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Benedikt W. Harrer
University of Maine - Main, benedikt.harrer@sjsu.edu

Virginia J. Flood
University of Maine - Main

Michael C. Wittmann
University of Maine - Main

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Students Talk about Energy in Project-Based Inquiry Science

Benedikt W. Harrer*, Virginia J. Flood†,** and Michael C. Wittmann*,†

*Department of Physics and Astronomy, University of Maine, Orono, ME 04469
†Center for Research in STEM Education, University of Maine, Orono, ME 04469
**Department of Chemistry, University of Maine, Orono, ME 04469

Abstract. We examine the types of emergent language eighth grade students in rural Maine middle schools use when they discuss energy in their first experiences with Project-Based Inquiry Science: Energy, a research-based curriculum that uses a specific language for talking about energy. By comparative analysis of the language used by the curriculum materials to students' language, we find that students' talk is at times more aligned with a Stores and Transfer model of energy than the Forms model supported by the curriculum.

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INTRODUCTION

Energy is at the core of scientific descriptions of physical and biological phenomena and is a ubiquitous concept across K-12 science standards [1, 2]. A deep, versatile understanding of energy is crucial for students as it becomes a central sociopolitical issue. However, how energy is modeled in physics and how it should be taught continue to be debated [3, 4]. Researchers have argued for energy as something quasi-material [5], as the ability to do work [6], as the ability to cause change [7], or as an abstract accounting system [8]. Thus, it is no surprise that previously documented ideas that students communicate about energy are often diverse and not always aligned with scientifically accepted physical models [9, 10].

How students talk about energy is likely to provide clues about how they think about energy [11]. Lemke [12] asserts that "learning science means learning to *talk* science" (pg. 1) and Roth and Lawless [13] argue that "science as culture [is] strongly characterized by its language" (pg. 369). Studies of experts' discourse about physical phenomena have revealed the use of indeterminate constructions [14] and flexible ontologies in their thinking about abstract concepts [15]. Recently, the microanalytic treatment of students' emergent discourse in science classrooms has proven to be a powerful tool in exploring how students develop new ideas [13, 16, 17].

We examine eighth grade students' emergent language in their first discussions about energy with a new research-based curriculum that uses a specific language for talking about energy. By comparing the language of the curriculum materials to students' talk, we find that students' language is more aligned with a different model of energy than that supported by the curriculum.

MAINE PHYSICAL SCIENCES PARTNERSHIP AND PROJECT-BASED INQUIRY SCIENCE

The Maine Physical Sciences Partnership (MainePSP) is a collaborative effort between The University of Maine, rural Maine schools, and nonprofit institutions to improve science instruction for grades six through nine throughout the state. As part of the activities of the MainePSP, teachers chose a set of modules from Project-Based Inquiry Science (PBIS) for use in teaching 8th grade physical science. Participating schools are currently piloting the research-supported [18] curriculum. Research on the implementation of these modules in classrooms is a current component of the MainePSP.

PROJECT-BASED INQUIRY SCIENCE: ENERGY

PBIS units typically present learners with a "big challenge." Students are exposed to science content connected to this challenge over a 14-week progression. In the PBIS: Energy unit, students are given the ultimate goal of designing a Rube Goldberg machine capable of turning off a light.

In this section, we present how energy is conceived and conveyed by PBIS, based on an analysis of the language of the curriculum materials in the beginning of this unit [19]. This language carries four propositions about energy.

Objects have energy. The phrasing of questions like "Do you think the soccer players *have* enough energy to play harder?" or "How can you know if the oven *has* enough energy to finish baking the cupcakes?" (pg. 3,

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emphases added) suggests to students that objects can have energy. The teachers' guide reinforces this notion by stating that the students "will learn to observe items that *have energy*" [20] (pg. 22, emphasis added).

Energy has different types. Emphasis is placed on the idea that energy has many different types ("In this Unit, you will learn how to identify [...] many different types of energy", pg. 3). For example, there are the energy a child has, energy that is released by light bulbs, energy a battery has, or energy that makes a car move (pg. 5).

Energy can be transformed and transferred. One of the most important aspects of energy in PBIS is that it can be transformed from one of these types into another. For example, "In a flashlight, a battery's energy is transformed into the energy released by a light bulb" (pg. 5). Questions like "Where does this energy come from, and where does it go?" (pg. 3) suggest that energy can also be transferred from one place to another.

Energy involves change. In the beginning of the energy unit, students are encouraged to think of energy as "the ability to cause change" (pg. 4). Changes in objects are to be considered indicators for energy transformations (pg. 8).

A FORMS MODEL OF ENERGY

The language PBIS uses to introduce energy seems aligned with a Forms model of energy that we are adapting from Kaper and Goedhart [3]. In this model, energy is described as something that objects with *observable and changeable properties* can have. It has different *forms*, each of which is associated with one of those properties. When two properties of the same object *change* simultaneously, energy is being *transformed* from one form to another. When one and the same property *changes* simultaneously for two different objects, it is reasonable to say that energy was *transferred* from one object to the other.

This model shares several characteristics with the PBIS way of describing energy: Objects *have* energy. Energy has to do with *changes* in objects. Particular changes indicate *energy transformations*, others indicate *transfer of energy*. The particular processes by which energy transfers or transformations occur are not part of either account.

As an example, we can describe the scenario in the upper right corner of Fig. 1 using language that aligns with the Forms model. A girl dumps trash out of a trashcan through a window onto a wheel that is set into motion by the trash. The window is up high in a wall, so the trash initially has a high vertical position (this position is a property of the trash) with respect to the ground - it has gravitational potential energy. The trash falls: It moves and accelerates downward. The motion of the trash (another property) is associated with its kinetic energy. While its vertical position above the ground changes, the speed changes. With this simultaneous change in two properties of the same object (the trash), we can say that energy has been transformed - from gravitational potential to kinetic energy. When the trash hits the wheel, it sets the wheel in motion while at the same time slowing down itself. One property (speed) changes simultaneously for two objects, and we have reason to say that energy has been transferred.

PBIS: ENERGY UNIT INTRODUCTION AND RUBE GOLDBERG ACTIVITY

The introductory section of the PBIS Energy Unit seeks to elicit students' ideas on energy and the different forms in which it exists [20]. In one of the introductory activities, students are asked to identify energy transformations in a Rube-Goldberg-like cartoon (see Fig. 1).

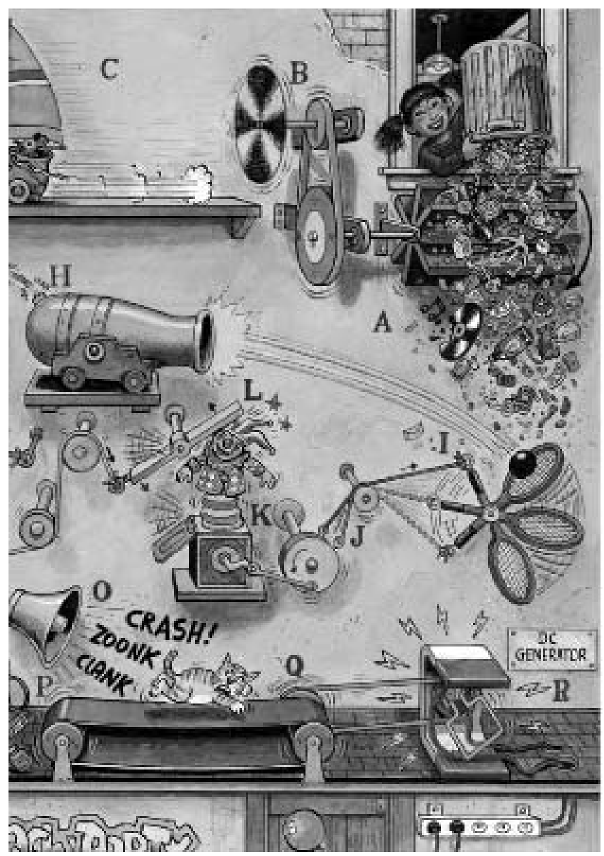

FIGURE 1. Trash to Stereo Server (T. Bunk; [19], pg. 11)

Working in small groups, students complete a worksheet, recording the "Changes/Work done" in each step (identified by letters in Fig. 1), the "Energy type in" and "types out" of each step, and the "Indicators of energy transformations" they find [19] (pg. 15).

STUDENTS’ TALK ABOUT ENERGY

Twelve small groups in six classes at three different schools were video-recorded during the first two weeks of working with the energy unit. We selected episodes of students completing the Rube Goldberg activity and analyzed the students’ discourse for the language they used while filling in the columns "Energy type in" and "Energy types out" for each step in their respective Rube Goldberg machines. Four distinctly different categories of students’ talk were identified.

Categories of Students’ Talk

Physics Vocabulary. Some students used single word terminology descriptors when talking about "Energy type in" at step A in Fig. 1, like "Kinetic." The use of physics terminology in students’ talk could be an indicator for their applying of physics concepts to the scenario. However, listing vocabulary words without connecting them to their observations or providing explanations for their word choice, does not clearly indicate understanding. The descriptors students use to fill in the "Energy type" columns (other examples include "Potential," "Sound," "Solar," or "Heat") seem related to the Forms model of energy in which each type of energy has its own name.

Narrative. Other students talked about the type of Energy In as "Girl dumps trash." This descriptive language suggests that the students are directly translating the picture into words. Students’ descriptions range from two-word phrases (e.g. "Burns rope") to more elaborate and informative sentences like "Ball goes down a ramp" that contain details which could provide answers to the questions What?, How?, or Why? Those answers would be useful for the creation of a coherent energy story of the scenario. While this is a necessary step toward further analysis of the scenario, students in this category never go beyond narrating what they can directly observe in the picture.

Object Acting. "Trash falling" is an example of students using a noun and a verbal to talk about an energy type: noun + verb-ing. The exact grammatical function and meaning of this combination of words can not be accurately determined because the students don’t use the phrase in a complete sentence. Whether "Trash-falling" is meant as a compound word, or as an abbreviation of the sentence "The trash is falling," the students seem to be describing the process the trash is undergoing in the moment the picture was taken. Details about this process in the picture (what caused the trash to fall? where is the trash falling?) are missing from the description. Further examples of this language use are "Hand moving," "Bag inflating," or "Propeller turning."

Action on an Object. Similar to the previous category, the fourth and last category is characterized by the students’ use of phrases containing a noun and a verbal. In this case, however, the order is reversed: verb-ing + noun. Students describing the "Energy Type in" at step A in Fig. 1 used the phrase "Dumping the trash." In this grammatical structure, the verbal seems to be a gerund, emphasizing the process of dumping by making it the subject of the phrase. The trash becomes the grammatical (and physical) object that is acted on. As in the previous category, details in the pictures are not mentioned by the students in their description of the energy types. Other examples of students using this construction are "Burning something," or "Pulling a string."

The last two categories, *Object Acting* and *Action on an Object*, show a higher level of abstraction from the picture in comparison to the *Narrative* category. Students specifically picked features of the picture that they deemed relevant for the task at hand and omitted others.

Of the described four categories, only the Physics Vocabulary category appears to be related to the PBIS or Forms model of energy. The emphasis on *processes* in the categories involving verbals is not part of the language used to describe energy in a Forms model, although looking for processes and mechanisms is an important part of analyzing and understanding physical scenarios.

A STORES AND TRANSFER MODEL

A different model of energy, a Stores and Transfer model, places emphasis on processes of transfer and transformation [21]. The focus in this model is on *storage and transfer* of energy in a system. The model postulates that energy can only be stored in three stores within a system. These means of storage are associated with motion, position, and intrinsic properties like temperature and phase (for more detail see the original publication). If there is an internal transfer of energy within a system *and* from one store to another, an energy transformation has occurred. The three primary mechanisms of energy transformations are work, and chemical and nuclear reactions. Energy transfers across system boundaries may occur by mechanisms that can be categorized into six processes: work, heat, matter transfer, mechanical waves, electromagnetic radiation, and electrical transmission.

To describe the example of the girl dumping trash onto a wheel in Fig. 1 using language that aligns with the Stores and Transfer model, we first choose our system to encompass trash and earth. Energy is stored within this system in the position of the trash relative to earth. Additional energy is stored in the motion of the trash. While the trash is falling, energy is transferred from the position store to the motion store: A transformation of energy occurs. Looking at the interaction between the trash and the wheel, we need to consider the trash-earth system *and* the wheel system. When trash hits the wheel's paddles, energy is transferred across the boundaries of these two systems. The mechanism for this transfer is matter transfer from the trash-earth system to the wheel system.

Students' use of verbal + noun constructions suggests that their thinking is focused on specific processes. The focus on these processes would allow students to describe how energy is stored in a system (e.g. "falling" and "pulling" both describe motion), and how energy is transferred across system boundaries (e.g. matter transfer through "trash falling", work done by "pulling a string"). We do not mean to imply that students are using the Stores and Transfer model, but rather that their language use early in the curriculum is at times more aligned with this model than with a Forms model as used by PBIS.

CONCLUSIONS

We have observed a mismatch between the way students talk about energy types in the Rube Goldberg activity and the language the curriculum uses. Students' talk–"Girl dumps trash," "Trash falling" and "Dumping the trash"–puts emphasis on one-object systems and the processes these systems undergo. This language lends itself to the use of a Storage and Transfer model of energy which would be useful for later studies in physics [21].

However, the language of the Forms model is used by physicists and in an early draft of the Next Generation Science Standards on energy for middle school. It is also the language used by the PBIS curriculum. For learners to participate in this language, their talk must be focused on properties of objects and on changes of these properties.

With this model in mind, the trash-dumping-scenario in Fig. 1 could be described as "the trash started out at rest in the can, then was set into motion; this change in speed is an indicator for translational kinetic energy;" "the trash was high up at the window, then it fell down onto the wheel; this change in position is an indicator for gravitational potential energy;" "the wheel started out not moving, then it started rotating when the trash fell onto it; this change in motion is an indicator for rotational kinetic energy."

Explicitly identifying change in properties of objects is uncommon in everyday language. We find that students, at least early on in the energy unit, tend to focus on objects and processes, not change. In order to enable students to successfully learn the PBIS model of energy and use the appropriate language to describe energy transfers and transformations using this model, they need guidance in recognizing and explicitly talking about change.

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