs] But it doesn’t…I don’t know, does it have more here?

344 Cindy: [interrupting] Does it have enough to…

345 Betty: …to go… [simult with Cindy] faster here?

346 Cindy: [simult with Betty] …get past the 2?

347 Alice: [interrupting] If no energy is being transferred… it should only be able to go up as high as it started from…I think.

348 Cindy: [agreeing] Ahhh.

349 [pages ruffling]

350 Betty: Where’s that car one [Q5]? So it’s kinda like this, isn’t it, because it’s going down so much quicker…I don’t know. We can say [position] 2.

351 Cindy: Let’s—yeah.
Betty: [interrupting] But it seems like it would go [emphasis] faaast then slow, and then slower.

Cindy: Then it slows down until it—

Alice: No, if it goes slower and slower then it’s going to be losing energy and it doesn’t lose energy.

Betty: It doesn’t say it goes slower and slower.

Alice: It’s gonna come down, and it’s gonna go up to a certain point, and then it’s gonna come back down and go back to this point.

Betty: Right.

Alice: What I’m saying, it can only go as high as it started from. It only builds up enough energy between here and here to go from here to here.

Cindy: But it has to slow down.

Betty: Mmm hmm.

Cindy: Yeah, that’s kinda what I was thinking too.

Betty: Mmm hmm.

Alice: But I don’t know the words for it.

Cindy: Wha—[crosstalk] We don’t need to; it’s multiple choice.

Betty: No.

Alice: Oh okay.

Betty: Okay. Alright, so we’re choosing 2? Sounds good to me.

**Question 7 [18:23]**

Alice: “A student uses a rubber band to shoot a toy car across a level floor. Imagine that no energy is transferred between the car and the floor or between the car and the air.” Alright, why don’t we just say a vacuum. “What happens to the total amount of energy in the system (car and rubber band) when the car is moving across the floor and is no longer in contact with the rubber band?”

Betty: Isn’t that the same thing as that one [Q5]?

Alice: I…That’s what I was just thinking.

[pause, ~9 sec]
Alice: “What happens to the total—” You know what, they’re asking to…they’re asking again to see if we’re gonna give a different answer than we gave over here.

Betty: Well, it’s—it’s not really asking the same question.

Cindy: It’s asking something different.

Betty: It’s asking something different, but it’s the same scenario, really.

Alice: [interrupting] “Imagine that no…” Okay: “What happens to the total amount of energy in the system when the car is moving across the floor and no contact…” [fades to a mumble]

Cindy: [interrupting] “What happens to the total amount of energy?” [confidently] It has to stay the same.

Betty: Yeah, because this [energy in Q5] stayed the same.

Cindy: [laughs] If we go with that theory.

Betty: [interrupting] [counting the bars on Q5] One, two, three, four, five; one, two, three, four, five—So if we chose this [answer choice C on Q5], this…elastic energy of the spring was—the total amount of that energy was transferred to the total amount of motion energy of the cart.

Cindy: Right…

Betty: And that’s what the—isn’t that the premise we’ve been using all along, [crosstalk] is the energy is never goes, and is never made, [crosstalk] it just changes?

Cindy: Yeah… It’s just different— [laughs] That is the theory we’ve been going on.

Alice: Okay, so what’s the answer?

Betty & Cindy: [laughing]

Cindy: Let’s stick with it. It’s been working!

Alice: [laughing] “It’s been working!”

Betty & Cindy: [continue to laugh]

Alice: Don’t mess with what’s working! Alright so what’s the right answer then? [begins to read through the answer choices out loud, while Betty and Cindy continue talking]

Betty: [loud whisper] We’re the only ones laughing…
Cindy: We’re allowed to laugh!

Betty: I know!

Cindy: [inaudible]

Betty: [mumbles from one of the answer choices] [answer choice] D…I think.

Alice: [continues reading] “…The total amount of energy in the system will decrease…[mumbling]…remain the same…” Yes. It has to remain the same.

Cindy: [simult] I’m—then I’m going with it.


Betty: [simult] Uh-huh.

Alice: Hey—we’re GOOD.

**Question 8** [20:10]

Betty: Okay, this is what I was talking about before.

Cindy: Mmm hmm.

Alice: “A student places a warm can of soda into a bucket filled with cold water. She places the lid on the bucket. Which of the following describes the energy transfer between the water and the can of soda in the bucket?” [reads answer choice A] [definitively] No. [reads choice B] [definitively] Yes.

Betty: [interrupting] That’s what you said—that’s what you say your husband would say, right?

Alice: Yes. [reads choice C] [definitively] No. [reads choice D]—[confidently] No.

Betty: We’re gonna go with B?

Cindy: Yeah.

Alice: The warmness is being transferred out of the can. So which one [answer choice] was that? So which—

Betty: That was…

Cindy: B.

Betty: B.

Alice: B. [silly & singsong] Turn page for the last question.
**Question 9** [21:03]

413 Alice: Alright.

414 Cindy: [lightly] “The images below show a block on a ramp…”

415 Alice: [interrupting] “The picture… The two pictures below show a block on a ramp. There is friction between the block and the ramp. In the first picture, the block has not started moving yet. In the second picture the same block is sliding down the ramp. What types of energy are in picture 1?” That would be…kinetic energy?

416 Betty: Kinetic.

417 Alice: Is that the one where it doesn’t…

418 Cindy: [interrupting] Potential.

419 Betty: [interrupting] Kinetic and potential.

420 Cindy: [confidently] No, kinetic is when it’s moving.

421 Alice: Oh, kinetic is when it’s moving.

422 Cindy: [interrupting] The motion energy potential energy.

423 Alice: Potential.

424 [pause, ~10 sec]

425 Cindy: Um…

426 Alice: “What types of energy are in picture 2?”

427 Cindy: That’s kinetic. But—

428 Alice: [interrupting] Would it also be potential, because it could move faster?

429 [pause, ~4 sec]

430 Cindy: [sounds unsure] Sure.

431 [brief pause]

432 Cindy: What’s the friction energy called though, like is—what’s the energy that’s gonna slow it down?

433 Alice: Friction.

434 Cindy: Is that a… is that…
Alice: Friction slows it down. Does it have another name?

Cindy: I don’t know. [laughing]

Alice: Oh.

Betty: I’m looking. There’s a—elastic energy is from the spring, we have Connecticut—kinet—[amused] “Connecticut…”—kinetic [laughs] [crosstalk], potential, motion energy, which is kinetic energy… [crosstalk] thermal energy—so is that the friction: thermal energy?

Cindy: [laughs]

[voice clicking]

Cindy: [answering Betty] No that’s heat. Thermal is the heat.

Alice: [simult with Betty] But it’s going to create heat by sliding things.

Betty: [simult with Alice] Is—the friction causes the heat.

Cindy: Thermal…

Betty: Right?

Cindy: Thermal energy, sure; let’s go with that. Right: if there’s friction, it’s gonna make heat.

Betty: Right, like this. [sound of rubbing hands together]

Cindy: Okay.

Betty: Because when you rub your hands together, you’ve got thermal—

Cindy: [interrupting] I think maybe I can—Maybe I can teach this.

Alice: Yes you can!

Cindy: [sighs loudly with relief]

Alice: Sure you can!

Betty: Of course you can!

Cindy: [laughs with exasperation]

Betty: It’s like anything else, you know, that you haven’t taught before.

Cindy: I know.
[Off topic [22:50 – 23:59]]

458 [Michael has approached Alice, Betty, and Cindy with interest that they have gotten to question 9]

459 Michael: So, um—how are you—how are you—how’s it going on this; I haven’t had a chance; I’ve been with other groups.

460 Betty: Waaaaa…we think—

461 Michael: Are you feeling more secure than you were when you started doing the survey?

462 Betty: Well, if we’re right. [laughs]

463 Cindy: Yeah: [crosstalk] can’t wait to see how our thinking—

464 Alice: Of course we’re right.

465 Betty: [interrupting] We went with one theory.

466 Michael: Yeah?

467 Cindy: We stuck with it, the whole time.

468 Betty: We all decided on—we stuck to the one theory.

469 Michael: What is your theory?

470 Alice: [joking] That we’re right!

471 Betty: We said we didn’t have to—

472 Michael: [laughs] [to Alice’s comment] Yes!

473 Betty: We were told we didn’t have to share, right?

474 Cindy: Yeah, we didn’t—

475 Michael & Alice: [laughing]

476 Cindy: Okay, here’s our theory: [crosstalk] The amount of energy doesn’t change; [crosstalk] it just transfers to different types of energy.

477 Michael: Yeah… Right… Sure!

478 Cindy: Is that right?

479 Michael: Yeah!
Cindy: Okay.

Alice: Yeah.

Betty: Alright!!

Alice: That was our theory.

Michael: That’s the right theory.

Betty: We did remember something! Yaaaaaay!!

Alice: That and the fact that there’s no such thing [crosstalk] as cold.

Cindy: That’s awesome.

Michael: [laughs] There’s no cold.

Betty: There’s no coldness.

Alice: Oh, so [crosstalk] and that really did apply to this question.

Michael: There’s no coldness.

Cindy: Well yeah, if our no coldness theory is right then we got those other [crosstalk]…ones right. So…

Alice: Yeah.

Betty: Thanks to the engineer [laughs] [crosstalk]—that she’s [Alice is] married to!

Michael: [laughs]

Betty, Cindy, & Michael: [laugh]

**Off topic [24:47 – 25:58]**

Michael: So, you guys have been answering the questions using that theory.

Betty & Cindy: [definitively] Yes.

Michael: What kinds of theories have you been using to think about the others, like, are you noticing, or have you really only been answering the correct versions and not really talking so much about what other ideas are in play?

Betty: [confidently] No, we—

Alice: No…
—we got rid of answers—

We talked about it.

Oh yeah.

—we decided which ones [crosstalk] didn’t work.

Yeah.

Okay.

Yeah [crosstalk] and we talked through what didn’t work.

[inaudible] narrowed it down.

Yeah.

Yup, so when we saw [crosstalk] that it increased or decreased the amount of energy in the system, we got rid of those.

Okay… Okay.

Right? Isn’t that what we did?

Yeah.

Yeah.

So you’re using your model also to get rid of some of the answers?

Yes.

Yes.

Awesome.

[quietly] Mmm hmm.

Okay… Alright. Have you had questions—now I’m trying to figure out the right way to ask this, because we’re stuck on trying to figure out certain things, so this is truly, like, [crosstalk] I need information [crosstalk]…is the way I’m trying to approach this—um… When there are answers that, it’s not you’re eliminating because of a reason, but if a kid were to give that answer, what must they have been thinking? Have you had any of those conversations?

Okay.

Mmm hmm.
524 Cindy: [to Michael] Oh no, we didn’t.
525 Betty: No. Not yet.
526 Michael: You didn’t? Okay. So you guys—
527 Cindy: We were more thinking like students and trying to cross stuff out.
528 Michael: Cool.
529 Betty: Yeah.
530 Michael: No, that works. So—
531 Betty: So we went, like, we went back to this one [Q5] [crosstalk] and decided that since this had five [bars on the graph] and this had five [crosstalk] and we do—use it as an answer, [crosstalk] over here [crosstalk] we transferred [crosstalk] our knowl—what we thought was our knowledge [crosstalk] [crosstalk] from one to the other.
532 Michael: Yeah…five… Okay… Ahhhh, number 7?... Yeah… Yeah…
533 Alice: Yeah.
534 Cindy: Oh, what we thought [crosstalk] was our knowledge being the [crosstalk] key word.
535 Michael: Gotcha.
536 Betty: Yeah… Being a little iffy.
537 Michael: Okay. That’s fine. So, you guys are slightly ahead ’cause you’re on number 9—
538 Cindy: [surprised] Oh!
539 Betty: Oh!
540 Michael: So—
541 Betty: No way!
542 Alice: That’s because we’re good.
543 Michael: [matter-of-fact, not condescendingly] Yeah. Um…
544 Alice: And right.
545 Cindy: You want us to go back and think about…
Michael: Could you go back and think about, like, what they might have been thinking [crosstalk] if they gave the other answers?

Cindy: Mmm hmm… Mmm hmm.

Betty: Okay…

Michael: Particularly to number 5…

Betty: Can we finish 9 first?

Michael: …and number 9. Yeah, number 9’s the other one.

Betty: Oh, okay.

Michael: Like, what kind of answers you give to number 9 and to…so…yeah.

Cindy: [confidently] Mmm hmm.

Michael: And then any others you want to do. Like, start looking for patterns, like, what kinds of question are these, like just kind of start analyzing, like, are these places where I needed to think more about the amount of energy doesn’t change, or this one’s about the transfer or, you know, the change of the energy within, you know, that sort of thing.

Cindy: Mmm hmm.

Michael: Or what kind of energy is it about, or something. So, just start telling me what you notice, like what do you see as patterns or as kinds of questions in here. ’Cause you guys are ahead, you get more homework. Hahaha.

Betty & Cindy: [sigh/laugh/groan]

Michael: [laughs]

Betty: That’s always the way, isn’t it?

Cindy: Thanks.

Betty: The smart kids get more work.

Cindy: Yeah.

Alice: That’s right.

Cindy: That doesn’t mean we’re smart.

Betty: [laughs]

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Cindy: Some of my smart kids rush through things so, “I’m done!”

Betty: [laughs]

Cindy: “No you’re not!”

Alice: [interrupting] Okay, so “for each type of energy identified in picture 2, say whether there is more than, less than, or the same amount [as] in picture 1.” So for kinetic energy, in the picture 1, it’s going to be the same as number 2; it’s still got the same kinetic energy.

Betty: Kinetic energy is motion energy.

Alice: [interrupting] I mean potential—sorry.


Alice: Potential energy.

Betty: Yeah…Yup.

Alice: They both have the same potential energy.

[pause, ~7 sec]

Betty: See they’re [members of another group are] discussing the actual…[crosstalk]…science behind it [types of energy, namely thermal]. [laughs]

Alice: Okay… On thermal, is there more or less…

[pause, ~4 sec]

Cindy: Those guys [in the other group] both taught this; that’s not fair; [crosstalk] they can have a conversation.

Betty: Yeah.

Alice: [interrupting] Okay. So for thermal energy, there’s more thermal energy in [picture] 2…

Cindy: [confidently] So there has to be less potential: there’s less potential, more kinetic and more thermal. Because that’s all there is in number 1. So if you have the same amount you can’t have the same amount of potential; that would be making more of the other two.

Betty: Right.

Cindy: So there has to be less potential
Alice: Say that again?...

Cindy: —and—

Alice: No, say it again?

Cindy: Potential energy was all you had in number 1, [crosstalk] so that’s—you’re getting less of that because you’re giving some away to make thermal and kinetic energy. So it doesn’t have as much potential energy anymore. Because it’s using that energy to move and create friction.

Alice: Okay…

Betty: So it’s been transferred into another form.

Cindy: Yeah.

Alice: But it still has the potential to move…

Betty: It does.

Cindy: But not as much, because y—

Betty: It’s now changed its form.

[Pause, ~5 sec]

Betty: It’s like slush, ice, and snow. [laughs]

Alice: [laughs]

Cindy: Sure.

Betty: [continues to laugh]

Alice: Okay, “what types of energy transformed from one to another?”

Betty: So, potential to kinetic to thermal? Is that right?

Alice: [softly] Sure.

[Pause, ~4 sec]

Alice: [quietly] I think…[inaudible]… [normal volume] “Describe the transformation??”

Betty: I didn’t do that part, I just did this. I made a little line.

Alice: Okay: kinetic creates heat.
Alice: [mumbles the words she is writing] “…moves…friction…causes…heat…”

Cindy: [whispers to herself] …the total energy increase…

Betty: Everything else is gonna be the same, right?

Cindy: Yeah. I’m trying to…

Alice: But it would stay the same, right?

Betty: Right.

**Revisiting questions for KCS [30:54]**

Alice: Okay, so, he [Michael] wanted to go back to [question] 5, to do what??

Betty: Um…

Cindy: [sighs] I don’t know.

Betty: [laughs]

Alice: Alright, so why would a kid possibly pick A? “Elastic energy of the spring…” Why would th—why would they say that stayed the same and the cart didn’t have any?

[conversation briefly off topic]

Betty: Okay, so why would they choose the other ones?

Alice: Why would they choose this one?

Betty: Well, I can—

Cindy: Are we—are we on [question] 5?

Betty: Yeh. I would say they would choose D because they’d think that the elastic energy would stay the same and the motion energy would go up.

Alice: Yeah.

Betty: They wouldn’t think it would lose any energy.

Alice: Yeah. I think you’re right.

[pause, ~7 sec]
Cindy: I hate to do this before we know if we’re right or not.

Betty: I know.

Alice: He said there’s no right or wrong.

Cindy: [mumbling and writing] “…would…stay…”

[pause, ~11 sec]

Alice: I have a [crosstalk] good theory for this one.

Betty: So and that’s a— I would think that that’s why a lot of these kids would get these wrong because they’re thinking that the energy is added…

Alice: Yup.

Betty: You know.

Cindy: Think the energy’s added. Ayuh.

Alice: So I think looking at B, I think they would say that—I think they would say the, um…because the spring went from here to here [crosstalk] that on the graph, it has to get bigger.

Cindy: It got bigger… Yuh. The spring got bigger so the…

[pause, ~11 sec, Michael is heard talking to another group in the background]

Betty: “Conservation of energy,” that’s what that’s called.

Cindy: What?

Alice: What’s that?

Betty: Conservation of energy, where nothing is gained or lost; it’s just transferred.

Alice: Yes! I’ve heard that before. Couldn’t have come up with it, but I’ve heard it.


Cindy: Oh!

Betty: I knew it.

Alice: [softly as she writes] “…spring that…”

Betty: Okay.
Alice: [continues mumbling]

Michael: [reading Cindy’s writing] “…think the elastic would stay the same but motion goes up.”

Betty: Yeah.

Michael: Cool.

Betty: That’s what we thought.

[conversation briefly off topic]

Betty: Okay, and then we’re supposed to look at—

Cindy: I don’t think they would pick that one [answer choice A] [crosstalk] because they know that it’s moving so it has to have some energy.

Betty: I don’t think they would either… Yup.

Alice: Unless they said that the cart didn’t have any energy of its own; it only had energy from the spring. And I think there’re part—there could be a group of kids that would say that.

Betty: Some kids would look at this and say, well, that’s the same length as that [bars on the graph], so we’re gonna choose D.

Cindy: [agreeing] Mmm hmm.

Alice: [agreeing] Mmm hmm. Yup.

[breakout group discussion ends/whole room discussion begins]

Omitted [34:37 – 36:26]

Wanting Answers [36:26]

[Michael has been explaining some of the student results on the survey]

Cindy: [whispers to group] I need the answers!

Betty: [laughs quietly]

[Michael talking, ~20 sec]

Cindy: [to Alice & Betty] Is he gonna give us the answers?

[inaudible]
Another small group discussion [37:07]

Betty: Alright.

Cindy: Alright, so [questions] 1, 5, and 8 [crosstalk] he wants us to look at? How their thinking might have changed from the beginning to the end?

Alice: So 4 and 6…

Betty: Right, why they gained so much. Well now they know the difference between motion and kinetic?

Alice: [interrupting] I don’t think there’s much change, because 4 and 6, as we already discovered, 4 and 6 are very much alike. So either they got it wrong and stayed wrong, or they got it right and they stayed right.

Betty: Oh.

Alice: ’Cause those two are, you know, virtually identical questions.

Betty: Right.

Alice: 7… where’s 7? Where is…

Cindy: Oh that’s the one with the car with the rubber band.

Betty: Yuh.

Alice: That’s the one with the rubber band, but we don’t know, did they all get it right and stayed there, or did they all get it wrong and stayed there?

Betty: Let’s see if we can find a pattern between 1, 5, and 8.

Alice: Oh, that’s the ones we’re supposed to be looking at, 1, 5, and 8?

Betty: I has [crosstalk] thermal energy, kinetic energy, motion energy…

Alice: Alright, number 1…

Cindy: So does 8—has—well, the thermal.

Betty: [interrupting] And 5 has—5 has motion energy… and elastic energy.
Cindy: But 8 does not; 8’s only the thermal.

Betty: Hmm.

Alice: Say that again?

Cindy: The heat transfer.

Betty: But they’re all the transfer of energy, aren’t they?

Cindy: Mmm hmm.

Betty: Aren’t those two more so, like, this one is more like—

Cindy: [interrupting] So they know more about the how energy is transferred?

Betty: —This one is more the swinging, [crosstalk] this one is the moving…right, and then—

Alice: That’s 2… I thought we were doing 1, 5, and 8.

Betty: We are.

Alice: Oh.

Betty: That’s what I’m saying. Like 6 is the “bally” one.

Alice: 6 and 4 is pretty much the same.

Betty: That’s a bally one, that’s a bally one, so the ones that—

Cindy: [amused] A “bally one!”

Betty: [laughing] The bally one!

Cindy: [mock authority] The bally ones!

Betty: [continues laughing]

Cindy: Their thinking didn’t change as much. [laughs]

Betty: Nooo, it didn’t! [laughs] It went to Bollywood! [continues laughing]

Cindy: [continues laughing]

Alice: [reading from student results] “A percentage of gain…”

Betty: So do you think that might have something to do with it?

Cindy: I think they learned [crosstalk] a lot about how energy transfers.
Alice: So, like… This one had about a 2 percent gain.
Betty: Right, and not so much what happens with something [crosstalk] that isn’t touching anything else.
Cindy: The movement of something… Yeah.
Betty: So when two things are touching, [crosstalk] and it’s easy to see how the transfer of energy from one to the other can go, and there’s actual movem—like, [crosstalk] movement across, then maybe that’s why they understood it better?
Alice: [inaudible] …Right… [sighs]
Betty: What do you think?
Alice: That—that—that sounds logical. ’Cause that’s what all of them are.
Betty: Okay, so, we think [crosstalk] 1, 5, and 9, it has to do with the transfer… [slowly as she writes] “of energy… from… object…”
Alice: Well no, 8 is—8 is the temperature one.
Betty: Yeah, but I’m not reading it. [continues to write] “…to object…” [laughs]
Alice: He said we didn’t have to read it out loud.
Betty & Cindy: [laughing obnoxiously] [putting fingers on their noses—see Alice’s comment below]
Cindy: [regarding Alice] She rolls her eyes at us!
Betty: [still laughing] “…from object to object…” uhhh…
Alice: [to the listener of the recording] They put their fingers on their nose; [crosstalk] that’s why I was rolling my eyes. [crosstalk] [crosstalk] He’s [Michael or other listener is] not gonna know; there’s no picture.
Cindy: Yeah, and you know what else I’m thinking too?
Betty: [laughs again]
Cindy: Our— Our theory about, like, we said it—it stayed the same, [crosstalk] and maybe they think—they thought before that it increased or decreased.
Betty: Mmm hmm…
Cindy: You know? Like the, [crosstalk] as it started moving they thought the energy increased, and they probably learned that, that it stays the same…just changes the type.

Betty: They may have—yeah, they might have learned that.

Alice: Yeah.

Betty: Yep. So that was a big lesson, now this one [question 2?], you know, whenever you sh—I was afraid it was two balls hitting each other, and that would be…if they—if two balls hit each other maybe they would have understood that one better.

[pause, ~7 sec]

Betty: And then… 5 is the same thing: this is pushing this, so it’s transferring energy from one thing to the other. So they probably get the fact that energy never goes anywhere. But when you just have the air, [crosstalk] they probably don’t understand—[crosstalk] just like me [crosstalk]—Where is that energy going? How does it hit the air?

Cindy: Mmm hmm.

Alice: Yeah… Mmm hmm.

Cindy: I’m kind of excited to teach this next year; [crosstalk] maybe I’ll actually understand it.

Betty: I bet… So with 2, 4, and 6… it’s the energy of the ball, I guess—

Cindy: And the movement kind of up and down the ramp, [crosstalk] or, you know, on a string, moving [crosstalk]—but it’s still that ramp function.

Betty: Yup… Mmm hmm… Right.

[pause ~4 sec]

Betty: There’s no heat involved; there’s nothing—no m—no, like, no different movement; it’s the same movement.

Cindy: Mmm hmm.

Betty: So with the cart, something actually moves, with this something actually moves, [crosstalk] and with this, something actually moves.

Cindy: Mmm hmm… Yeah.

Betty: The movement stays the same.
Betty: Okay?

Cindy: Okay.

Betty: And then that one I can see why 8 went up too, for the same reason: it’s the same thing.

Alice: Mmm hmm… Yup.

Cindy: Uh huh.

Betty: Plus, this one they would see happen all the time.

Cindy: Right.

Betty: Everyone knows what happens with that.

Betty: Does that sound right?

Cindy: [leaves the room temporarily]

Betty: So we could be totally wrong on 2, 4, and 6, also.

Alice: [yawns] Oh, we’re always wrong.

Betty: [laughs] It’s been so long since I did this stuff.

Alice: Yeah, I don’t do this at all, um, when my kids come to me, we may be reading it out of the book, but it’s not like I’m in the class helping him with the experiments and, you know, doing any of that hands-on.

Betty: Mmm hmm.

Alice: Mostly I’m with a sixth grader, and the sixth graders do SEPUP.

Betty: Mmm hmm.
Man 2 (from another group): …As many times as we’ve said, “the amount of energy stays the same,” [crosstalk] and done and proven [crosstalk] [crosstalk] that the amount of energy stays the same, [crosstalk] still about 50% of the kids say that it’s—it’s not the same.

Michael: Mmm hmm.

Cindy: [whispering] Yesss!

Betty: [whispering] Hey, we were right!

Michael: [laughs]

Omitted [52:31 – 53:20]

More affirmation [53:20]

Man 1: [to full group] The [answers to the] first 3 were A.

Michael: [affirming] Yeah.

Man 1: And the first 3 had pretty good gain.

Cindy: [whispered, excited] Yesss!

Michael: Yep. Even though [crosstalk] the first three…just a minute…

Betty: [barely audible] Yay!

Omitted [53:29 – 54:33]

Own that theory! [54:33]

[In a full-room discussion, Michael is directing a question to Alice, Betty, and Cindy]

Michael: You guys decided, we’re gonna answer all these questions [crosstalk] based on the theory—how did you guys describe it? Energy—?

Cindy & Betty: [laugh anxiously]

Betty: It never…it just stays. It never leaves.

Michael: Energy stays the same, [crosstalk] and you just change the kind of energy that it is and where it is, but, you know…So you guys, like, set up the rule: It is conservation of energy—BAM.

Alice: Yeah.

Cindy: We stuck with our theory.
Michael: And that got you through the whole test, right?
Cindy: Yeah.
Michael: So, once you have that as your idea of energy, then it’s hard to not think of it in every single question…

**Omitted** [55:02 – 1:09:40]

**Getting pedagogical** [1:09:40]

800 [Michael has introduced the trend between teacher prediction of student answers and student improvement]
801 Michael: Talk amongst yourselves for like a minute or two and then we’ll have the large group conversation…
802 Betty: [to Alice and Cindy] Were these [teachers in the study] all PBIS people?
803 Cindy: Yeah.
804 Betty: These were all PBIS people?
805 Cindy: Mmm hmm.
806 [pause, ~6 sec]
807 Michael: [talking to another group in the background]
808 Betty: [inaudible] some people that were not in PBIS?
809 Michael: [in background, talking to another group] Oh right, yes, these are the data of the students in those teachers’ classes. So…
810 Betty: [to the room at large] And they were all PBIS classrooms?
811 Michael: [to Betty] All PBIS classrooms, yeah.
812 [pause, ~5 sec]
813 Man 1: So you—so clarify for me, [crosstalk] so I get this right.
814 Michael: Yeah?... Sure… Please, yeah.
815 Man 1 So what we’re saying is: almost 40% of the kids got it right in the classrooms where the teachers thought they would get it right. And then a little less than that, 35% [crosstalk] got it right in the rooms where the teachers thought they wouldn’t get it right but couldn’t say why.
Michael: Yeah... Yeah.

Man 1: So that’s how I’m reading it; so those bins here: these are the actual student performance results and these are the bins of the different classrooms.

Michael: Yeah. [interrupting] Of the students in those bins.

Man 1: Okay.

Michael: Yuh, of the teacher—those are the students of the teachers in each bin.

Man 1: Alright… Alright.

Betty: [quietly] Okay.

Michael: Yeah.

Man 3 (from another group): [facetiously] Alright so the teachers who thought they’d get it wrong made sure that they’d get it wrong, and they did get it wrong.

[general laughter]

Man 4 (from another group): No this—this—that was the—pretest, before they taught any energy.

Michael: Yeah, this is…

Man 3: But the pretest is the—is all the same, if you’re right, they’re the same?

Michael: On the pretest everybody did about the same.

Betty: Mmm hmm.

Michael: Yeah.

Man 3: But the ones who thought there would—along with.

[general muttering]

Michael: On the post score, those guys are getting 75%. Those are they answered correct.

Man 3: Ohhhhh okay.

Michael: [inaudible] the opposite way! [laughs]

Alice: [to Betty and Cindy] Well, that’s easy to explain, because if they were able to identify the misconception, they taught until the misconception wasn’t there.

Betty: [acknowledging] Mmm.
Alice: They corrected the misconception; how would they learn it?

Betty: And they took the test first. Yeah.

[Pause, ~3 sec]

Alice: [Simult with Michael] [to Betty and Cindy] But if you can’t identify what the misconception is, you can’t teach it correctly.

Michael: [Simult with Alice] [continuing a conversation with the room at large] …The teachers who are aware of what their students are thinking are teaching in a way that helps the students learn it.

Man 3: Makes sense.

Michael: Yeah, but what does that mean? What is it that you are actually doing differently; in what way are you teaching so that the students do better?

Woman 1 (from another group): Well you’re anticipating what the misconception is, [crosstalk] so if you—if you know what their misconceptions are, or could be, then in your teaching you’re makings sure that you are clearly stating or addressing or modelling that this can’t be; you can’t—you can’t think this way, it’s gotta be… this way.

Betty: Right.

Man 5 (from another group): Versus if you [crosstalk]—versus if you—if you think they’re gonna get it right, you’re always gonna glaze over whatever that concept is.

Woman 1: Like “coldness” don’t… Right.

Man 5: And you already assume this is so obvious that I don’t even [crosstalk] need to spend any time with it.

Woman 1: Yeah.

Michael: But those are two separate answers: yours [Man 5’s] is a time-on-task answer: Just simply spending the time on the—you’re not even spending time on it if you think your kids are gonna get it right. And you’re [Woman 1 is] saying the particular way in which you are spending time on it is that you’re aware of and addressing the wrong answer.

[Murmur of understanding from someone]

Michael: Okay. But—

Man 5: No, I think it’s—it’s the same thing.

Woman 2 (from another group): It’s the same thing.
Man 5: It’s just that if you—if you think your kids already know—or, are gonna get it right because they don’t—if you don’t think they have a misconception that’s an easy answer, [crosstalk] you’re not gonna go in depth—as in depth as if you think that they do have a misconception which you’ll try to teach against that misconception.

Michael: Okay.

Betty: [to room at large] [inaudible] I think it might have to do with questioning too. You know, like, what [Woman 1 is] saying is why do you think—why can this not be? [fingers drumming, ostensibly] Why does it have to be this way? And then the kids can say, well it can’t be this way, because…this.

Alice: And so you correct it.

Betty: So they’re proving it while they’re disproving it.

Alice: Right.

Cindy: [laughs awkwardly]

Man 6 (from another group): Rather than just saying, “what’s the answer?”

Betty: Yeah.

Alice: Right.

[various murmurs of agreement]

Betty: Yeah. So…

Man 3: It could be the case of the teacher telling a story, working into an explanation that ends up with that incorrect misconception, and then blowing it to bits. You know that as—as everyone is sucked into the story, says, “But wait, this can’t be!” and that kind of thing. And showing how it—it falls apart. And how it must be the other thing.

Michael: Yeah.

Man 3: The—basically building on the misconceptions.

Man 7 (from another group): Yeah, it could be as simple as, like, as you’re setting up the demonstration or the lab or whatever, and you’ll just be like, “Alright, when we do this, this conception is going to happen, right?”—“Yeah! Yeah, that’s what we think is gonna happen.” Boom, that didn’t happen: why not?

Michael: Okay.
Man 7: As opposed to just, “Let’s see this demonstration. Do you guys—do you guys see what happened there? What happened? Yeah: right. Moving on…”

[laughter]

Michael: But—it’s—what—what—

Man 7: You’re not addressing what they—what they were gonna incorrectly think ahead of time.

Michael: But, it feels to me I—mean, these are great things and it feels to me like you guys are describing different variations on what you do when you have—when you know what the misconception’s gonna be. I mean they feel very different: one of them is in a… setting up a lab situation, and eliciting from them the incorrect response so they’re invested in when the response is different. Right? Another one is figuring out ways to tell them in a different fashion, or to…to, like—in one case you might already have the experiment and you focus on it; in other cases, you might be going out of your way to design an experiment so that they are confronted with this thing; another way that I haven’t heard but that…that I’ve thought of in other ways is like, when I know what the wrong answer’s gonna be, oh man, students don’t even have to say it: I’m there like 5, 10 words ahead of them: I’ve already figured out where they’re going, and I can get there before them and, start responding to it in a way, like I can start dancing around other—you know…but, um, [Man 3], you were gonna say something, and then [Man 8 (from another group)] [mumbling] okay.

Man 3: I don’t think it matters: how—how you—how you get to the—how you deal with the misconception. I think it’s—in your formative assessments or whatever, you—you go until you make sure they don’t have it anymore. And then when they take the test, they—they don’t have it anymore. I think that’s really the key. Not how you teach it, but that you keep doing it until you know that they don’t have it anymore.

Betty: [sighs]

Man 3 (from another group): Regardless of how you taught—teach it.

Michael: [laughs]

Woman 1: And I think the key really is knowing what misconceptions could be for that particular concept. And not going into it with, “Oh, well this is so easy that they’re not gonna have any; we’ll just move on.” Because that’s not typical.

Woman 3 (from another group): Sometimes I think if you just put that misconception out there, if you just let it stand, and then some of the other kids start to look at it and go, “that can’t happen that way,” then some of those other kids actually turn that teaching around, so you just kinda stand and facilitate [crosstalk], and then they really, basically figure it out themselves.
Michael: [laughs]

Betty: Right, and—and you wanna allow for that misconception to be out there [crosstalk], so you want to be—have a, you know, a climate in your classroom where someone can be wrong: “Okay, let’s—who’s got this answer, who’s got this answer, who’s got this answer; let’s figure out why we all come to th”—you know… Like a real scientist does! [laughs]

Woman 3: Yeah.

Alice: Exactly. Exactly.

Michael: [interrupting] You guys are starting to [inaudible] why the middle bar looks the way that it does compared to the other two, by the way. So, um—the middle bar has a gain—I know the numbers; the gains on these questions happen to be 6, 12, and 37 percent. So the.. the shift, the increase. So the gains for the middle group are twice as high as the gains for the left group, and a third of what—the right group. But, um… basically, you guys are—you’re sending out there, like, even if you don’t know what the specific idea is that’s out there, at least if you’re teaching in a way that opens up the possibility of it being out there, that the—more students will engage with it, simply because you allow for it to be in the classroom. Even if you didn’t, in that moment—we don’t know everything about possible student incorrect answers, but at least if you have a climate of a classroom where student ideas are being elicited, more of them are being dealt with, even if they weren’t yours that were being dealt with. Is that—

Woman 3: [inaudible] just turn you off, you know, so it’s nice to have those out there and have them work through them sometimes, and let them help each other rather than us just always, this is why it’s wrong, and…

Man 9 (from another group): Sometimes just not giving the answer, I mean, [crosstalk] [crosstalk] kids hate it when I say I don’t know, they know that I know.

Woman 3: Yeah.

Betty: Yeah.

Man 1: [interrupting, jokingly] You’re just reinforcing that behavior, [Man 9]; that’s all you’re doing is reinforcing its behavior.

Man 9: I know.

Betty: [laughs]

Man 9: I’ve covered up collaboratives; I think it’s worn off. I just—I’ll say I don’t know and they’ll be—look at me like, “I know you know the an”—” well [crosstalk] I’m not gonna tell you the answer; [crosstalk] of course I know what the answer is,
but... and so then they just have to think about it more, and then eventually we will talk about the right answer, but...

898 Michael: [laughs twice]

899 Betty: You’re right: they do hate “I don’t know”: when I put a math problem [crosstalk] up on the board, “What’s the answer to that?”—“I don’t know; I haven’t done it yet. You guys do it for me and then tell me what you get.”

900 Man 9: Not to/o [inaudible]

901 Alice: [laughing] I do the same thing!

902 Woman 3: [interrupting] And you can only ask clarifying questions; that’s all you can ask.

903 Michael: Yeah.

904 Woman3: You can’t say “I don’t know” or “I don’t get it,” you have to ask me a question to help you get to that point. It works really well for me.


One last SE indicator? [1:22:18]

905 [Room at large has been discussing potential misconceptions on Q5]

906 Man 10 (from another group): Or—or—or, just looking at it, I mean, we’ve been telling them the energy’s the same; they look at the graph and the energy’s the same as the graph [inaudible]

907 Michael: [laughs] I hadn’t thought of that one!

908 Betty: That’s what I said.

909 Michael: Yeah.

910 Betty: That’s why I said they would choose it.

911 Michael: Yeah.

912 Woman 1: Yeah, that’s what I chose.

913 Michael: So, the energy has to be the same at s—at some point, but after—okay. Um...Why might they say that the energy of the spring is still the same, even though it’s no longer compressed?

914 Man 11 (from another group): The cart’s still moving?

915 Alice: Because it’s boinging.
916  Michael:  [amused] It’s “boinging?”

917  Betty:  [laughs] Yeah.

918  [Room at large continues to talk about spring-related misconceptions]


   End of recording [1:29:16]
APPENDIX B: ENERGY SURVEY

The tasks are presented separately to include relevant data and literature from

http://assessment.aaas.org/

KCS Prediction Task: Please circle the scientifically correct answer, and put a square around the most common wrong student answer, and then write a quick sentence about what the student was thinking.

Question 1

A student shoves a box, and it slides across the floor. As the box slides across the floor, the box slows down and both the box and the floor get a little warmer. What happens to the energy of the box as it slides across the floor and comes to a stop and why?

A. The motion energy (kinetic energy) of the box decreases and its thermal energy increases because the motion energy is converted into thermal energy.

B. The motion energy (kinetic energy) of the box decreases and its thermal energy stays the same because motion energy is used up and is not converted into thermal energy.

C. The motion energy (kinetic energy) of the box stays the same and its thermal energy increases because new energy in the form of thermal energy is made.

D. Both the motion energy (kinetic energy) and the thermal energy of the box decrease to zero because the box is no longer moving and an object has energy only when it is moving.
Question 2

A student is playing with a pendulum (a ball attached to the end of a string). He gives the ball a push and watches the ball as it swings from side to side. After a while, the ball stops swinging.

Why does the ball stop swinging?

A. The motion energy (kinetic energy) of the ball is transferred somewhere else, like the air, as the ball swings from side to side.

B. A little bit of the ball’s motion energy (kinetic energy) is used up each time it swings from side to side, but the motion energy is not transferred anywhere else.

C. Some motion energy (kinetic energy) is transferred somewhere else, like the air, and some motion energy is used up.

D. An object only has motion energy (kinetic energy) when a person makes it move, and the student is no longer pushing the ball.
A cook uses an iron frying pan to cook a meal. After cooking, he places the hot frying pan on the counter. After a while, the frying pan, the counter, and the air in the room will be at the same temperature. Why?

A. Because thermal energy will be transferred from the frying pan to the counter and from the frying pan to the air

B. Because coldness will be transferred from the counter to the frying pan and from the air to the frying pan

C. Because thermal energy will be transferred from the frying pan to the counter and from the frying pan to the air, and coldness will be transferred from the counter to the frying pan and from the air to the frying pan

D. Because thermal energy will be transferred from the frying pan to the air, but thermal energy will not be transferred from the frying pan to the counter.
Question 4

A ball, starting from rest at Position 1, rolls back and forth along a curved track and eventually stops rolling. As the ball rolls along the curved track, the track and the ball get a little warmer.

How does the total energy of the ball and track system change as the ball rolls along the track? (Assume that no energy is transferred to or from the surroundings.)

A. The total energy of the ball and track system increases because new energy in the form of thermal energy is made as the ball rolls along the track.

B. The total energy of the ball and track system decreases because the ball loses all of its energy and eventually stops rolling.

C. The total energy of the ball and track system increases as the speed of the ball increases, and it decreases as the speed of the ball decreases.

D. The total energy of the ball and track system does not change because even though energy is transferred between the ball and track, no energy was added to or released from the ball and track system.
Question 5

A student compresses a spring and holds a cart next to the spring. The graph shows the amount of elastic energy the spring has when it is compressed and the amount of motion energy (kinetic energy) the cart has before it starts moving.

After he lets go of the cart, the spring pushes the cart and the cart rolls across the floor.

Which of the following graphs represents the elastic energy of the spring and the motion energy (kinetic energy) of the cart when the cart is rolling across the floor and the spring is no longer in contact with the cart? (Assume that no energy is transferred between the spring and its surroundings and no energy is transferred between the cart and its surroundings.)

A.  

B.  

C.  

D.
Question 6

Imagine a ball on a track where no energy is transferred between the ball and the track or between the ball and the air around it. The ball starts from rest at the position labeled Start and moves along the track toward Positions 1, 2, and 3.

![Diagram of a ball on a track with positions labeled 1, 2, and 3]

What is the highest position the ball will reach before stopping and going back down the track? (Remember that no energy is transferred between the ball and the track or between the ball and the air around it.)

A. Position 1  
B. Position 2  
C. Position 3  
D. It depends on how much the ball weighs.
Question 7

A student uses a rubber band to shoot a toy car across a level floor. Imagine that no energy is transferred between the car and the floor or between the car and the air.

What happens to the total amount of energy in the system (car and rubber band) when the car is moving across the floor and is no longer in contact with the rubber band?

A. The total amount of energy in the system will increase because the motion energy (kinetic energy) of the car increases and the elastic energy of the rubber band stays the same.

B. The total amount of energy in the system will increase because the increase in the motion energy (kinetic energy) of the car is more than the decrease in the elastic energy of the rubber band.

C. The total amount of energy in the system will decrease because the increase in the motion energy (kinetic energy) of the car is less than the decrease in the elastic energy of the rubber band.

D. The total amount of energy in the system will remain the same because the increase in the motion energy (kinetic energy) of the car is the same as the decrease in the elastic energy of the rubber band.
Question 8

A student places a warm can of soda into a bucket filled with cold water.

She puts the lid on the bucket. Which of the following describes the energy transfer between the water and the can of soda in the bucket?

A. Thermal energy is transferred from the can of soda to the water so the can of soda gets cooler and the water stays the same temperature.

B. Thermal energy is transferred from the can of soda to the water so the can of soda gets cooler and the water gets warmer.

C. Coldness is transferred from the water to the can of soda so the can of soda gets cooler and the water stays the same temperature.

D. Coldness is transferred from the water to the can of soda so the can of soda gets cooler and the water ice gets warmer.
9. The two pictures below show a block on a ramp. There is friction between the block and the ramp. In the first picture, the block has not started moving yet. In the second picture the same block is sliding down the ramp.

1. block at rest
2. block moving

What types of energy are in picture 1?

What types of energy are in picture 2?

For each type of energy identified in picture 2, say whether there is more than, less than, or the same amount as in picture 1.

Were any types of energy transformed from one type to another? If so, describe the transformations.

Does the total energy increase, decrease, or stay the same?
BIOGRAPHY OF THE AUTHOR

Paul Wilson was born and raised in Maine. He graduated from Hampden Academy in 2006 and received his Bachelor of Science in Electrical Engineering from the University of Maine in 2012. Paul used to believe that being an engineer was the best way to exercise his love for all things STEM, but then discovered that there is a wealth of nerdiness in teaching. Paul’s hobbies include bike riding, environmental activism, attempting the world record for longest graduate program enrollment, and playing guitar. He currently lives in South Portland, Maine with his dog Moxie. Paul is a candidate for the Master of Science in Teaching degree from the University of Maine in May 2022.