Exploring Sixth Grade Students Model-Based Reasoning about Energy Flow Between Societal and Earth Systems

Subject & Problem

There is a global focus to create an energy literate populace so that societies will reduce energy consumption, decrease environmental damage, and increase public health (United Nations [UN], 2015). The significance of developing energy literacy is elevated given the importance and severity of global carbon emissions, which directly relates to human energy consumption. Buildings, in particular, drive energy consumption and global carbon emissions (U.S. DOE, 2015). Over one-third of global final energy use and nearly 40% of global carbon dioxide emissions are from building construction and operation (GABC, 2018). The U.S. Department of Energy ([DOE] 2012) defines an energy literate citizen as someone who can trace energy flow within and across societal and Earth systems and use this knowledge to make informed decisions and take informed action on societal energy use. However, tracing energy is challenging as it flows within and across energy systems that span both Earth and societal systems, such as within and between a building and the surrounding environment. Both students (and adults) struggle to make sense of how energy flows within and across human and Earth systems and determine system impacts (Coyle, 2005; DeWaters & Powers, 2011).

Tracing energy flow requires systems thinking abilities. Systems thinkers can look at individual parts and processes of a system and understand how these individual elements affect the system as a whole (Booth Sweeney & Sterman, 2007). Systems thinking is an essential 21st century practice for STEM literacy, yet is one of the most difficult higher order thinking skills to master (Duschl et al., 2016). An essential part of developing systems thinking is through model-based reasoning (MBR) which provides a means to describe, explain, and predict system behavior (Verhoeff et al., 2008). MBR engages students in developing, evaluating, and revising their own models of an entity, phenomenon, process, or system (Duschl et al., 2016; Schwarz et al., 2009). The model serves as a reasoning tool because when students model, they represent both hidden and visible components while showing and reasoning about the interactions between these components and proposing how and why these interactions occur (Verhoeff et al., 2008).

While there is an extensive literature base on the energy ideas students hold (reviewed in Duit, 2014), there are few studies that examine how elementary students use scientific modeling to conceptualize and reason about the interrelationships between societal and Earth systems or how students consider the ways that societal energy systems interact with natural energy systems. Our 3-year, NSF-funded exploratory project is situated in this space. We are creating a place-based energy curriculum in which 6th-grade students' (aged 11 – 12) model-based reason (MBR) about energy flow within and across their school building and the surrounding environment. Within this work, we focus on the energy flow relationships within and between the school building and the surrounding environment, spaces in which students' have a multitude of energy experiences daily. Here, we report our year 1 (Y1) baseline MBR findings of the energy flow ideas students held at the start of 6th-grade prior to experiencing any energy curriculum. Our research question is: *What are incoming 6th-grade students MBR about energy flow between their school building and the surrounding environment?*

Theoretical Framework

MBR occurs through the act of students drawing their ideas and writing about their drawings. We use modeling in the form of drawings because of the multiple affordances present within the act of drawing in science such as considering how their drawings correspond to and are coherent with the scientific phenomenon (Tytler et al., 2020). Students draw an initial model in response to a question or problem that links to scientific phenomenon (Schwarz et al., 2009). This model is developed using their prior knowledge, which demonstrates their conceptual understanding at that moment in time. Students include *components*, which are the inscriptions they use on their drawings to create their model such as words, numbers, objects, or other symbols. Students then make connections between the components, where they may articulate the relationships that exist. These are their modeled *sequences*. Finally, students identify cause and effect occurrences with the underlying mechanisms through their articulated *explanatory processes* (Author, 2016; Authors, 2019). Together these three features– *components, sequences*, and *explanatory process* –identify the elements that students are using to make sense (i.e., MBR) about key concepts and issues (Lehrer & Schauble, 2012). When students use MBR, they are able to take apart the system and select which components, processes, and levels to make visible. This allows for foregrounding some interrelationships and backgrounding others as students figure out how the system's elements work together (NGSS, 2013).

Design & Procedure

Five 6th-grade teachers from the same school district within a small Midwestern city self-selected to participate in this 3-year project. The teachers were all certified to teach science at the 6th-grade level and each taught for this district for greater than 5 years. The data reported here are project baseline data collected in project Y1. For this study year, the district had 18,282 K-12 students with 43.7% of the students eligible for free/reduced lunch. Energy is the first science unit taught in 6th-grade, so data collection for each teacher began on the first or second day of the academic school year. The data was collected during the COVID-19 pandemic in which all participating classrooms were virtual so data were collected virtually. For data collection, we used the application Nearpod which was approved by the district as an application for students use.

There was no curriculum intervention in Y1 as our focus was to collect and analyze MBR baseline data for what incoming 6th grade students know about energy flow between the school building and the surrounding environment. However, since we wanted students to model their ideas, all teachers implemented a modeling lesson prior to beginning their business-as-usual energy unit. The modeling lesson included scientific modeling background knowledge for teachers and provided questioning prompts to ask students during a discussion about scientific modeling. After the discussion, students were introduced to the open-ended modeling task and associated writings. Within Nearpod, students were asked to draw a model to answer the question "*How does energy flow from the environment to your school building? Next use the green pen color and add to your drawing: How does energy use in the school building affect the environment?*" Students were provided two prompts: "include the most important parts of the system" and "If helpful, use *words* and/or *numbers* to label parts of your model." After students drew their models, they answered two questions about their models: "*What does your model show?*" and "*What does your model help you think about?*" Each drawing with the associated writing constituted one unit of analysis. Using the same modeling lesson, we also collected post-model data but it is not relevant to the research question presented here.

Our sample size for this reported study was n = 130. Data were analyzed both quantitatively and qualitatively. First, we developed quantitative rubrics using the theoretical framework described above. The rubrics served as measurement tools for students' models for components, systems, and explanatory process. For components, the rubrics measured the kinds and quantities of energy components as societal (e.g., electrical lines, solar panels, wind turbines) or Earth system which we separated into abiotic (e.g., sun, air, water, ground) and biotic (e.g., animals, plants, people). The sequences measured the relationships students indicated between the components, such as showing the links in energy flow between the electrical lines and buildings. The explanatory process rubric dimension assessed if and how students were making sense of the connections within their sequences, such as stating that there was a relationship between electrical lines and buildings, how the relationship occurred (building uses energy that is transported on power lines), and why the relationship occurred (to turn on lights inside the building). We describe the development of the rubric and provide the rubrics in the full paper. We completed interrater reliability in which two coders each coded the same 10% of the sample Cohens Kappa between 0.61 and 0.80 (Landis & Koch, 1977) is defined as substantial agreement between coders. Our Cohen's Kappa measurements were: *0.71 for components*, *0.71 for sequences*, and *0.62 for Explanatory Process*, all within substantial agreement. The data were then divided among both scorers to complete. After scoring, we qualitatively analyzed the models with associated writings. We used the rubrics to define patterns (Ryan & Bernard, 2010) within the data for how students modeled and wrote about energy flow within and across societal and Earth systems. As patterns emerged, the data were reduced to elucidate key factors relevant to our research question. Our qualitative themes are presented below.

Findings & Analysis

Quantitative Analysis & Findings

Out of the three elements, (components, sequences, and explanatory processes), components had the highest average (See Table 1). The most frequent component was power lines (51%) and the second most frequent component was the sun (22%). Overall, sequences that were present were typically one link connecting the energy source (either the sun or power line) to the building as a whole (50%). In explanatory processes, students indicated that energy flow occurred between an object to the building in very general terms such as the power line or the sun "supplied energy." However, they rarely included what the supplied energy was used for within the building (such as turning on lights or heating and cooling). Only 22% of student models indicated environmental effects from energy flow to and from their buildings. When students did include impacts to the environment in their model, it was a general explanatory process that energy flow caused "pollution" without indicating how or why this occurred.

Table 1. **Model Scoring Descriptive Analysis**

	Components	*Sequences*	*Explanatory Process*
Min and Max Possible Scores	Min= 0, Max = 4	Min= 0, Max= 6	Min= 0, Max= 3
Average	2.49	1.11	1.54
Standard Deviation	1.12	1.06	0.79

Qualitative Analysis & Findings

We identified two themes: 1) Energy Flow Ideas and 2) Energy Flow in Human Systems

Energy Flow Ideas

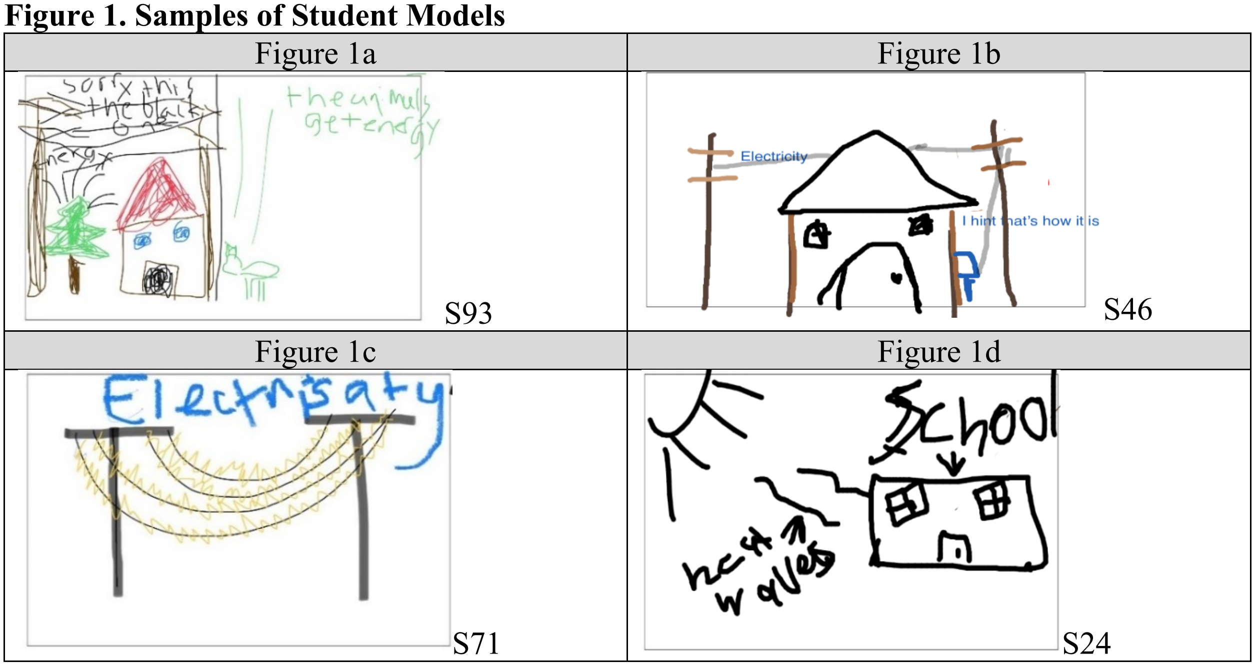
Students articulated that energy was something "we use every day" but consistently interchanged the term "energy" with the term "electricity". When considering if energy flows between the building and natural environment, they discussed this does not occur because the natural environment does not need electricity, but humans do. In their models, they showed two separate images, one for energy in a human system and one for energy in a natural system (Figure 1a). To differentiate between the two systems students described food chains as a way that energy flows in the natural environment stating "… an animal comes and eats some plants and gets energy. Then a bigger animal comes and eats that one and the food chain keeps going. Until an animal dies and decomposes and helps the soil which is giving back to the natural environment." (Student 138). Statements such as this did not overlap with mention of social systems, like buildings and infrastructure, indicating that students differentiated between energy in natural systems versus social systems. Using this differentiation between the two systems, students did not articulate an overlap between energy flow across the systems. They did discuss that energy flow was important to each system, but that humans generated energy for human use, and natural systems (such as a food chain) generated energy for its own use; the two systems did not intersect.

Energy Flow in Human Systems

There were two groups within this theme that related to the two highest component types evidenced in student models, power lines and the sun.

Energy from Power Lines. Fifty-one percent of the models contained electrical power lines. The power lines were drawn either above ground connected to poles or below ground under the grass (Figure 1b). Within this group, 25% of the models included sequences in which the power lines were connected to a building while the other 25% did not connect the power lines to anything else (Figure 1c). In those models that connected the power lines to a building, some students did consider a purpose of the power line such as: “My model shows electric wires like you see next to roads. The yellow is the entertainment around it that provides us to use our devices.” (Student 135). In addition, students’ models that connected the power line to the building also considered if energy used by the building had an effect on the surrounding environment. Students articulated in their drawings and writings that the energy, in general, “gives off pollution” and specifically, the power lines that supplied energy also “gives off pollution.” The student models that included power lines, but did not connect the powerline to a structure rarely had an explanatory process. If students did include an explanatory process, it was general that “energy flows…through power lines” (Student 134). In addition, when power lines were not connected to a structure, students also did not include environmental impacts.

Figure 1. Samples of Student Models



Energy Flows from the Sun. The next most frequent modeled component by students was the sun. Within 50% of these student models, the sun is indicated as providing energy in which heat waves come from the sun in the direction of the building (Figure 1d). However, within the remaining 50% of these models, students also included solar panels on their models and indicated a sequence between solar panels, sunlight, and energy for the building. Students’ writing with these models was: “Solar panel taking in sunlight and converting it through the machine to energy to power the school" (Student 144). Students' explanatory process did not include end uses for energy in the building (such as for heating water, air conditioning, lightening, etc), but did consider a way to harness energy for building use.

Contributions to the Teaching & Learning of Science

This study is of interest to the NARST community as it uses MBR to explore the ways in which upper elementary students think about energy flow across societal and Earth systems. Knowing students' baseline energy literacy is vital to developing curriculum and instruction that supports students in understanding how energy is harnessed from Earth systems and used by societies, what effects this has on Earth systems, and how to reduce societal energy flow impacts to Earth Systems (Liu & Park, 2014; NGSS, 2013; U.S. DOE, 2012). Our findings indicate that students drew on their own observations and experiences of energy used in their daily lives to consider energy flows to their school building. Within their drawings and writings, they used notions of energy from their "life-world domain" (Duit, 2014, p. 76) in which energy, as they are most familiar with it, was electricity. In so doing, they used an alternative framework in which *energy is functional* (Watts, 1983). Within this framework, the purpose of energy is to make human life more comfortable such as powering a device and turning on lights.

There were few instances in which students considered what effects may occur on Earth systems from energy use within their school building. When students did consider impacts from energy flow from Earth systems to societal systems, they articulated pollution as the effect. However, their understanding of pollution was nebulous in which energy, in general and regardless of source, caused pollution. Hearing through media outlets about "pollution" and "energy" in relation to electricity, without learning about how electricity may cause pollution could lead to this general association (Rodriguez et al., 2015). In addition, cause and effect between energy and pollution is not linear and occurs throughout the system, which is a complex association that requires temporal and spatial systems thinking (Booth Sweeney & Sterman, 2007).

Second, our results indicate that while students considered energy flow within Earth systems and societal systems, they kept these systems in two different siloes. In one silo, animals use chemical energy garnered from the sun for food, while in the other silo, humans use electrical energy that may be garnered from the sun or from power lines. Prior research suggests that citizens view the purpose of Earth systems to meet their personal needs and for their own satisfaction; they typically do not consider how these systems interact and what effect societal energy needs may have on the Earth system (Kandpal & Broman, 2014). This may be because links between societal and Earth systems has historically not been a part of science instruction. Coyle (2005) considers not explicitly teaching the overlap of societal and Earth systems within formal education as the "single biggest problem in the environmental knowledge gap" (p. 14). To discuss and propose solutions for 21st century global energy issues, students should understand the energy systems interrelationships between societal systems and Earth systems, and the impacts of harnessing energy for societal use (Coyle 2005; Kandpal & Broman, 2014).

Even though both MBR and systems thinking are included in the NGSS, opportunities to engage in these practices are rare within science learning environments (Author, 2016). Development of systems thinking requires curricular and instructional support (Booth Sweeney & Sterman, 2007; Verhoeff et al., 2008). Our Y1 baseline results highlight the need for curriculum materials that teach energy ideas through considering how energy flows within and across societal and Earth Systems. In Y2, we will pilot our project curriculum materials in which 6^{th}-grade students will use MBR throughout their curriculum unit consider energy flow within and across their own school building and surrounding environment.

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