Modeling Energy Flow and Matter Cycling: How the Curricular Approach Influences Students Development of Models

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ABSTRACT

This paper discusses how a middle school ecology unit, *Disruptions in Ecosystems: Ecosystem Interactions, Energy, and Dynamics* incorporates the practice of modeling in the teaching and learning of the concepts of matter and energy in ecosystems. Specifically, the appropriate selection and use of instructional strategies around the practice of modeling are presented in the context of three years of curriculum revisions. Each year expert reviews, teacher feedback, and student work samples were used to inform improvements of the curriculum for the subsequent year of field testing. When compared across the scope of the project, analysis of these feedback mechanisms indicate that the project has made substantial progress in integrating the practice of modeling in order to support three-dimensional teaching and learning of the topics of matter and energy.

Introduction

The Science and Engineering Practices in the NGSS serve to articulate how scientists and engineers develop their understanding of the natural world, and how they approach investigating phenomena and problems in their work (NGSS Lead States, 2013). Incorporating the practice of developing and using models has brought a new focus to K-12 science education, as this practice has been largely ignored in previous standards. However, the developers of the K–12 Framework for Science Education and the NGSS have recognized and brought to the forefront of science education the idea that models are essential to scientists for representing their current understanding of natural phenomena and processes and for sharing their understanding with colleagues (Schwarz et al., 2009). This new emphasis has required curricula to shift significantly in order to provide appropriate opportunities for students to develop, use, and revise their own models, as well as respond to models developed by their peers (Krajcik & Merritt, 2012). Concurrently, teachers require support for the development of their own understanding of the practice and how best to incorporate modeling into their instruction.

The NSF-funded project described in this paper is working toward the development of a model curricular unit and professional development support that endeavors to guide teachers as they begin to implement, and support their students learning of, the NGSS. Over the course of the project, particular consideration has been made to the effects of educative instructional materials (e.g., Davis & Krajcik, 2005) and professional development on teachers and students, in the hope that lessons learned from this project will further inform the field on how our current knowledge in this area aligns with the implementation of these new standards. This paper focuses in particular on the progression of our understanding of how best to incorporate the practice of developing and using models when teaching concepts related to the movement of matter and energy in ecosystems. Through four rounds of field testing and revision based on teacher and expert feedback as well as analysis of student work, much has been learned about how best to incorporate the use, development, and revision of models in middle school curricula.

The partners in this project include the American Museum of Natural History (lead institution and leader of professional development), The Lawrence Hall of Science (instructional materials development partner), The University of Connecticut (research partner), and WestEd (evaluation partner).

Overall Project Approach

The Lawrence Hall of Science (The Hall), with the support of the American Museum of Natural History (AMNH), has developed a middle school NGSS-aligned ecology unit. Portions of the unit were based on the AMNH River Ecology teaching case materials, developed and studied with prior NSF support. The Hall team has also worked closely with expert panel members and participating field test teachers, with the aim of ensuring that the final curriculum provides a model that exemplifies best practices for supporting the vision of the *Framework* and the NGSS.

The instructional materials unit, titled *Disruptions in Ecosystems: Ecosystem Interactions, Energy, and Dynamics*, focuses on the NGSS performance expectations in Life Science Core

Idea 2: Interactions, Energy, and Dynamics Relationships in Ecosystems in order to help students answer the question, “How does a system of living and nonliving things operate to meet the needs of the organisms in an ecosystem?” All three sub-ideas of the Core Idea are addressed: Interdependent Relationships in Ecosystems; Cycles of Matter and Energy Transfer in Ecosystems; and Ecosystem Dynamics, Functioning and Resilience. In order to address a bundle of performance expectations, the learning goals and performance tasks for the unit were derived directly from the NGSS disciplinary core ideas (DCIs), science and engineering practices (SEPs), and crosscutting concepts (CCCs) aligned with the performance expectations, as shown in Table 1. Crossed out text indicates content that was not emphasized in the unit. As indicated in the table, some performance expectations were addressed across multiple chapters, within the five-chapter sequence. Each chapter is based on the BSCS 5E Instructional Model (Bybee et al 2006). Additionally, each one includes formative and summative assessments, designed based on evidence of learning specifications derived from the bundles of performance expectations.

Table 1: Bundles of Performance Expectations in each unit of Disruptions in Ecosystems

Chapter	Performance Expectations
1. Wolves in Yellowstone	**MS-LS2-2:** Construct an explanation that predicts patterns of interactions among organisms across multiple ecosystems.
	MS-ESS3-4: Construct an argument supported by evidence for how increases in human population ~~and per capita consumption of natural resources~~ impact Earth’s systems.
2. Ecosystem Models	**MS-LS2-3:** Develop a model to describe the cycling of matter and flow of energy among living and nonliving parts of an ecosystem.
	MS-PS1-5: Develop and use a model to describe how ~~the total number of atoms does not change in a chemical reaction and thus~~ mass is conserved.
	MS-ESS2-1: Develop a model to describe the cycling of Earth’s materials and the flow of energy that drives this process.
3. Interactions between Populations and Resources	**MS-LS2-1:** Analyze and interpret data to provide evidence for the effects of resource availability on organisms and populations of organisms in an ecosystem.
	MS-ESS3-4: Construct an argument supported by evidence for how increases in human population ~~and per capita consumption of natural resources~~ impact Earth’s systems.
4. Zebra Mussels	**MS-LS2-4:** Construct an argument supported by empirical evidence that changes to physical or biological components of an ecosystem affect populations.

	MS-LS2-1. Analyze and interpret data to provide evidence for the effects of resource availability on organisms and populations of organisms in an ecosystem.
5. Designing Solutions	**MS-LS2-5:** Evaluate competing design solutions for maintaining biodiversity and ecosystem services.
	MS-ESS3-3: Apply scientific principles to design a method for monitoring and minimizing a human impact on the environment.
	MS-ESS3-4: Construct an argument supported by evidence for how increases in human population ~~and per-capita consumption of natural resources~~ impact Earth's systems.

Previous papers describe in detail the design-based research approach used to guide development of the overall unit (Nagle et al., 2016; Willcox et al., 2017). This paper will focus on the iterative development of Chapter 2, *Ecosystem Models*, and how developers revised the materials based on specific feedback. This paper is not an in-depth analysis of student work, rather it is an examination of general trends seen in the teacher and expert feedback as well as student work samples to inform curricular revisions for this unit, in particular in regards to incorporating the practice of using and developing models. To provide context, an outline of each of the five chapters in the unit is provided in Table 2, below. In Chapter 1, *Wolves in Yellowstone*, students are introduced to interdependent relationships in ecosystems (e.g. food webs, predator-prey relationships, etc.) using the SEPs of explanation and argumentation and incorporating the CCCs of cause and effect and patterns. As shown in the table, these SEPs and CCCs are integrated in subsequent chapters. However, only Chapter 2, *Ecosystem Models*, provides a particular focus on the SEP of developing and using models. This decision was based on the alignment of the three dimensions laid out in the NGSS. The modeling practice is incorporated in various ways throughout the unit, but is the primary practice emphasized in Chapter 2.

Table 2: Overview of NGSS elements in Disruptions in Ecosystem unit

Instructional Sequences	***1. Wolves in Yellowstone***	***2. Ecosystem Models***	***3. Interactions between Populations & Resources***	***4. Zebra Mussels***	***5. Designing Solutions***
Chapter Summary	Students investigate the issue of the reintroduction of wolves to the Greater Yellowstone Ecosystem.	Students explore the effects of natural disasters on ecosystems.	Students analyze the impact of humans on commercial fisheries.	Students analyze short and long-term data on the effect of zebra mussels on the Hudson River and Great Lake Ecosystems.	Students evaluate and design solutions for environmental challenges in a variety of ecosystems.
Disciplinary Core Ideas	LS2.A Interdependent relationships in ecosystems ESS3.C Human impacts on Earth systems	LS2.B Cycles of matter and energy transfer in ecosystems ESS2.A Earth's materials and systems PS1.B Chemical reactions	LS2.A Interdependent relationships in ecosystems ESS3.C Human impacts on Earth systems	LS2.A Interdependent relationships in ecosystems LS2.C Ecosystem dynamics, functioning, and resilience LS4.D Biodiversity and Resources	LS2.C Ecosystem dynamics, functioning, and resilience LS4.D Biodiversity and Resources ESS3.C Human impacts on Earth systems ETS1.B Developing possible solutions
Main Science and Engineering Practices	Constructing explanations and designing solutions Engaging in argumentation from evidence	Developing and using models	Analyzing and interpreting data Constructing explanations and designing solutions	Asking Questions Analyzing and interpreting data	Constructing explanations and designing solutions Engaging in argumentation from evidence

			Engaging in argumentation from evidence	Constructing explanations and designing solutions Engaging in argumentation from evidence	
Main **Crosscutting Concepts**	Patterns Cause and Effect	Energy and Matter Stability and Change	Cause and Effect	Stability and Change Cause and Effect Patterns	Stability and Change Cause and Effect
Primary **Performance Expectations**	MS-LS2-2 Construct an explanation that predicts patterns of interactions among organisms across multiple ecosystems	MS-LS2-3 Develop a model to describe the cycling of matter and flow of energy among living and non-living parts of an ecosystem	MS-LS2-1 Analyze and interpret data to provide evidence for the effects of resource availability on organisms and populations of organisms in an ecosystem	MS-LS2-4 Construct an argument supported by empirical evidence that changes to physical or biological components of an ecosystem affect populations	MS-LS2-5 Evaluate competing design solutions for maintaining biodiversity and ecosystem services

Integrating the Practice of Modeling with the Concept of Matter and Energy in Ecosystems

The curriculum development group from The Hall initially reported on the first round of unit design, field testing, and feedback (Nagle et al., 2016). Analysis of expert reviews, teacher feedback, and student work samples indicated that the project had made substantial progress in designing of curriculum to support three-dimensional teaching and learning. The results also suggested next steps for revision and enhancement of the curriculum, particularly in Chapter 2 and the use of the practice of modeling. In 2017 the curriculum development group reported on the implementation of these revisions, and the feedback received from field test teachers and expert reviewers who had worked with the second field-test edition (Willcox et al., 2017). This feedback, in turn, has led revisions to produce a third edition, which will be field tested in the Fall of the 2017–2018 school year. Revisions for the second and third field test versions of the unit have focused significantly on the use of the scientific practice of modeling to understand concepts related to the flow of energy and cycling of matter in ecosystems. Through access to three years of field test data, feedback, and revisions, on curriculum focused on teaching the practice of modeling, we are able to respond to the question: *How can we effectively integrate the practice of modeling with the scientific concept of the cycling of matter and flow of energy in a middle school, NGSS-aligned curriculum?*

Year One Field Test and Revisions

In *Disruptions in Ecosystems,* Chapter 2 focuses on the flow of energy and cycling of matter in ecosystems emphasizing the practice of developing and using models. It has been well documented that students have many enduring misconceptions around energy and matter (Brook and Wells, 1988; Chen et al, 2014; Smith and Anderson, 1988). From the outset of the development of Chapter 2, particular attention was paid to these misconceptions to ensure they were addressed either directly or indirectly using a variety of instructional strategies. Table 3, below, briefly outlines the first field test version of Chapter 2.

Table 3: Ecosystem Models, First Field Test

Activity Title	**5E Phase**	**Description**
2.1 A Living Model of an Ecosystem	Engage/Explore	Analyze statements on energy and matter; set up ecosystem model (bottles)
2.2 Energy Flow in Ecosystems	Explain	Reading with anticipation guide
2.3 Energy Pyramid	Explore/Explain	Develop a model of an energy pyramid
2.4 Matter in Ecosystems	Explore/Explain	Ecosystem model exploration (Act 1); Reading
2.5 Fire in Yellowstone	Elaborate	Card sort with succession after fire and in a pond, with captions
2.6 Modeling Energy Flow and Matter Cycling in an Ecosystem	Evaluate	Develop a 3-d model that shows food web, cycling of matter, and flow of energy

The first field test was conducted with 25 New York City public school teachers teaching at least one middle school (grades 6-8) science class. Teachers provided feedback as they were teaching through surveys at the activity, chapter, and unit level. Teachers also participated in focus groups and a large-group feedback discussion during their final day of professional development. Each teacher provided student work samples from five students selected at random. In addition to the teacher feedback and work samples, a panel of experts was convened to provide written feedback and participate in an in-person meeting to discuss their reviews of the unit.

In the first field test version, the summative assessment for the unit included three-dimensional models (dioramas) created by the students, as well as two written analysis questions. The models were generally more simplistic than anticipated, and did not tend to reflect an understanding of the flow of energy and cycling of matter (see Appendix A for samples of student models). The written analysis items and sample responses are shown in Table 4 below.

Table 4: First Year Field Test Sample Assessment Responses

Analysis Item 1
Imagine that a science museum is making a very large version of your model (the diorama) for a museum display. Write three captions explaining the model for members of the public who will view the display. The captions should describe: • interactions between living organisms • the cycling and conservation of matter between abiotic and biotic parts of the ecosystem • the source, flow, and loss of energy from abiotic and biotic parts of the ecosystem
Sample Response (6th Grade): "a. All living organism eat each other except trees. (grass←rabbit←coyote). b. when an animal or human grows bigger and older the matter it has or have is cycling to withstand the new body. However abiotic organism matter cycles but doesn't change or grow. c. The sun provides energy for producers so that they can produce food. When an biotic factor eat's another, 10% goes to the scavenger who eat's it and 90% goes to the decomposers."
Sample Response (8th Grade): "a. predator and prey. competition. mutualism. parasitism. and comensalism. b. Air cycles from trees to animals, but food transfers from the sun to the plants which gets retained into the animals that eat the plant. Now it could get transferred into plants again if the animal dies by itself, but if the animal is killed by another some energy goes to that animal. c. When an animal is killed 10% of the energy goes to the killer or the plants if it died by itself."
Analysis Item 2
A large volcano erupts. A thick cloud of volcanic ash blocks sunlight from reaching the surrounding ecosystem for several months. Predict how the flow of energy and the cycling of matter would be affected by the ash cloud and explain how this would affect the organisms in your model.
Sample Answer (6th Grade): "The energy and matter will eventually die out because there is no sunlight. It will affect my ecosystem because no sunlight will kill the producer and then the primary consumers will die, then the secondary consumers will die which will cause the tertiary consumer to die."
Sample Answer (8th Grade): "The flow of energy will be less because of less sunlight through ashes less organisms/consumers because of lack of plants. The cycling and matter would be limited becauses of lack of animals. So this could cause a decreases in producers and consumers."

Feedback from field test teachers was generally positive. Teachers reported that three-dimensional learning "was happening," and that students were engaged in the learning. Critical feedback included the need for a larger emphasis on matter, that students mastered the idea of the flow of energy but were still somewhat confused by matter cycling, and that the curriculum "wasn't explicit enough specifically about atoms cycling repeatedly." One teacher reported, "[students] can say energy flows and matter cycles, but don't actually understand. 8th graders did understand matter." Expert reviewer feedback suggested the chapter could be improved through closer adherence to the 5E model as originally described in Bybee et al. 2006. Developers also felt that students' responses did not reflect a clear understanding of the cycling of matter. As seen in Table 4, students understood that matter and energy were important for ecosystem function and that both energy and matter moved within the ecosystem, but neither the students models nor their written explanations indicated an understanding beyond organisms eating each other and energy coming from the sun. In response to the combination of feedback and student work analysis, developers chose three areas of focus for revising the chapters: 1) simplify and reduce overall number of models used, 2) better reflect 5E model, 3) have students create an initial model and revise it throughout the chapter to better address/prevent misconceptions.

Year Two Field Test and Revisions

As shown in Table 5, using the strategy of students creating and revising their own model throughout the chapter also addressed the need to simplify and reduce the number of models in the chapter.

Table 5: Ecosystem Models, Second Field Test

Activity Title	5E Phase	Description
2.1 Ecosystem Changes	Engage	Analyze and discuss ecosystems (illustration) and ecosystem disruptions; composting
2.2 Life and Death in an Ecosystem	Explore	Develop Yellowstone ecosystem model (YEM); analyze model of change in ecosystem over time
2.3 Matter in Ecosystems	Explain	Analyze scientific findings about matter in ecosystems; develop a model for cycling of matter
2.4 Energy Flow in Ecosystems	Explain	Add flow of energy to YEM; read about photosynthesis; model revision
2.5 Energy Tracking	Elaborate	Analyze existing models re energy; develop energy pyramid model; YEM revision
2.6 Modeling Energy Flow and Matter Cycling in an Ecosystem	Evaluate	Develop a 3-d model that shows food web, cycling of matter, and flow of energy

In the second field test year, approximately 20% of the original field test teachers were invited to field test again and new teachers were recruited to make up a cohort of 25 New York City public school teachers. Teachers were asked to field test in at least one middle school science class. Feedback collection was slightly reduced, asking teachers to respond to chapter and unit surveys with the option of adding activity-level comments in the chapter surveys. Again, small focus groups and whole-group feedback discussions were held on the final day of professional development and student work samples from 5 students per teacher were collected. A smaller group of experts was also asked to review the curriculum, providing written feedback.

Similar to the first field test, in the second field test version, the summative assessment for the unit included three-dimensional models (dioramas) created by the students, as well as two written analysis questions. However, directions for the models provided more specific scaffolding. The written analysis items were revised to try and better capture students' understanding of the cycling of matter. The written analysis items and sample responses are shown in Table 6 below. In analysis item 1 revisions are shown in italics. Analysis item 2 was significantly changed, adding the specific scaffolding of a writing tool, the Explanation Tool, that students had used throughout Chapters 1 and 2.

Table 6: Second Year Field Test Sample Assessment Responses

Analysis Item 1
Imagine that a science museum is making a very large version of your model [the diorama] for a museum display. Write three captions explaining the model for members of the public who will view the display. The captions should describe: • interactions between living organisms • the cycling and conservation of matter between abiotic and biotic parts of the ecosystem • the source, flow, and loss of energy from abiotic and biotic parts of the ecosystem • *what would happen if a disease killed off the top level of your ecosystem*
Sample Response (6th Grade): "a) The interactions between living organisms is they spred energy but some other interactions are predator prey and mutualism, but also commensalism with competition. b) abiotic is when an organism or something is not real not living. In other words, biotic is something that is real and living. c) Some sources are heat, some sources of biotic things are grass, H2O wich is (water). d) what would happen is the ecosystem would get contaminated and most of the living things/organisms would get killed."
Sample Response (8th Grade): "a) The interactions between living organisms can be the grasses to the bison. For example, the bison eats the grasses. b) Matter cycles between the abiotic and the biotic parts of the ecosystem. For example, the matter can cycle from the grasses to rain and back to the grasses because the grasses die without water and then when it rains the the grasses gets the matter back because they water helps the grasses grow and stay alive. c) When the plants die the 90% of the energy goes into the environment and the rest of the energy which is 10% goes to the next consumer which is the animal that ate the plant in the first place. d) If a disease kills off the top of your ecosystem then the population of the consumer that the top animal ate before will increase and then the population of

the primary consumer will decrease and then the population of the producer ill increase as well.”
Analysis Item 2
Using the *Explanation Tool*, construct a scientific explanation for the following. A landslide occurs along the side of a mountain that causes the forest at the bottom to be covered with 20 meters of rocks and soil. Predict how the flow of energy and the cycling of matter would be affected both in the short term and in the long term. Use the steps below to guide you as you use the Explanation Tool. – Question: Record the question “How would a landslide affect the flow of matter, cycling of energy, and organisms in an ecosystem?” – Evidence: Use evidence from this chapter that helps you to answer this question. – Science Concepts: List any science concepts that are connected to the evidence and might help answer the question. – Scientific Reasoning: Describe the scientific reasoning that connects the evidence and science concepts to the question you are trying to answer. – Claim: Based on the evidence of patterns in the data and on your scientific reasoning, state your claim about the effects of the landslide on matter, energy, and organisms in the ecosystem.
Sample Answer (6th Grade): “The ecosystem will disappear then be resilient and come back again. Energy just flows not cycle and matter cycles in an ecosystem. When an ecosystem dies the plants come first, then the animals. Photosynthesis is the process of using water and carbon dioxide to make sugars. The source of all energys is the sun. Energy flows in one direction matter cycles in an ecosystem. Energy just flows not cycle. Matter cycles. First the plants come back then the animals come.”
Sample Answer (8th Grade): “Landslide’s affect the flow of energy, cycling of matter, and of organisms in that ecosystem because of disruption in a food web since disrupting one part of a ecosystem messes up everything. The evidence I use was from my KWL chart and it said when you disrupt one part of the ecosystem the rest of it messes up or collapse. The science concept disruption in a food web and the evidence I just stated about how mess up one part of the ecosystem makes it all collapse connects. They connect because if a landslide disrupts a ecosystem then there won’t be no flow of energy or cycle of matter because some animals would die or leave the ecosystem and the non-living things in the ecosystem would get mess up.”

Teacher feedback from the year 2 field test indicated that the chapter had been more successful in helping students develop a deep understanding of matter an energy. Teachers also reported that they felt much more comfortable with their own understanding of the topic of matter and energy, but that it was still difficult for students to understand and for them to teach. One teacher reported "I learned how important it is to incorporate models in a curriculum. I learned that most students struggle to understand what is matter. I learned a great way to teach how matter and energy connect to one another. Usually students learn what is matter and what is energy but they do not connect the two. I feel this chapter really addressed that." (Stiles, 2017)

The teachers generally reported that the most challenging portion of the chapter was the analysis of scientific findings in Activity 2.3 (see Table 5). This activity had students examine findings, which they discussed in small groups to determine how the findings related to the movement of energy and matter in ecosystems. For example, one finding was experimental results showing that a tree grown in soil can gain a significant amount of mass over time, without a significant change in the mass of the soil. As students discuss this finding they should realize that the tree must be gaining mass from a source other than the soil. Teachers reported that their students struggled with this activity, but that the supports provided (an anticipation guide, graphic organizer, use of diagrams/models) were helpful and suggested additional supports be added in particular for that activity. This echoed the suggestions from the expert reviews that pertained specifically to Chapter 2.

Student models improved slightly from the first year (see Appendix B for sample models). Students indicated the difference between matter and energy more clearly, and incorporated more information about where the energy and matter moved in the ecosystem. Students' written responses still indicated difficulty in articulating the movement of energy and matter in ecosystems. Sample responses (see Table 6 above) do use the phrases "energy flows" and "matter cycles." They also indicated that a disruption in an ecosystem would interrupt the flow of energy and cycling of matter. However, it is unclear that students have an overall understanding of these processes within an ecosystem. Additionally, it is hard to differentiate between the students struggling with written responses and a lack of understanding of the concepts. For instance, one student wrote "Matter cycles between the abiotic and the biotic parts of the ecosystem." Has this student completely misunderstood the cycling of matter? Or do they simply not know how to articulate the complex idea of individual atoms moving through the ecosystem between organisms and the environment? Teachers' expressed that they were seeing deeper understanding of these concepts than in previous years, but that students still struggled.

Based on this feedback and analysis of student work samples, developers took a two-tiered approach to the revisions for Chapter 2. First, their general revisions focused on even further reducing the number of models in the chapter, adding more analysis of existing models, and increasing the opportunities for students to develop and revise their models over the course of several activities. Secondly, specific to Activity 2.3, developers deepened the teacher support for the activity adding more background so that teachers had a better initial understanding of the findings the students were analyzing. They decreased the number of scientific findings for students to analyze, and added a graphic organizer specific to that activity to scaffold the analysis process. Overall the revisions were less extensive and more focused than the revisions after the first field test.

Year Three Field Test and Revisions

One concern, particularly with the 3-dimensional models being used as an assessment opportunity, was that many students might not be able to effectively communicate their understanding of the complex topic of matter and energy in ecosystems using drawings or diagrams alone. Initially the curriculum utilized a combination of models that were drawn (or built) and more traditional written analysis items and small group or class discussions. However, developers hoped to find a less traditional, truly three-dimensional approach that could present students with the opportunity to convey their understanding of all three dimensions relevant to a PE within a cohesive assessment opportunity. In the third-year field test, this led to the integration of captions for students' models (in previous years students had analyzed pre-written captions, and written captions in response to analysis questions, but without the emphasis on incorporating them into their models). This relatively simple instructional tool allowed students to add details to their models to demonstrate their understanding. Having these captions as evidence of student understanding provided both teachers in the classroom and developers examining the student work after the fact a more consistent method for assessing all three dimensions of student learning. Table 7 calls out two opportunities, one mid-chapter and one in the final assessment, where students incorporated captions into their models. As part of the instruction, students were also given example captions to analyze and match with photos, and other informal opportunities to add captions to drawings or photos to explain phenomena.

Table 7: Ecosystem Models, Third Field Test

Activity Title	5E Phase	Description
2.1 Ecosystem Changes	Engage	Analyze and discuss ecosystems (illustration) and ecosystem disruptions; composting
2.2 Life and Death in an Ecosystem	Explore	Develop Yellowstone ecosystem model (YEM)
2.3 Matter in Ecosystems	Explain	Analyze scientific findings about matter in ecosystems; develop a model for cycling of matter (include captions)
2.4 Energy Flow in Ecosystems	Explain	Add flow of energy to YEM; read about photosynthesis; model revision (add abiotic factors & 10% rule)
2.5 Disruptions and Food Webs	Elaborate	Analyze disruption in model
2.6 Modeling Energy Flow and Matter Cycling in an Ecosystem	Evaluate	Develop a 3-d model that shows food web, cycling of matter, and flow of energy (include captions)

The third-year field test is in process. It is again comprised of 25 New York City public middle school science teachers, with approximately 20% of the teachers returning from previous field tests. As in earlier years, teachers are giving feedback through surveys at the chapter and unit level, in small focus groups, and in a large group discussion on their final professional development day. Collection of student work is ongoing, however initial samples indicate that revisions to Chapter 2 have led to improved models. The specific requirement of including captions on their models in the evaluate activity has led to more complex models (see Appendix A for sample student work). Students used the captions to specifically indicated where matter and energy were coming from and going to (e.g. "the seeds get their energy from the sun and matter from carbon dioxide" and "[from worms] matter goes into the soil"). They also showed some of the concepts of movement more clearly (e.g. 8th grade sample indicates 90% of energy from organisms being lost to the environment as heat) but not in entirety (e.g. 8th grade sample indicates carbon dioxide and water coming from organisms, but doesn't indicate where they go so the cycle is incomplete).

Sample student responses to the final two written analysis questions are shown below. Students identify sources of matter and energy, and articulate the concept of disruptions in ecosystems causing overall disruptions in the movement of energy and matter (e.g. "The matter starts at the producers and goes all the way to the decomposers. The decomposers turn the matter to water and CO_2 to help the plants grow." and "…when a biotic factor dies the energy flow is stopped.")

However, these responses also indicate students are still struggling to articulate the overall concepts of movement of energy and matter in ecosystems. It is likely that this challenge is in part due to students not being well-versed in the practice of explanation. This practice is introduced in Chapter 1 of the *Disruptions* unit, but for students struggling with written expression it is likely that more time is needed for them to be able to incorporate concepts as complex and the movement of energy and matter in ecosystems in a full explanation. It is also clear from some of the student responses that misconceptions about the movement of matter and energy in ecosystems still remain.

Table 8: Third Year Field Test Sample Assessment Responses

Analysis Item 1
Imagine that a science museum is making a very large version of your model [the diorama] for a museum display. Write three captions explaining the model for members of the public who will view the display. The captions should describe: • interactions between living organisms • the cycling and conservation of matter between abiotic and biotic parts of the ecosystem • the source, flow, and loss of energy from abiotic and biotic parts of the ecosystem
Sample Response (7th Grade): "a) Each organism is a source of matter (food) for the other animal. Since there is more than 1 consumer they are in competition with each other for food. In an ecosystem the decomposers get to eat the leftover animal. b) The matter starts at the producers and goes all the way to the decomposers. The decomposers turn the matter to water and CO_2 to help the

plants grow. The level 1 producers (usually plants) give off oxygen which is food for the organisms. c) The main source of energy in the ecosystem is the sun. Energy flows through the ecosystem by giving the producers energy to grow. The loss of energy is that 90% of the energy goes to the ecosystem."
Analysis Item 2
Using the Explanation Tool, construct a scientific explanation for the following. *A disease kills off the consumers in the top level of your ecosystem.* Predict how the flow of energy and the cycling of matter would be affected both in the short term and in the long term. Use the steps below to guide you as you use the Explanation Tool. – Question: Record the question "How would a disease that kills off consumers in the tip level of your ecosystem affect the flow of matter, cycling of energy, and organisms in an ecosystem?" – Evidence: Use evidence from this chapter that helps you to answer this question. – Science Concepts: List any science concepts that are connected to the evidence and might help answer the question. – Scientific Reasoning: Describe the scientific reasoning that connects the evidence and science concepts to the question you are trying to answer. – Claim: Based on the evidence of patterns in the data and on your scientific reasoning, state your claim about the effects of the landslide on matter, energy, and organisms in the ecosystem.
Sample Answer (7th Grade): "The scientific question is how would a disease that kills off the consumers in the top level of our ecosystem affect the cycling of matter, flow of energy and organisms in the ecosystem? My claim is that the jellyfish and Narwhal will increase if the polar bears decrease. Then the rest of the food chain will be unstable and a smaller circle. My evidence is that the top level consumer is the polar bear eats the narwhals and jellyfish. My concepts is the amount of jellyfish and Narwhal is affected by the polar bears. My scientific reasoning is how since the polar bears are the top level consumer the jellyfish and Narwhal will increase. Also the cycle of energy will be smaller. If the polar bears get killed by a disease the decomposers that decompose it might be infected and might infect the rest of the food chain. This is what I think will happen if the top level consumers die."

While a final analysis and revision plan will not be completed until the conclusion of the third-year field test, initial feedback from teachers who have completed teaching the unit indicate a continued need for supporting diverse learners throughout the unit, including Chapter 2. One particular area of concern that has been consistent across years is the amount of written assessments and the need to differentiate support for all learners, particularly English Language Learners. This need has been a focus throughout the development of the unit, and the final round of revisions will continue to endeavor to include appropriate supports and a variety of assessment types wherever possible. Incorporating the practice of modeling provides an excellent opportunity for students to demonstrate their understanding in non-traditional ways, but as discussed can pose challenges in terms of students being able to fully express what they have learned and does not fully mitigate the challenge of some of the misconceptions around the movement of energy and matter in ecosystems. Our final revisions will focus in particular on revising the teacher guide with this challenge in mind, providing additional teacher support for differentiation within the classroom particularly in regards to assessments.

Conclusion

This project has presented an excellent opportunity to investigate how best to incorporate the practice of using and developing models in the context of matter and energy in ecosystems. Through three iterative cycles of development, field testing, and revisions of a curricular unit focused on the NGSS PE related to MS-LS2 (Ecosystems: Interactions, Energy, and Dynamics) curriculum developers have been able to implement and refine instructional methods in regards to students use and understanding of models of ecosystems. Results indicate that allowing students to generate their own models, which they continuously revise over extended learning opportunities is key to student understanding as well as to effective assessment of what students have learned. Additionally, limiting the number of models allows students to focus on model revision and improvement, ultimately leading to a better learning experience. Providing specific scaffolds and structures that help support model generation, revision, and explanation helps all students.

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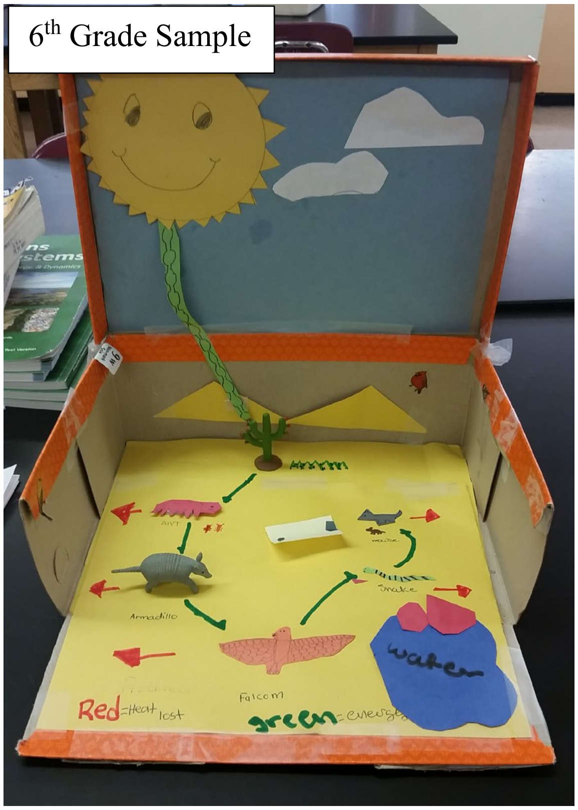
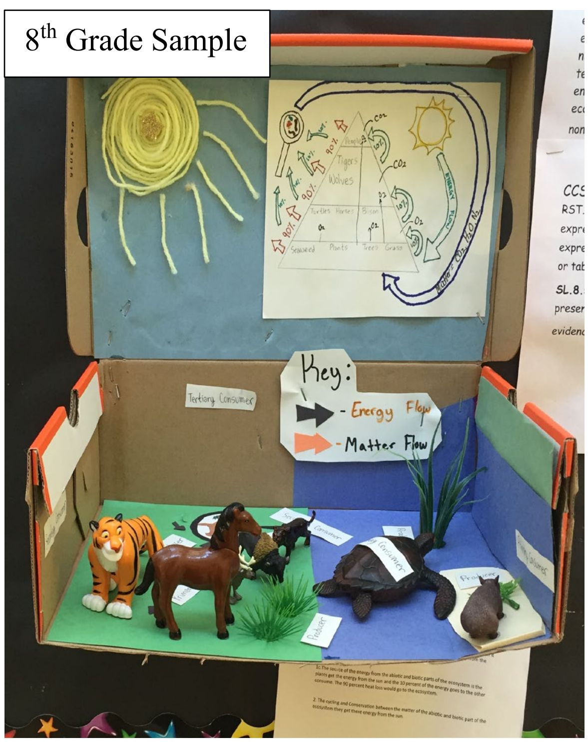
Appendix A: Selected Sample Student Work

Year One Field Test Samples: Evaluate Activity

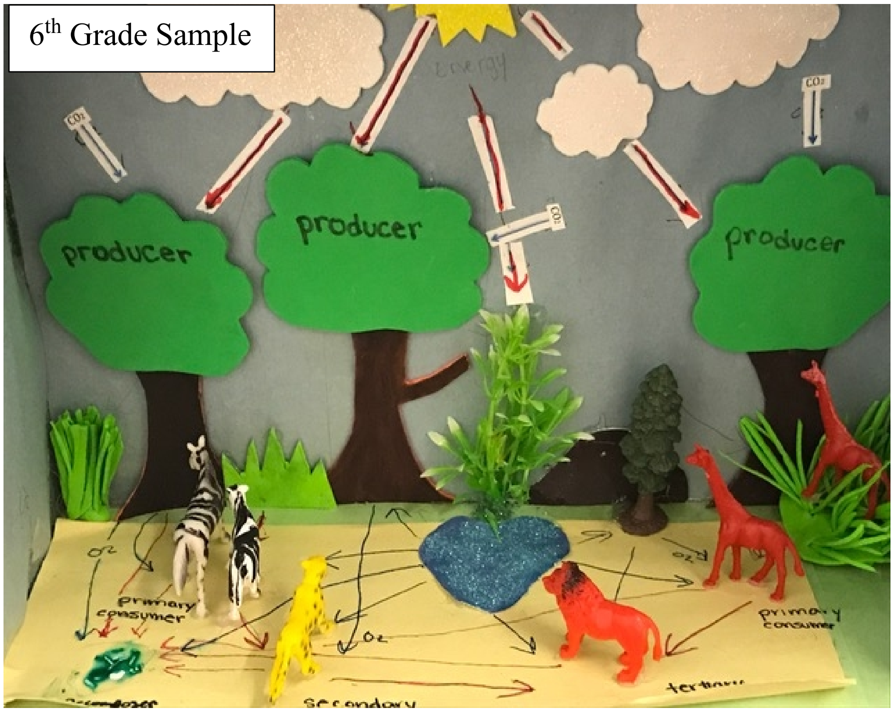
6th Grade Sample



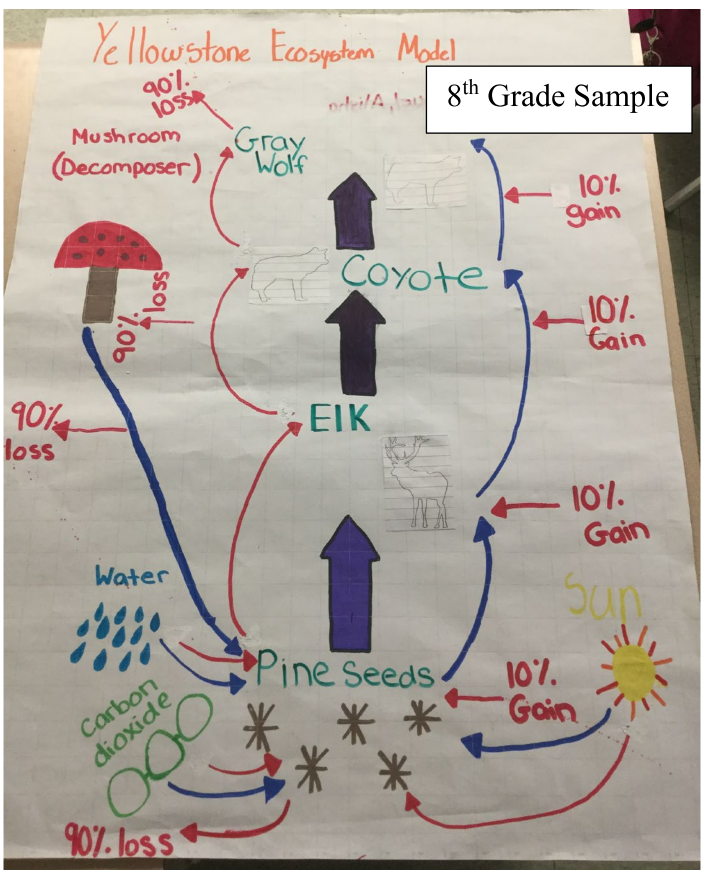
8th Grade Sample



Year Two Field Test Samples: Evaluate Activity



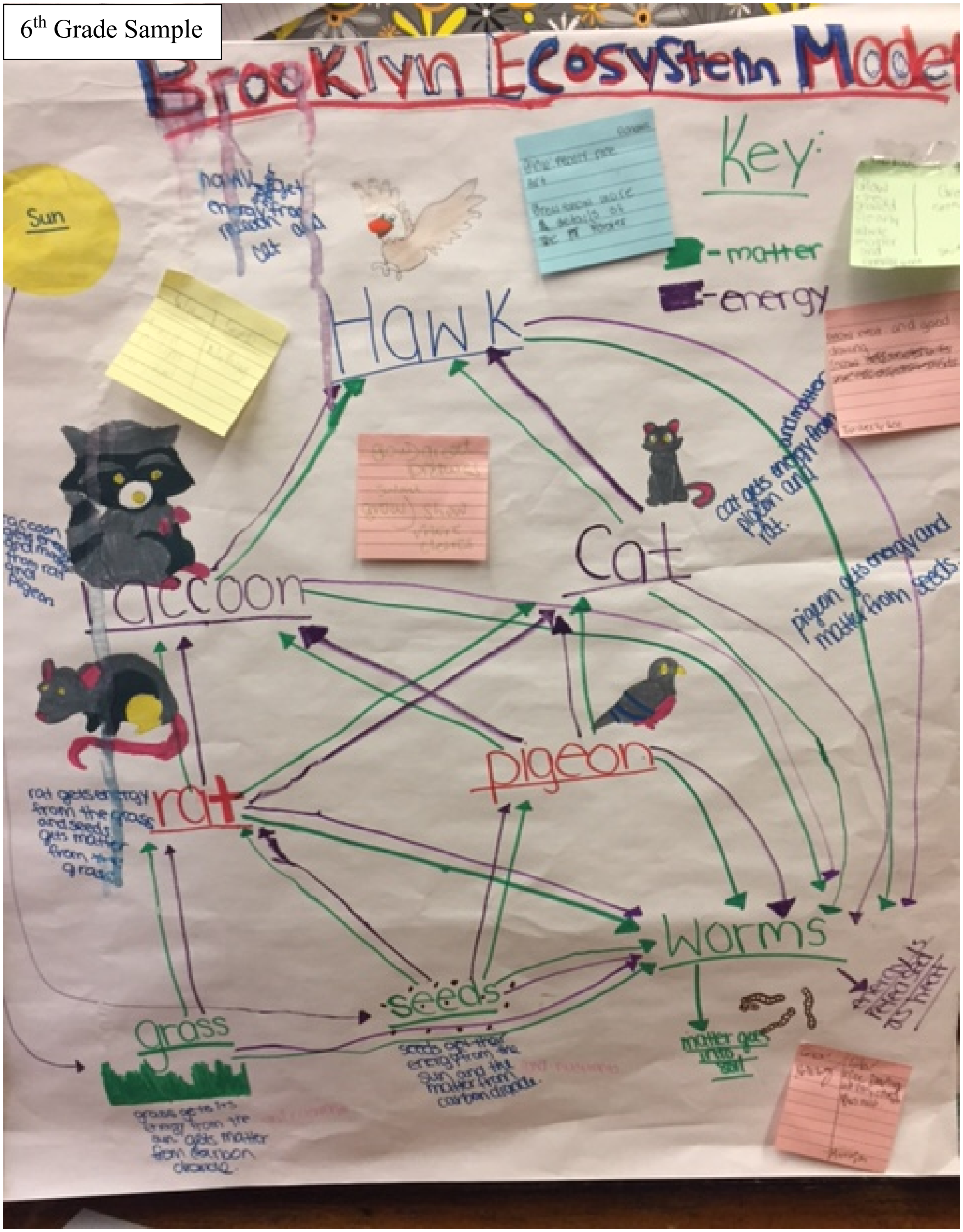
6th Grade Sample



8th Grade Sample

Year Three Field Test Samples: Evaluate Activity

6th Grade Sample



8th Grade Sample