Developing the Practice of Modeling in an NGSS-aligned Educative Middle School Ecosystems Instructional Materials Unit

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ABSTRACT

This paper describes how the practice of modeling has been integrated into the design of a middle school ecology unit, *Disruptions in Ecosystems: Ecosystem Interactions, Energy, and Dynamics.* This unit was developed as part of a larger project to support the vision of the K-12 Science Education Framework and the Next Generation Science Standards (NGSS). The unit supports the learning and instruction of a bundle of middle school Next Generation Science Standards and their related Common Core State Standards. The development of the instructional unit and accompanying professional development model is part of a larger collaborative effort between the American Museum of Natural History, the University of Connecticut, and the Lawrence Hall of Science to study the effects of implementing a professional development program designed around best practices and research-based results, and grounded in educative instructional materials (for the teacher and student). Two years of field testing, feedback, and revisions of the instructional materials and professional development model have informed this work. Analysis of expert reviews, teacher feedback, and student work samples 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 described in the NGSS articulate the ways by which scientists and engineers come to understand the natural world and solve related problems (NGSS Lead States, 2013). One of these practices, developing and using models, adds a new focus to K-12 science education, having received little attention in previous science standards. The developers of the K–12 Framework for Science Education and the NGSS have recognized 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). Because of the newfound emphasis placed on modeling in K-12 science education, curricula will need to provide opportunities for students to develop, use and revise their own models, as well as respond to models of their peers. At the same time, teachers will need to be supported in understanding this practice and helping their students engage in it.

The NSF-funded project described in this paper set is attempting to help with the considerable challenges inherent to transitioning to and implementing the NGSS. It seeks to advance our knowledge of the effects of educative instructional materials (e.g., Davis & Krajcik, 2005) and professional development (PD) on teachers and students. In particular, this paper focuses on the use of the modeling practice in one chapter of the student and teacher instructional materials and PD activities developed in this project, and how that particular chapter has been revised based on two years of field testing and feedback from New York City public middle school teachers, as well as experts in the educational field.

The partners in this project include the American Museum of Natural History (lead institution and leader of professional development, James Short, PI), The Lawrence Hall of Science (instructional materials development partner, Barbara Nagle Co-PI), The University of Connecticut (research partner, Suzanne Wilson Co-PI), and WestEd (evaluation partner, led by Katherine Stiles).

Overall Project Approach

The Lawrence Hall of Science (The Hall) worked closely with the American Museum of Natural History (AMNH) to develop a middle school NGSS-aligned instructional unit based in part on the AMNH River Ecology teaching case materials that were developed and studied with prior NSF support. Integrating the dimensions of the NGSS presents new opportunities and challenges for curriculum developers as well as for learners and educators. The Hall team has worked closely with all project partners, expert panel members, and participating teachers to ensure that the instructional materials being developed provide a model that strongly supports the vision of the *Framework* and the NGSS. The learning goals and performance tasks for the unit were derived from the NGSS disciplinary core ideas, science and engineering practices, crosscutting concepts, and corresponding performance expectations. The team endeavored to ensure that the model is practical and includes appropriate supports for teachers and students.

The unit, titled *Disruptions in Ecosystems: Ecosystem Interactions, Energy, and Dynamics*, addresses a bundle of performance expectations through a series of instructional sequences (chapters) based on the BSCS 5E Instructional Model (Bybee et al 2006). To be consistent with the shifts and innovations of the NGSS, and to make connections across disciplines, performance expectations were bundled in each chapter as shown in Table 1. Some of the performance expectations were revisited in later chapters. The bundles of performance expectations were used to inform the development of the evidence of learning specifications that were later used in the development of formative and summative assessments. Crossed out text refers to portions of the performance expectations that were not emphasized in the unit.

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.

The unit focuses on the NGSS (NGSS Lead States, 2013) 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?" The instructional materials unit addresses all three sub-ideas: Interdependent Relationships in Ecosystems; Cycles of Matter and Energy Transfer in Ecosystems; and Ecosystem Dynamics, Functioning and Resilience. Table 2, on the following page, describes the five instructional sequences (chapters) in the unit, and how these sequences integrate the three dimensions of the NGSS.

The development of the instructional materials has been guided by the essential elements of design-based research (Cobb & Gravemeijer, 2008; Collins, Joseph, & Bielaczyc, 2004). The iterative approach to development and revision central to design-based research was informed by the backward design model (Wiggins & McTighe, 2005). This process includes three steps: 1) identifying the targeted learning outcomes (NGSS performance expectations) as outlined in Table 1, 2) determining the acceptable evidence of student learning in order to develop performance tasks, and 3) development of instructional sequences to provide students opportunities to learn the core ideas, crosscutting concepts, and science practices described in the three dimensions of the NGSS performance expectations. These steps were completed by applying the *Five Tools and Processes for NGSS* (http://www.amnh.org/explore/curriculum-collections/five-tools-and-processes-for-ngss, AMNH, BSCS, WestEd, 2015). The *Five Tools* are a systematic process for professional development leaders to work with teachers to create NGSS-aligned instructional materials, instruction and assessments. By using the *Five Tools and Processes,* teachers can translate science concepts, practices, and performance expectations (NRC, 2012; NGSS Lead States, 2013) into multiple instructional sequences that form an NGSS unit. Table 2 was developed using "Tool 1" from the *Five Tools,* during which a "unit blueprint" is created – this blueprint maps out the standards across the learning sequences to share how intentional we were with the planning of which DCIs, SEPs, CCCs and PEs were used to drive the instruction and assessment in each sequence.

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 Engaging in argumentation from	Asking Questions Analyzing and interpreting data Constructing explanations and designing solutions Engaging in	Constructing explanations and designing solutions Engaging in argumentation from evidence

			evidence	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

Development of the Modeling Practice

In *Disruptions in Ecosystems*, students explore disciplinary core ideas related to ecosystems, with each of the five chapters foregrounding a specific set of science and engineering practices that help students understand the disciplinary core ideas and crosscutting concepts of the unit. The chapter focusing on the flow of energy and cycling of matter in ecosystems (Chapter 2) emphasizes the practice of developing and using models. Throughout the course of six activities, students explore these concepts in the context of the Yellowstone National Park ecosystem. Research has shown that students possess many misconceptions around energy and matter, and that these misconceptions are enduring (Brook and Wells, 1988; Smith and Anderson, 1988). In developing this chapter, particular attention was paid to these common misconceptions and their treatment in the materials to ensure that students were able to address them either directly or indirectly.

We collected feedback on the first field test version from staff with expertise in ecology, instructional materials development, and literacy in science. The expert panel recommended that the three dimensions of the NGSS be brought more into balance. The science and engineering practices had seemed to be driving some of the chapters, when instead the practices should support the content. The panel also recommended that the Teacher's Guide include more educative elements that focus on what is most important, and that the initial chapters, including Chapter 2, be revised to better reflect the 5E model (Bybee, 2013). Both the panel and the teachers consistently recommended that the crosscutting concepts be more explicitly addressed for both teachers and students.

Feedback from teachers on the first version of Chapter 2 showed that scientific modeling was relatively new to them, and that this chapter helped them see the role of models in science and how modeling helps scientists develop explanations. Thus, they did find the Teacher Guide educative about modeling. They also reported that their students were highly engaged in these activities. However, they shared difficulties they had in managing several of the activities, and that students did not always develop an understanding of the science concepts and ideas underlying the models. Our examination of student models corroborated this feedback, with several of the student models either encompassing misconceptions or errors about energy and matter, or simply being replicas of an ecosystem without possessing any explanatory features. The practice of modeling was not helping students develop a deep understanding of the concepts and ideas around energy and matter in ecosystems.

In revising Chapter 2 for a second field test, we made two major changes in our approach to the use of models to deepen understanding of matter cycling and energy flow in ecosystems. First, we simplified the models and reduced the overall number of models so that teachers could more easily manage them and so that students could focus on a smaller number of models. Second, the primary model used throughout the chapter is one initially developed and continually revised by students as their understanding about energy and matter grows and becomes more refined. Students develop their initial models independently in their own science notebooks. Next, through discussion, groups of students develop a consensus model (Krajcik and Merritt, 2012), which they revise over the course of three activities. The teacher references these models as the class develops consensus explanations for understanding how energy flows and matter cycles in an ecosystem. By having students repeatedly revise their models to incorporate their new learning, we expect that students will develop more accurate conceptions about ecosystems.

The science concepts being addressed in this chapter, the flow of energy and cycling of matter in ecosystems, are among the most challenging ideas in the life sciences, with students holding durable misconceptions that persist into adulthood (Brook and Wells, 1988; Smith and Anderson, 1988). To help students wrestle with these concepts in a way that helps them revise any misconceptions, we presented the concepts as a series of scientific findings. Students were required students to make sense of these findings and tie them together to construct their understanding about the cycling of matter and flow of energy.

The revised version of Chapter 2 was field-tested during the Fall semester of the 2016–2017 school year. Teacher feedback and student work collected deepened our understanding of how best to integrate modeling in the instructional materials, and final revisions are currently being completed.

Current Instructional materials Revisions

Overall, teacher feedback indicated that the second field test version of the instructional materials was much more successful in helping students develop a deep understanding of the concepts and ideas around energy and matter. While teachers reported that these concepts were still very difficult for their students, they found that overall students had a much better grasp of these concepts than either with the first field test version or with previous curricula teachers had used. Additionally, many of the teachers reported that their own understanding of energy and matter in ecosystems had improved dramatically. Some of the more germane feedback we received from teachers on the end of year survey pertaining to our major revisions included:

- I had little experience with teaching with models and how to help students to express their thinking through models. This was an excellent way of doing this. I feel more comfortable in this area. Also the details on how matter is transferred through the ecosystem is like I have never seen before. It really helps students to focus on the content and helps them to use what they learned to express their thinking.
- 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.
- I improved my understanding of how to approach the subject of carbon in the growth of plants, it also made me more aware of why the students have a hard time with that concept (Stiles, 2017).

Current revisions, based on the most recent field test, are focusing primarily on deepening teacher support for teaching some of the critical, more complex activities in this chapter. One activity in particular, in which students interpret major scientific findings around matter cycling in ecosystems, posed significant challenges for students and teachers. Revisions for this activity are focusing on reducing the number of findings that students interpret, and increasing the support in the teacher materials. We are also providing a graphic organizer to help students as they think through and make sense of the findings.

Next Steps

This round of revisions will be the final major revisions for the unit. The unit will undergo one more round of field testing with New York City teachers, with the intent of focusing on the professional development accompanying the instructional materials, including the professional development around teacher matter and energy. This final round of field testing should provide data on the effectiveness of the use of modeling in this context.

Conclusion

We have used a backward design process to develop a middle school ecology instructional materials to support a bundle of NGSS PE related to MS-LS2 (Ecosystems: Interactions, Energy, and Dynamics) and MS-ESS3 (Earth and Human Activity), and MS-PS1 (Matter and Its Interactions) Feedback from teachers who field tested the initial instructional materials during the 2015–2016 school year and the revised instructional materials during the 2016-2017 school year has provided critical input for developing a more effective instructional materials around the practice of modeling as it relates to matter and energy in ecosystems. Results obtained from expert reviewers and the field test teachers indicate we have made substantial progress over the iterations of the field test. We are currently revising the instructional materials for a third and final time, with the intent of further revising the professional development plan to provide explicit, appropriate support for teachers and students around the teaching and learning of this difficult topic in a way that best utilizes the three dimensions of the NGSS.

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