K-12 Teacher Understanding of Energy Conservation:

Conceptual Metaphor, Dissipation, and Degradation

By

ABIGAIL R. DAANE

A dissertation submitted in partial fulfillment

Of the requirements for the degree of

Doctor of Philosophy

Seattle Pacific University

April 24, 2015

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Date 8-19-2015

Dedication

For all the incredible women in my life who support me
as role models and as strong, discerning friends, most especially:

Mom, Heather, Lindsey, Courtney, Erin, Jane, Chaundra, Jennifer, Mary C., Vashti, Mary L., Mary Y., Stephanie, Ms. Rawls, Darby, Maria, Dane, Cher, Lindsay W., Lindsay O., Mary Jo, Lezlie, Leslie, Rachel, Sam, Amy R., Gina, Carolina, Ximena, Debra, Amy V., Nicole, Nyaradzo, Molly B., Michele, Michelle, Meg, Beth, KMac, Nissa, Erin, Ann, Caroline, Traci, Grandma,

And for Ember, may you grow up in a world where women know no boundaries.

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Table of Contents

List of Tables iii

List of Figures iv

Abstract 2

Chapter 1: Introduction 4

Problem: A Lack of Teacher Preparation to Teach about Energy 4

Theoretical Foundation of Study 7

Research Design 9

Chapter Information 10

Chapter 2: The pedagogical value of conceptual metaphor for secondary science teachers 10

Chapter 3: Energy conservation in dissipative processes: K-12 teacher expectations and strategies associated with imperceptible thermal energy 13

Chapter 4: Goals for teacher learning about energy degradation and usefulness 17

Chapter 2: The Pedagogical Value of Conceptual Metaphor for Secondary Science Teachers 22

Chapter 3: Energy Conservation in Dissipative Processes: K-12 Teacher Expectations and Strategies associated with Imperceptible Thermal Energy 52

Chapter 4: Goals for Teacher Learning about Energy Degradation and Usefulness 68

Chapter 5: Conclusion 85

Overarching Implications 85

A. Teachers need to develop a coherent energy model including energy conservation 85
B. Teachers have resources for learning about energy conservation 86
C. Teacher resources emerge from microanalysis of professional development courses 87
D. Teachers can be supported in developing a coherent energy model by using their own resources 88
Limitations to the Methodology 90
Areas for Further Research 92
References 94

List of Tables

Chapter 2 Table 1 28

List of Figures

Chapter 1 Figure 1 15

Chapter 2 Figure 1 32

Chapter 2 Figure 2 33

Chapter 2 Figure 3 36

Chapter 2 Figure 4 39

Chapter 3 Figure 1 54

Chapter 3 Figure 2 57

Chapter 3 Figure 3 62

Chapter 4 Figure 1 74

Chapter 4 Figure 2 76

Chapter 4 Figure 3 76

Chapter 4 Figure 4 77

Chapter 4 Figure 5 77

Chapter 4 Figure 6 80

Seattle Pacific University

Abstract

K-12 Teacher Understanding of Energy Conservation:

Conceptual Metaphor, Dissipation, and Degradation

By Abigail R. Daane

Co-Chairpersons of Dissertation Committee: Dr. Rachel E. Scherr, Department of Physics & Dr. Andrew Lumpe, Department of Education

In K-12 educational settings, conservation of energy is typically presented in two ways: the conservation of energy principle (energy is neither created nor destroyed) and the sociopolitical need to conserve energy (we guard against energy being used up). These two meanings of conservation typically remain disconnected from each other and can appear contradictory, even after instruction. In an effort to support teachers in building robust understandings of energy from their existing knowledge, I designed a study to investigate the productive ideas in K-12 teachers' conversations about energy. A micro-analysis of discourse, gestures, and artifacts of professional development courses revealed teachers' productive ideas about three aspects of energy: conceptual metaphor, dissipation and degradation. In learning about energy, K-12 teachers come to use conceptual metaphors in their own language and value attending to students' metaphorical language as a means of formative assessment. Teachers' conversations about dissipation suggest that apparent difficulties with energy conservation may have their roots in a strong association between forms of energy (thermal) and their perceptible indicators (warmth). Teachers address this challenge by employing an exaggeration strategy to locate the dissipated thermal energy, making the energy indicator perceptible.

Finally, teachers' unprompted statements about sociopolitical aspects of energy are related to both statements from the NGSS and aspects of energy degradation. I conclude that energy conservation can be better taught and learned in K-12 Education by: 1) understanding and applying conceptual metaphors about energy in K-12 settings, 2) using prior experiences to better understand dissipative energy processes involving imperceptible thermal energy, thereby understanding how energy conservation applies in all situations, and 3) connecting productive ideas about sociopolitical aspects of energy to canonical physics.

Keywords: energy conservation, K-12 teachers, dissipation, degradation, conceptual metaphor

Chapter 1: Introduction

Problem: A Lack of Teacher Preparation to Teach about Energy

Energy conservation is central both in a sociopolitical sense and in the formal study of physics, but the term has a different meaning in each context. In physics, energy conservation refers to the idea that the same total quantity of energy is always present in any isolated system; energy is neither created nor destroyed. In the public consciousness, however, energy conservation refers to the idea that we have to guard against energy being wasted or used up; the energy available to serve human purposes is both created, (i.e., in power plants), and destroyed (i.e., in processes that render it unavailable to us).

Recently the Next Generation Science Standards (NGSS), a set of standards that promote elementary and secondary students' development of scientific knowledge and practices, were developed for K-12 science education. They emphasize energy conservation as both core knowledge and a crosscutting concept and describe the second law of thermodynamics in terms of energy availability decreasing through processes. Instructors of science are in a special position in that they can introduce both formal science concepts and social responsibility to the next generation by adapting their teaching to include these standards. They have the opportunity to help their students connect ideas about energy in both contexts and make energy instruction relevant. However, little time or effort has thus far supported teachers in learning about the NGSS and their connections to the real world.

Teachers need to be given the opportunity to engage with the NGSS and be supported in developing a deep understanding of both the standards' content and classroom application. In Seattle Pacific University's Energy Project professional development courses for K-12 teachers, learning takes place in the context of a novel, rich representation that promotes teacher engagement and facilitates public discourse about their ideas. The teachers' ideas about energy concepts gathered during such instruction can be used to improve teacher professional development as well as K-12 instruction. In particular, teachers' productive ideas about energy conservation in the context of three topics: conceptual metaphors, energy dissipation, and energy degradation, can be used to improve the teaching of energy conservation in K-12 education. Such improved instruction can support learners' engagement with sociopolitical issues surrounding today's energy usage.

Just like the majority of secondary and university students (Chabalengula, Sanders, & Mumba, 2012; Solomon, 1985a, 1985b), most science teachers can easily recite the conservation of energy principle. However, in thinking about how this principle can be best taught and learned, the scientific community has not yet reached a consensus (Feynman, Leighton, & Sands, 1963; Scherr, Close, McKagan, & Vokos, 2012; Warren, 1982). This lack of consensus may result from the abstract nature of energy itself and the metaphorical descriptions of energy that are used in both everyday and scientific language. Several conceptual metaphors, or ontologies, for energy are used in classrooms today (Amin, 2009; Dreyfus et al.2014b; Scherr, Close, & McKagan, 2012). One conceptual metaphor, the energy-as-a-substance metaphor, has the particular affordance of supporting the understanding of the conservation of energy principle (Duit, 1987; Scherr, Close, Close, and Vokos, 2012). Teachers can benefit from an awareness of conceptual metaphors used in teaching and learning about energy in K-12 education (Chapter 2).

Even with the application of the substance metaphor to energy instruction, understanding the conservation of energy principle in real world situations can be difficult (Duit, 1983; Solomon, 1992). Students and teachers often find it difficult to model energy conservation through dissipative processes, or processes where the kinetic energy of bulk, macroscopic motion transforms (or dissipates) into the thermal energy of random, microscopic motion; instead, they describe the energy as decreasing throughout the process (Chabalengula et al., 2012; Kruger, 1990; Loverude, 2004). Chapter 3 demonstrates that when K-12 teachers engage in tracking energy through dissipative processes, they struggle to identify the production of thermal energy, even as the teachers recognize that energy must be conserved. However, the original scenario can be productively linked to an exaggerated scenario in which the evidence for energy becomes perceptible. The exaggerated version allows teachers to reconcile the apparent disappearance of perceptible indicators of energy with their understanding of conservation and justify the production of thermal energy in the original process.

Another manifestation of the struggle to conserve energy in real world situations comes about when students and teachers use their knowledge of sociopolitical energy implications in physics class. In many situations, researchers have documented students' tendency to rely on the everyday ideas of energy conservation (e.g., saving and using up energy), instead of the conservation principle (Goldring & Osborne, 1994; Solomon, 1983). In Chapter 4, everyday ideas about energy being wasted and used up are presented as productive ideas about energy degradation and are shown to be not necessarily in conflict with the conservation of energy principle. Looking into the broader educational community, few existing K-12 curricula support learners in integrating energy conservation (in the physics sense) with energy waste (in the sociopolitical sense). Thus, from previous research and teachers' productive ideas found in their discussions, we develop and share new learning goals for teacher professional development about energy.

These learning goals align with canonical physics and the NGSS. They can be used to build a sophisticated understanding of energy in physics and society, one that is both useful for K-12 teachers and their students and responsible to corresponding topics in formal physics (including energy degradation and the second law of thermodynamics).

The recent introduction of the NGSS requires a change in the pedagogical and content knowledge necessary for teaching about energy concepts associated with energy conservation: conceptual metaphors about energy, energy dissipation, and energy degradation. Teachers have not been prepared to address the new standards and need to be supported in developing both their ideas and their curricula about energy concepts.

Theoretical Foundation of Study

Learners have rich stores of intuitions about the physical world, informed by personal experience, cultural participation, schooling, and other knowledge-building activities (Daane, Vokos, & Scherr, 2013; Dewey, 1938; diSessa, 1993; Duckworth, 1996; Elby, 2001; Hammer, 1995, 2000). Some of these intuitions are "productive," meaning that they align at least in part with disciplinary norms in the sciences, as judged by disciplinary experts (Hammer, 1996b; Hammer, Goldberg, & Fargason, 2012; Harrer, Flood, & Wittmann, 2013). Learners may only apply these intuitions episodically: at some moments of conversation with instructors and peers there may be evidence of productive ideas, whereas at other moments productive ideas may not be visible (Amin, 2001; Gupta, Hammer, & Redish, 2010).

I conceptualize learning as a process of growth through which the "seeds" of learners' early ideas mature, through experience, to become more logical, coherent, consistent with observed evidence, and otherwise more fully scientific. Effective instruction, in this view, is instruction that provides favorable conditions for growth. This general conceptualization is common to many specific theories about teaching and learning (Bruner, 1960; Dewey, 1938; Montessori, 1978; Piaget & Inhelder, 1969; Rousseau, 1921; Vygotsky, 1986b). Some research contrasts this general conceptualization with other conceptualizations that see learners as hindered by ideas that are fundamentally flawed, and instruction as repairing or replacing learners' ideas (Hammer, 1996a, 1996b; Smith, diSessa, & Roschelle, 1994).

Learners' ideas play the privileged role using the theoretical stance above. Other theoretical perspectives give primacy to canonical understanding and the extent to which learners have or have not achieved it. Regarding the energy concepts, however, there are two practical reasons for valuing learners' ideas as the raw materials for building instruction toward appropriately re-worked canonical understandings as opposed to evaluating learners' ideas on their alignment (or not) with standard canonical knowledge. First, if one used an evaluating-student-ideas-for-alignment approach, the list of "problematic ideas" would be long and disjointed, partly due to the fact that energy conservation and degradation are often shrouded in mystery (relating to degradation and the second law of thermodynamics) and misinformation or unmotivated, inaccessible mathematical formalism (relating to energy conservation). The specific research regarding learners' ideas is addressed in each chapter. Second, if one were to privilege the typical canonical approach in physics, one would privilege the analysis of reversible processes in idealized situations (e.g., Carnot cycle), whereas everyday experience mainly consists of highly irreversible processes. Thus, rather than thinking of learners' ideas as flawed relative to disciplinary understandings, they are valued as productive resources and identified by the precise ways in which they can be built upon toward a new conceptualization of the content in ways that are responsible to the discipline. It is with this theoretical stance that we approach data collection and analysis.

Research Design

In effort to better understand teachers' thinking about energy concepts and identify their productive ideas, the majority of my data comes from Seattle Pacific University's Energy Project teacher professional development (PD) courses. For elementary (K-8th grade) teachers, we offer full-day, weeklong first and second year PD courses. For secondary (6th-12th grade) teachers, the full-day first and second year PD courses span two weeks. In these courses, teachers spend much of their time working in small groups and engaging in many, in-depth conversations about a variety of energy topics.

In each course, teachers are grouped into four to eight small groups, and two groups are audio and video recorded daily. While recording, researchers observe and document each course with real-time field notes, flagging interesting moments throughout the day. Additionally, researchers collect artifacts during their observations (including photographs of whiteboards, written assessments, and teacher reflections).

Later, researchers identify video episodes from the data corpus to share with a research team. I use the term "episode" to refer to a video-recorded stretch of interaction that coheres in some manner that is meaningful to the participants (Jordan & Henderson, 1995). Many of these episodes include teachers' sharing their ideas about energy content and corresponding pedagogy. These episodes are the basis for collaborative analysis, development of research themes, literature searches, and the generation of small or large research projects. For my analyses, video episodes are identified through (1) initial observations by videographers, (2) a search for key terms in the field notes which could relate to energy conservation (e.g., entropy, spreading, dissipation, thermal energy, wasted, useless), and (3) the inclusion of teachers' ideas about the relevant energy topics. I used peer examination/peer review to establish the validity of the video analysis, triangulating multiple communication markers (e.g., discourse, gesture, eye contact, tone of voice), and multiple sources (e.g., video, audio, photographs, field notes, observations, lesson plans) for each episode (Creswell, 2013; Maxwell, 1992; Merriam, 1995).

Chapter Information

The following sections contain information about each chapter including: the relevant physics, research questions, data summary, and results.

Chapter 2: The pedagogical value of conceptual metaphor for secondary science teachers.

Physics instruction has long struggled to define the concept of energy in a manner accessible to K-12 students. Secondary textbooks typically describe energy as something that "enables an object to do work" (Hewitt, 2002, p. 106). Avoiding explicit descriptions of the ontology of energy (or what kind of thing energy is) altogether is another tactic; the authors instead use work done to describe a change in energy (Cutnell & Johnson, 2009). The definitions of energy found in textbooks and state standards are described as inadequate (Duit, 1981; Kraus & Vokos, 2011; Ogborn, 1990) and some researchers recommend moving away from defining energy in terms of work (Ogborn, 1986; Solomon, 1982). Others argue that energy should be described as an abstract concept without the use of metaphors (Feynman et al., 1963; Papadouris & Constantinou, 2010; Reiner, Slotta, Chi, & Resnick, 2000; Slotta & Chi, 2006; Swackhamer, 2005, Warren, 1982).

A growing body of research promotes the use of metaphors when describing energy (e.g., Amin, 2009; Duit, 1987). Humans use conceptual metaphors to communicate about abstract concepts (Lakoff & Johnson, 1999) (e.g., love is a journey) (Lakoff & Johnson, 1980). Since love is an abstract idea, or conceptual domain, describing it as a journey projects certain characteristics of a journey onto love. Amin (2009) supports the argument that we use conceptual metaphor to communicate by stating, "abstract concepts are understood in terms of multiple, experientially grounded metaphors structuring understanding of different aspects of the concept," (p. 179). In the case of energy, several conceptual metaphors are used by experts and novices, including energy as a substance-like quantity, a stimulus, or a location (Scherr et al., 2012). The energy-as-a-substance metaphor can be effective for instruction (Amin, 2009; Duit, 1987; Gupta et al., 2010; Scherr, Close, McKagan, et al., 2012). Energy Project instructors promote the energy-as-a-substance metaphor for energy at the secondary level, primarily because it supports conservation of energy (Scherr, Close, Close, et al., 2012).

While explicit acknowledgment of metaphorical language is valued and studied by researchers (e.g., Amin, 2009), secondary science teachers are generally not expected to learn about its application to energy instruction. Yet, a greater awareness of metaphors could lead to improved education about energy. We seek to identify teachers' understandings and perceptions of energy metaphor in their own language and their classrooms using the following research questions.

1. Do teachers accept the need for metaphorical language in describing energy?
2. Do teachers find pedagogical value in understanding a) their own use of conceptual metaphor and b) their students' choice of metaphor when describing energy?