

Development of a Socio-Ecological Learning Performance for Middle School Students' Ideas about Energy Flow AERA, 2024

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Purpose and Objectives

The study purpose is to elucidate a learning performance for how students developed systems thinking about energy system components and relationships across a new 10-week socio-ecological unit. Systems thinking is a key competency that all individuals should hold in order to “advance sustainable development” (UNESCO, 2017, p. 10). Socio-ecological systems thinking “seeks to overcome the dichotomy between natural and social systems by viewing the interrelationship between society and nature as a system in its overall context” (Mehren et al., 2018, p. 688). The unit focused on energy flow from natural resources (e.g., wind, sun, and coal) to human energy resource use in the built environment focusing on light, electrical, and thermal energy. The unit focused on characterization of causes and effects that affect large-scale system behavior such as the interrelationship between electrical energy and carbon emissions (Bar Yam, 2016). Focusing on large-scale system behaviors is a “short cut” (Bar Yam, 2016, p. 74) to reduce students cognitive load in considering the temporal and spatial interactions across two large systems.

To support systems thinking development, the unit was designed using the systems thinking hierarchical framework ([STHF] Ben-Zvi Assaraf & Orion, 2010). Each lesson of the unit embedded the STHF levels in hierarchical fashion so that students’ progressively experienced higher levels of systems thinking across the unit. Since modeling is essential to developing a system understanding (Tytler et al., 2020; Tripto et al., 2018) students drew systems models throughout the unit to support their development of the energy components and relationships within the socio-ecological system. While there is much guidance in how students build systems thinking within natural phenomena (e.g., Yoon et al., 2018), there is not much information about how students develop systems thinking within socio-ecological systems. To elucidate how this develops, we developed a learning performance which is a practice-based micro-level view of how students develop a practice (systems thinking) about a concept (energy flow) across a single unit (Zangori & Forbes, 2016). They differ from learning progressions which are a macro-level characterization of cognitive development of discipline-specific expertise across several grade bands (e.g., Herrmann-Abell & DeBoer, 2018). Learning performances are used to inform design and alignment of curriculum, instruction, and assessments, and serve as learning progression foundations (Shin et al., 2010). In this proposal we *a) develop an empirically tested learning performance framework for middle school students’ systems thinking about energy within a socio-ecological system and b) use the learning performances to analyze students’ socio-ecological energy system thinking development.*

Theoretical Framework

This study is situated in model-based learning to understand how students’ systems thinking about energy flow developed across the unit (Tytler et al., 2020; Tripto et al., 2018). Model-based learning is a multi-phase process in which students develop, use, evaluate, and revise a 2D diagrammatic model in response to a question or problem about scientific phenomena (Schwarz et al., 2009). Students hold a repertoire of conceptual models about systems developed from their observations, experiences, and inferences over time about the

system (Linn, 2012). These building blocks are the foundation for their cause-and-effect reasoning about system relationships and are used to define overall system behavior. Students develop their conceptual systems models through the creation of a pencil-and-paper 2D diagrammatic model where they make their conceptual building blocks visible to both themselves and others. Within their 2D model, they consider the components of the system (elements, objects, and entities) and how these components causally interact (Tripto et al., 2018). As students “use evidence to sort out, compare, and analyze” (Linn, 2012, p. 244) their developing understanding of the system, they return to their subsequent models to evaluate and revise their model based on their new understanding. Each developed model serves as concrete representation of students’ abstract ideas of energy flow within a system, where students choose which cause-and-effect relationships of energy flow within the system to amplify while reducing system complexity through backgrounding other system elements (Tytler et al., 2020). Students’ models serve as a reasoning tool for them to use to make sense of causal relationships and to define their understanding of system behavior. As their conceptual systems model repertoire increases, their causal reasoning also gains in complexity as they integrate new understanding (Linn, 2012).

Methodology

Context. This study examined how a new NSF-funded socio-ecological unit supported sixth grade students in developing systems thinking about energy flow within and across a societal system (their school building) and a natural system (natural resources). The study takes place in a small Midwestern city. Five 6th-grade teachers from three different schools within the same school district implemented the 10-week socio-ecological unit shown in Table 1. Two of the teachers were case study teachers who permitted researchers to observe all enactments of the unit, were interviewed weekly, and to collect all student written work completed within the unit. The case study teachers taught three to four sections of science daily for 48 minutes each with class sizes ranging from 17-28 students ($n = 228$)

Data Collection. For this study, we only analyzed data for students who completed 2D paper and pencil diagrammatic systems models at three time points: at the start of lesson 1 was the premodel; between lesson 2 and 3 was the midmodel, and after lesson 4 was the postmodel ($n = 112$ students). Each model was drawn to the same prompt: *How does energy flow from the environment to your school building; how does energy use in the school building affect the environment?* Students responded to two writing prompts about their models: *What does your model show?* and *I think this is important to show about energy flow because...* At each time-point, students were given 20 minutes to draw their model and answer the reflective questions about their models. In addition, at the mid- and postmodel, students were asked to evaluate their previous model by giving it a rating of 1 to 5 and explain their rating. They were also asked to reflect on what they had learned since the last system model. All student drawings and writings were collected by teachers and scanned by the research team.

Data Analysis. We used the systems thinking hierarchical framework (STHF, Ben-Zvi Assaraf & Orion, 2010) to develop the learning performance. The STHF has six levels of systems thinking spread across three milestones that are applicable in the middle school classroom: Milestone 1: Systems components analysis (Level 1, identify system components and processes), Milestone 2: Synthesis of system components (identify simple [Level 2] and dynamic [Level 3] relationships among components; Level 4, organize components and processes in a framework of relationships; and Level 5, identify cyclic nature), and Milestone 3: Implementation (Level 6, understand hidden system dimensions). We used construct centered design (CCD) to empirically ground the learning performance through iterative data analysis (Shin et al., 2010). First, we analyzed 10% of the data for each modeling time point using the

STHF predefined levels. When we found a common pattern of models did not meet STHM levels, we proposed a new level and empirically grounded the new level with a new 10% data subset for each modeling time point. Once all levels were empirically grounded, the completed learning performance was used as a scoring rubric to analyze student's systems models of the socio-ecological energy system, the second study goal. The rubric levels examined the dimensions in which students represented and connected components and included causal reasoning about those connections (see Table 2). Finally, we qualitatively analyzed the models and writings using classical content analysis (Patton, 2001) using the learning performance levels as a priori codes. Qualitative analysis involved an iterative process of data coding, displaying and verification to elucidate the quantitative findings.

Results

Our first research goal was to *develop an empirically tested learning performance framework for middle school student's systems thinking about energy within a socio-ecological system*. The completed learning performance with example systems models is shown in Table 2. The analysis of student's models yielded six levels. During learning performance development, we uncovered a pre-analysis milestone that was not within the STHF. The first level on STHF is components and processes within the system. However, we found in the pre-models that some students were unable to identify energy flow components and/or identified wind and sun as "general energy" without energy connections. Evidence of the pre-analysis milestone diminished in the mid- and post-models, so we considered the pre-analysis levels as energy systems precursors. These were partial ideas about socio-ecological energy flow students held at the beginning of the unit. Our analysis also suggested that students entwined STHF levels 3 and 6. As students represented and wrote about dynamic energy relationships within the system (STHF Level 3), they also included the hidden system dimensions not visible at the system level (STHF Level 6) such as energy transformations and energy loss as thermal energy.

Our second research goal was to *use the learning performances to analyze students' socio-ecological energy system thinking development*. We examined the data both quantitatively and qualitatively. The quantitative results indicate that across the unit, students' consideration of relationships between components significantly increased across the three modeling time points $F(1,209)=3118.3, p=0.001$. On average, students increased .667 rubric levels from pre to mid-model and increased .883 rubric levels from mid to postmodel. Table 3 shows the frequency of models at each time point. The presence of the precursor level reduced from pre- to post-model, as students' ideas of the components and relationships for energy flow within a socio-ecological system developed. In addition, Table 3 shows that few students obtained level 6. Within our qualitative analysis, we found that, while students did increase in considering relationships and connecting causality to those relationships, their relationships focused on either the societal system (energy flow within the building) or the natural energy system (energy flow from natural resources to the building) but students rarely connected these systems. Overall, students understood the human system (energy flow within the school building) or the natural system (natural resources that produce energy for the school building) but did not consider the cyclical connections between these systems (i.e., increases to thermal and light energy in a school building impacts natural resource use and may change emissions into the natural system).

Significance

The systems model data provided a conceptual window into students' developing systems thinking across the unit (Linn, 2012). Students' knowledge at the start of the unit was fragmented with pieces of energy ideas. However, across the systems models, we saw those fragmented

ideas become connected to scientific principles about energy. Students were able to place their energy ideas within their classroom everyday experiences, such as thermal bridges around windows which cause hot and cold air exchange from inside to outside. Or, showing solar panels “taking in kinetic energy from the sun in the form of light waves” to transfer to a “power plant.” In addition, students’ models did not follow all hierarchical levels found within the STHF. Recent research has suggested that students’ ideas about energy and energy flow are woven together in “a complex networks of ideas” (Hermann-Abell & DeBoer, 2018, p. 3) in which energy ideas co-develop. This may provide insight into why their represented systems relationships did not follow the STHF. Further research is needed.

While there is a body of work exploring students’ systems thinking development about scientific phenomena (Yoon et al., 2018), socio-ecological systems thinking is a relatively new research area (Mehren et al., 2018). For students to become informed citizens, it is crucial that they consider the interconnections across societal and natural systems and how these interactions define overall system behavior (UNESCO, 2017). Yet few science units are standards-aligned while also making connections to everyday societal systems (NAESEM, 2018). Our implications will highlight how this unit was successful in helping students increase their knowledge of energy flow within a system but fell short of supporting students in making connections of energy flow across the socio-ecological system. Further research needed within this arena. As such, our study is of interest to professional developers, curriculum developers, and policy makers.

Note

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Table 1.

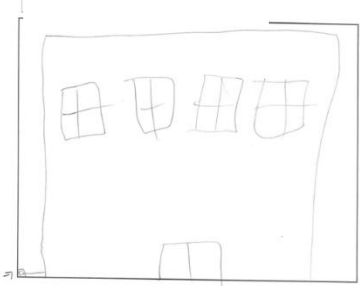
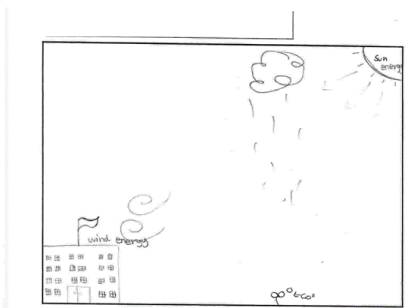
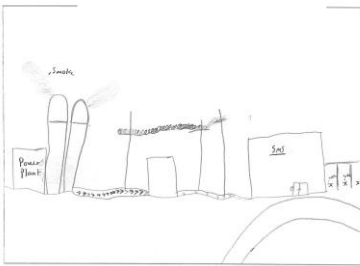
Curriculum Unit Outline

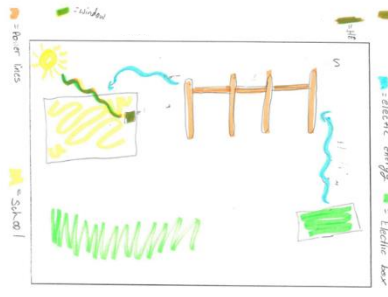
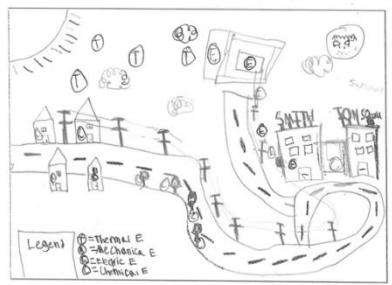
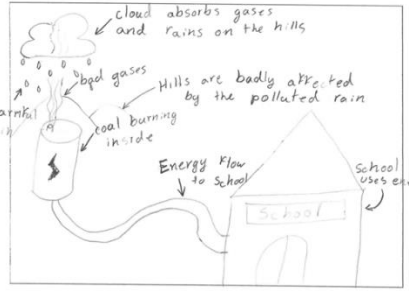
Lesson No.	Lesson Title	STHF	Description
1	Introduction to Energy Systems	Analysis of System Components	Presents the overall energy system. System components focus energy source origination within natural systems (renewable versus non-renewable) that supply energy to the school building and human energy consumption within the building (e.g., light switch behaviors) to energy outputs from the building (e.g., carbon emissions).
2	Lighting our Classroom	Synthesis of systems components	School building components are focused to teach different energy forms (such as light energy and thermal energy). As students learn about sequences of energy transfer and transformations between building components,
3	Staying Warm and Cool in our Classroom		students form ideas for how the individual components link together and causally interact. Students trace energy flow through the building elements

4	Designing and Constructing Your own Classroom	Implementation	Students use their knowledge to engineer an energy efficient one-room building and examine how their choices impact natural resource systems.
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Table 2.

Empirically Grounded Learning Performance with Examples

Milestone	Level	Description	Example
Pre-Analysis of Systems Components	1	Unconnected objects(s)	A single object without connection such as a school building.  Model Writing: My model shows a school.
	2	A process outcome	Energy pieces, such as wind and sun but no direct relationship or processes connected to the energy pieces  Model Writing: My model shows energy.
Analysis of Systems Components	3	System Components and Processes (Hypothesized as Level 1)	Sequences without specifying causal connections.  Model Writing: How energy gets to school

	4	Identify simple relationships between or among system's components** (Hypothesized Level 2)	Naming and linking energy components.  Model Writing: My model shows two ways that energy gets to the school. Energy from the sun goes to the electric box for the school and electrical energy comes from the electric box to the power lines to the school.
Synthesis of System Components	5	Dynamic Relationships Between Components	Consideration of linear and/or non-linear causal sequences that include hidden and visible energy processes  Model Writing: My model shows thermal energy given off from the sun, mechanical energy used by cars, electrical energy in power lines to the school and from the power plant, and chemical energy being used in houses. Without energy buildings won't have internet, electricity, heat and AC and if our environment didn't have energy ecosystems would die.
	6	Organize the systems' components, processes, and their interactions within a relationship framework (Hypothesized Level 4)	Sequences with energy components linked in a cyclic causal chain Model Writing: My model shows how burning coal can help the school because coal produces energy from the power plant that goes to the school for electricity but ruins the ecosystem because of emissions. 

Note. The blue text represents levels that were added from STHF during iterative analysis

Table 3.

Frequency of Rubric Levels at Each Time Point

Level	Frequency in Percent		
	Premodel	Midmodel	Postmodel
1	4.0%	1.3%	0
2	22.7%	6.7%	12%
3	0.0%	0.0%	5.3%
4	53.3%	62.7%	33.3%
5	20%	25.3%	32%
6	0.0%	4.0%	17.3%