Developing an NGSS-aligned Educative Middle School Ecosystems Curriculum Unit

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ABSTRACT

This paper describes the design of a middle school ecology curriculum unit and professional development program to support the vision of the K-12 Science Education Framework and a bundle of middle school Next Generation Science Standards and their related Common Core State Standards. The development of the curriculum and 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 materials (for the teacher and student). Twenty-five middle school science teachers from New York City public schools participated in twelve days of professional development over a six-month period and field-tested the curriculum unit, *Disruptions in Ecosystems: Ecosystem Interactions, Energy, and Dynamics,* during the 2015-2016 school year. Analysis of expert reviews, teacher feedback, and student work samples indicate that the project has made substantial progress in designing of curriculum and professional development to support three-dimensional teaching and learning. The results also suggest next steps for revision and enhancement of the curriculum and professional development to provide more explicit support for teachers and students, including strategies for diverse learners and educative elements to support teachers' science content knowledge and pedagogical content knowledge.

Introduction

The *Framework for K-12 Science Education* (NRC, 2012) provides a new vision for addressing the precarious state of U.S. science education. Building on a growing body of research (e.g., College Board, 2009; NRC, 2007, 2009) and on the cumulative nature of learning, the *Framework* proposes that K-12 science education be coordinated around three intertwining dimensions (disciplinary core ideas, science and engineering practices, and crosscutting concepts) across four scientific disciplines: life sciences; Earth and space sciences; physical sciences; and engineering, technology, and practical applications of science (College Board, 2009; NRC, 2012; NGSS Lead States, 2013).

The Next Generation Science Standards (NGSS Lead States, 2013), authored by a consortium of 26 lead states facilitated by Achieve, Inc., provide a set of rigorous science standards based on the *Framework.* An important feature of the NGSS is the focus on "knowledge in use." Unlike many state standards, the NGSS performance expectations require students to demonstrate their understanding of science through the application of science and engineering practices (Robelen, 2013). Central to the NGSS are performance expectations (PEs), which integrate the three dimensions of disciplinary content, practices, and connections to specify what students should be able to do at the end of instruction. The NGSS do not prescribe curricula or instruction, but instead are intended to guide the development of such materials.

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 curriculum materials (e.g., Davis & Krajcik, 2005) and professional development (PD) on teachers and students. Our hypotheses are that teachers who participate in well-specified PD that teaches them how to use well-specified curriculum concerning middle school ecology will show greater gains in their content knowledge for teaching and pedagogical content knowledge, and their students will demonstrate higher levels of understanding of disciplinary core ideas about ecosystems, relevant science and engineering practices, and crosscutting concepts. This paper describes the principles and processes used to develop the first field test edition of the student and teacher curriculum materials and PD activities, and summarizes the findings from the 2015–2016 field test in the classrooms of 25 New York City public middle school teachers.

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 (curriculum partner, Barbara Nagle Co-PI), The University of Connecticut (research partner, Suzanne Wilson Co-PI), and WestEd (evaluation partner, led by Katherine Stiles).

Approach

The Lawrence Hall of Science (The Hall) is working closely with the American Museum of Natural History (AMNH) to develop a middle school NGSS-aligned curriculum 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 works closely with all project partners, expert panel members, and participating teachers to ensure that the curriculum being developed provides a model significantly aligned with the vision of the *Framework* and the NGSS. The learning goals and performance tasks for the unit are derived from the NGSS disciplinary core ideas, science and engineering practices, crosscutting concepts, and corresponding performance expectations. The team endeavors 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. 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 aligns with the NGSS (NGSS Lead States, 2013) performance expectations in Life Science Disciplinary Core Idea 2: Interactions, Energy, and Dynamics, and focuses on helping 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 curriculum 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 curriculum 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 curriculum, 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. Through classroom testing and review by educators and researchers, the curriculum development team is obtaining evidence about the alignment among the curriculum, assessments, and instructional goals, and revising the materials accordingly.

Based on the NGSS performance expectations outlined in Table 1, performance tasks were developed for each sequence. Performance expectations are not tasks; they specify student performance across three dimensions (what students need to know and be able to do). Using "Tool 2" from the *Five Tools*, the bundled performance expectations for each sequence in the unit were "unpacked" in order to develop specifications for the evidence that would demonstrate students have achieved and/or surpassed the performance expectation. These specifications addressed all the three dimensions embedded in each performance expectation from MS-LS2 (Ecosystems: Interactions, Energy, and Dynamics), as well as the bundled performance expectations from MS-ESS3 (Earth and Human Activity) when appropriate. The evidence is obtained through observations of students and/or student work products and helped to inform the development of both formative and summative assessments. The evidence of learning specifications look similar to the performance expectations but are written as statements and can be used to develop task prompts as well as to check for alignment with the performance expectation.

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 evidence	Asking Questions Analyzing and interpreting data Constructing explanations and designing solutions 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

The assessment specifications were used to develop two sets of performance tasks. The first set of tasks was embedded in the Evaluate activities at the end of each of the five chapters in the unit. These tasks generally related closely to the contexts and examples used in the chapters. The second set of tasks was developed as a series of end-of chapter assessments. They were developed in more general contexts with the intent that they could be used with other NGSS-aligned curricula. In addition, formative assessment tasks were designed at key points throughout the unit to determine students' progress toward the final learning goals. Scoring rubrics were developed for each performance task, setting forth both general levels of performance and specific indicators of performance at each level for each task. See MacPherson et al. (2016) for a detailed description of the performance tasks included on the chapter assessments.

The BSCS 5E Instructional Model (Bybee, 2013) provides a framework for developing an integrated and coherent instructional sequence in each of the five chapters in the unit. This model has been used to develop a number of curricula that have had a significant impact on science education (Bybee, et al., 2006) and is consistent with the research on how people learn (NRC, 1999) and how students learn science (NRC, 2005). ***Engage lessons*** initiate the instructional sequence and should (1) activate prior knowledge and make connections between the students' past and present learning experiences, and (2) foreshadow activities and focus students' thinking on the topics and learning outcomes in the forthcoming lessons. ***Explore lessons*** provide students with a common base of experiences within which they identify, actively explore, and begin developing science core ideas, crosscutting concepts, and science practices. ***Explain lessons*** involve developing an explanation of the core ideas, crosscutting concepts, and science practices students have been exploring. Students verbalize their conceptual understandings and demonstrate their ability to engage in science practices. Teachers introduce formal labels, definitions, and explanations for concepts, practices, skills, or abilities. ***Elaborate lessons*** extend students' conceptual understanding through opportunities to apply knowledge, skills, and abilities. Learners transfer what they have learned and develop broader and deeper understanding of concepts about the contextual situation, refining their skills. And ***Evaluate lessons*** entail students assessing their understanding and application of core ideas, crosscutting concepts, and science practices to solve a problem or complete a task, which includes a performance assessment or student project (Bybee, 1997, 2013).

The materials provided to teachers are intended to go beyond simple instructions for running the activities, and include educative elements based on the design heuristics of Davis and Krajcik (2005) to promote teacher learning. These nine design heuristics are organized into three groups: 1) supporting pedagogical content knowledge (PCK) for science concepts, 2) supporting PCK for scientific practices, and 3) supporting science content knowledge (S-CK). We are emphasizing specific heuristics in these three areas as appropriate to each chapter. For example, to support PCK for science concepts related to food webs, the teacher materials include educative elements based on Design Heuristic 2, supporting teachers in using scientific instructional representations. This supports the integration of modeling and content knowledge in the NGSS performance expectations for community relationships and food webs. To support PCK for science practices, educative elements focus on two additional heuristics related to science practices: Design

Heuristic 4, supporting teachers in engaging students with analyzing and interpreting data (a central element of the River Ecology materials) and Design Heuristic 7, supporting teachers in engaging students in making explanations based on evidence. The second field-test edition will focus on expanding support for teachers' development of S-CK (Design Heuristic 9). As noted previously, the integration of the three NGSS dimensions will be a challenge for teachers. The curriculum's educative elements are designed to help teachers integrate these elements.

The unit includes instructional activities, embedded formative assessments, and literacy strategies to support reading, writing, and discussion in science. The activities include a mix of hands-on, reading, discussion, multimedia, and analysis of authentic scientific data sets accessible online. The River Ecology case materials were modified for use in Chapter 4 to provide vivid examples of how disciplinary core ideas, practices, and crosscutting concepts are integral to scientists' ways of investigating and thinking about ecological problems. The materials include text passages, video segments, and an interactive web-based data analysis tool. The video segments feature scientists and their research. These videos weave together interviews, field and laboratory footage, and animations to illustrate science concepts and provide the learners with opportunities to observe and hear directly from the scientists how they plan their research, collect data, and make sense of their findings. Finally, these materials provide learners with access to secondary data sets via web-based interactive data visualization tools. Students use the scientific data sets and visualization tools to formulate questions and develop explanations based on claims, evidence, and reasoning.

In addition to aligning with the science standards, the unit integrates the Common Core State Standards (CCSS) in English Language Arts and Mathematics based on the NGSS connections (NGA-CSSO, 2010) (see Table 3).

Table 3: CCSS in ELA and Mathematics

Sequence	Common Core State Standards
1. Wolves in Yellowstone	**RST.6-8.1** Cite specific textual evidence to support analysis of science and technical texts **WHST.6-8.9** Draw evidence from informational texts to support analysis reflections and research
2. Ecosystem Models	**RST.6-8.7** Integrate quantitative or technical information expressed in words in a text with a version of that information expressed visually (e.g., a flowchart, diagram, table)
3. Interactions between Populations & Resources	**WHST.6-8.2** Write informative/explanatory texts to examine a topic and convey ideas, concepts, and information through the selection, organization, and analysis of relevant content **Statistics and Probability 6. SP.B.5** Summarize numerical data sets in relation to their context
4. Zebra Mussels	**WHST.6-8.1** Write arguments to support claims with clear reasons and relevant evidence **RI.8.8** Delineate and evaluate the argument and specific claims in a text, assessing whether the reasoning is sound and the evidence is relevant and sufficient
5. Designing Solutions	**RST.6-8.8.** Distinguish among facts, reasoned judgment based on research findings, and speculation in a text

Portions of each of the five chapters were piloted by the Hall in Bay Area classrooms during the 2014–2015 school year. This pilot provided evidence about classroom feasibility, students' ideas and learning, and the essential educative elements for teachers who will implement the materials. This evidence led to revision and expansion of the chapters to create the first field test edition of the unit.

The Curriculum

As the title suggests, disruptions to ecosystems provide an overarching context for the unit. Here we outline the phenomena that students explore in each of the chapters. The unit begins with the reintroduction of wolves to Yellowstone National Park as the first example of human impact on the environment. The second chapter of the unit introduces abiotic factors as the sources of ecosystem disruption, using the Yellowstone fires of 1998 as an example. In chapter 3, the focus returns to that of human impact on ecosystems by first examining the issue of overfishing followed by an introduction to the creation of dead zones through run-off. In chapter 4, invasive species represent the source of disruption as students investigate the effect of the presence of zebra mussels in the Hudson River ecosystem. The last chapter of the unit shifts student thinking towards developing and evaluating solutions related to the human-caused disruptions to ecosystems.

As part of the student supports for the unit, two scaffolding tools were developed in order to support teachers and students in the scientific practices of explanation and argumentation. These tools build on an earlier tool developed for the River Ecology project. Our previous research documents the appeal of these tools to teachers. (Mikeska, et al., 2013; Wilson, et al., 2012). The Explanation Tool helps guide students in developing a scientific explanation for questions that focus on explaining phenomena, allowing students to connect science concepts to data. For example, in one activity students read several scenarios describing interactions between a population and an abiotic or biotic factor. They then examine graphs of the same populations without knowing which populations correspond to which graph. Students then focus on one scenario and develop an explanation for the question "Which graph best represents the patterns of interactions described in your scenario?" The tool is structured to have students brainstorm a list of the evidence applicable to the question asked, then write a claim based on that evidence and list supporting science concepts. They then briefly explain the reasoning that relates their evidence and relevant science concepts to support their claim. Finally, they write a complete statement that incorporates all of this information in a formal scientific explanation.

The second tool, the Argument Tool, is used to address questions that can be answered with multiple claims and requires students to evaluate the evidence supporting each claim before choosing one to address in their argument. For example, in one activity students construct an argument to answer the question "Should the wolves in the Greater Yellowstone Ecosystem be allowed to increase, decrease, or stay the same?" Students first examine the evidence that supports each claim, often gathered from previous activities and explanations they have developed. Next the students evaluate the quality and strength of the evidence that supports each claim, before moving on to construct a written scientific argument, based on the evidence available and scientific reasoning, that led to their argument for a specific claim. They conclude by writing a brief rebuttal explaining why they did not argue for the other claim(s).

The unit also includes embedded literacy strategies to support students' understanding of the text. The strategies used include anticipation guides, Stop to Think questions (questions embedded alongside readings at specific points for students to pause and make meaning of the text), and Read, Think, and Take Note (designed to assist students in making meaning of the text as they read by recording their thoughts, reactions, and understanding of the text). All embedded strategies were used multiple times to ensure students had adequate practice, and were incorporated based on their appropriateness for the specific text in the activity. Teacher supports for implementing the strategies included suggestions for modeling and scaffolding the strategies, in particular for English Language Learners and other groups of diverse learners. In the next revision developers will focus on improving teacher supports for these strategies and incorporating more strategies around student discourse.

The Professional Development

Curriculum materials are only as good as the teachers who use them. Desimone (2009) argues that high quality PD includes: (1) opportunities for teachers' active engagement; (2) a focus on specific content and how students learn that content; (3) coherence (with both teacher knowledge and state/district policy); (4) collective participation; and (5) time (how much time remains disputable). Darling-Hammond (2010) asserts that effective PD is "sustained, ongoing, content-focused, and embedded in professional learning communities…[and] focuses on concrete tasks of teaching, assessment, observation" and that it "is often useful for teachers to be put in the position of studying the very material that they intend to teach to their own students" (pp. 226-227). Teachers need both PD *and* strong instructional materials, as well as repeated opportunities to practice putting what they learn into practice (Osborne, et al., 2013).

In response, we have developed a well-specified PD program in which teachers received 12 days of PD, concentrated in summer and fall experiences. Table 4, on the following page, summarizes the professional development schedule. The first session was a two-day workshop (early summer) focused on the shifts in the NGSS and an introduction to teaching using the 5E model. The second session was a five-day late-summer institute focused on the first three instructional sequences, including the embedded teaching tools or scaffolds, literacy supports, and formative/summative assessments. The third session was comprised of three one-day PD sessions (held on three Saturdays in the fall) while teachers were teaching the unit. These sessions included a focus on the fourth and fifth instructional sequences, as well as further reflection on the shifts in their teaching. The final session was a two-day workshop after teachers completed the unit to reflect on their teaching, and to focus on how to use the teaching tools and strategies in the unit and apply them to *other* science units.

Table 4: Professional Development Schedule

2 Days: June 30 – July 1, 2015	NGSS 3D Learning and BSCS 5E Instructional Model; Using Chapter 1: Wolves in Yellowstone
5 Days: August 24 – 28, 2015	Immersion into Student and Teaching Materials: Chapters 1-3; Ecosystems Unit Conceptual Flow
1 Day: October 3, 2015	Immersion into Student and Teaching Materials: Chapter 4 Part 1; PD to Support Implementation
1 Day: October 24, 2015	Immersion into Student and Teaching Materials: Chapter 4 Part 2; PD to Support Implementation
1 Day: November 7, 2015	Immersion into Student and Teaching Materials: Chapter 5; PD to Support Implementation
2 Days: February 17-18, 2016	Applying Teaching Practices and Tools from Ecosystems Unit for use in other science content classes; Gathering Feedback on Field-test/Implementation

Mechanisms for teacher learning

In previous research describing teacher learning in the Urban Advantage program in New York City (Mikeska et al., 2013; Wilson, et al., 2011, 2012), we have documented three key program features that promote teacher learning: 1) having teachers witness the complex work of scientists; 2) recreating similar experiences for teachers to engage in to understand this work; and 3) providing ongoing support to teachers as they explored how to adapt those experiences (and all accompanying materials) for instruction in middle school classrooms (see Figure 1).

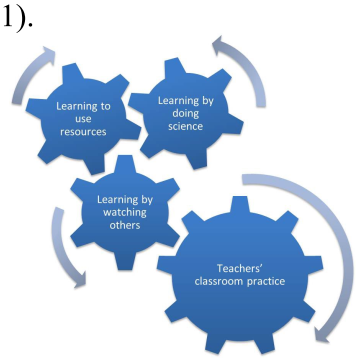


Figure 1. Mechanisms of Teacher Learning

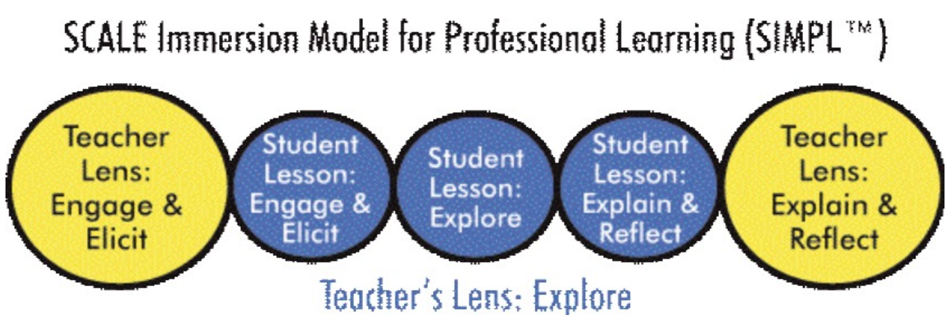
Thus, teachers are afforded multiple opportunities to observe and engage in the different types of science practices, with regular opportunities to both reflect on their own learning of science and how they might use those experiences to inform their own teaching of middle school science. Because the PD materials and pedagogies are offered to teachers as models – not mandates – for how they might engage their own students in authentic science experiences, teachers then go back to their classrooms and try their own instructional approaches. In this way, participating teachers are positioned as professionals who bring important knowledge and experience to bear on the creation of appropriate curriculum materials. In fact, they help museum staff create new materials. Just as the professional developers engage teachers in experiences that require them to draw connections between data and then to later apply those connections to the design of their own investigations, teachers engage museum staff in drawing connections between how they teach the teachers and how the teachers teach their students, all of which flows into the redesign of the instructional materials for students and teachers. This view of teachers as professionals and the dynamic and iterative relationship between materials development and "the field" are fundamental to *instructional* reform. Research on comprehensive school reform has demonstrated persuasively that "expert" levels of instructional practice require developing teachers' expertise so that they can adapt materials to students' needs in the contexts of changing classrooms (e.g., Cohen et al., 2013; Rowan et al., 2009).

Development of PD intervention

We developed the PD model to support teachers during the field-testing of the middle school ecology curriculum unit. This PD was designed using an immersion into inquiry PD strategy (Loucks-Horsley, et al., 2010) that explicitly allocates time for teachers as learners to experience both the role of students learning from the curriculum and the role of teachers using the curriculum.

We used a specific immersion model for teachers-as-learners called the SCALE Immersion Model for Professional Learning (SIMPL) (Lauffer, 2010). In the SIMPL approach (see Figure 2 below), participants are engaged in learning sessions that are designed with both a targeted pedagogical learning outcome and a science-content focus. At the center of the approach, in the blue segments, teachers experience lessons with instructional materials focused on the pedagogical approaches teachers are to use in their classrooms.

Figure 2



Thus, during the PD phases shown in blue, teachers experienced instructional sequences from the ecology unit as learners (Figure 1's "learning by doing science" gear), while PD facilitators model the pedagogical approaches they are to use in their classrooms (Lauffer, 2010). These lessons from the ecology curriculum are surrounded by PD activities, shown as yellow segments, that surface teacher-learners' prior conceptions and ask them to reflect back on their initial conceptions and be metacognitive about their own learning of both science content and pedagogy. This process of teacher-learners learning in multiple roles, as well as reflecting on the science content and pedagogical approach, is intended to support the development of science content knowledge and pedagogical content knowledge to effectively implement the curriculum and reflect on and modify their teaching.

The instructional materials were designed using principles for educative materials design. This is essential to our approach, as we see classroom experience as a major context for teacher learning and our revision of the materials to be educative for teachers is a strategy for enhancing what teachers are able to learn in their classrooms (Figure 1's "learning through classroom experience" gear). In terms of Figure 1, the goal of the PD was to increase the iterative, dynamic interactions among and between what teachers learn in the professional development program and in their classrooms.

Findings

Feedback on the curriculum was collected from six expert panel members, 25 field test teachers, and Hall staff with expertise in ecology, curriculum development, and literacy in science. The expert panel members met with the team during a two-day meeting in New York, when the materials were still in draft form, and then read the first field test edition and responded to questions in their areas of expertise, which focused on 1) the NGSS and three-dimensional learning, 2) the 5E Instructional Model, 3) literacy and mathematics strategies and connections to Common Core standards, 4) the NGSS PE and formative and summative assessments, 5) supporting ELL students and diverse learners, 6) teacher's guide format, design, and support for inclusion of educative components, and 7) usability. The teachers completed extensive surveys after teaching each activity, chapter, and the complete unit. The final day of the PD focused on teachers providing the team with extensive feedback and suggestions for the improvement of each chapter. In general, the reviews included positive comments on the overall support for three-dimensional learning in the curriculum and assessment, the inclusion of scaffolds for the practices, the inclusion of literacy strategies, and certain educative elements in the teacher's guide. Some teachers commented that they had seen great engagement from their students and that they hoped to apply what they had learned about teaching from the unit across their curriculum. Teachers also commented how their own understanding of ecosystems has deepened. They reported learning a lot more about ecology and how to teach it, especially in relation to the flow of energy and cycling of matter and the complexity of the content for students.

There was significant overlap in the recommendations of the expert panel and the teachers for revision of the curriculum. Revision to develop the second field test edition of the unit for testing in the 2016–2017 school year will focus on addressing the following recommendations.

- Bring the NGSS three dimensions more into balance. In the field test version, the science and engineering practices seemed to be driving some of the chapters, when instead the practices should support the content. Reviewers and teachers consistently recommended that the crosscutting concepts be more explicit for both teachers and students.

- Increase the variety of supports for reading, writing, and classroom discourse to make the unit more usable for a wider range of students, especially English Language Learners.
- Include more educative elements in the Teacher Guide. These elements should focus on what is most important and the design should support teachers in finding what they need so the educative elements do not overwhelm the teachers.
- Introduce the explanation and argumentation tools more gradually, focusing at first on using them for discussions and informal explanations before developing formal written explanations. Be strategic in the use of the tools so that students have ample opportunity to improve in their use of the practices to make sense of phenomena, while limiting their use to reduce the likelihood of students becoming overwhelmed.
- Reduce the length of the unit. The first field-test version was too long to be practical in an already-crowded school year.
- Revise the early chapters of the unit to better reflect the 5E model.

Feedback on the professional development was collected via online surveys after each professional development event. Feedback was also collected through focus group discussions with the external evaluator during the final day of professional development. Key recommendations follow.

- The final 2-day PD session in Feb. was intended to extend teachers' awareness and understanding of ways in which to use several of the Ecosystems' components as they continue to teach science. This focus differed from prior professional development sessions where the emphasis was on supporting teachers to implement the Ecosystems unit with their students during the field test. Based on teachers' ratings in their final PD survey, most, but not all, of the teachers increased their awareness of how to use the literacy strategies, explanation, the research on learning, the 5E Model, and the NGSS and the NYS science standards to inform their teaching of science, with fewer teachers providing high ratings for their understanding of how to support students in the scientific practice of argumentation.
- During the focus group discussions with the evaluator, the field test teachers were asked to reflect on the extent to which the 12 days of professional development supported their learning and their implementation of the Ecosystems unit. Overall, the teachers commented that they learned a great deal about the NGSS and 3-Dimensional learning. Most teachers increased their understanding of the 5E Instructional Model, with many using it to redesign and teach other science content, and some teachers have explicitly shared the Instructional Model with their students.
- Feedback was also shared about the structure of the PD itself. Teachers shared that the professional development sessions should occur more frequently and over a longer period of time; a shorter summer institute focused on the NGSS and the 5E Instructional Model, reconvene closer to the start of school focused on Chapter

1, reconvene for subsequent chapters in two to three week time periods, and provide optional online discussions while teachers are implementing the unit.

Next Steps

The unit will be revised based on the feedback received from the teachers and the expert review panel, as well as the results of examining student work samples. The professional development program will be revised based on feedback received from the teachers and input from the research team and evaluator. The revised version will be field tested in 2016–2017 by a new cohort of teachers in NYC Public Schools. These teachers will receive twelve days of PD according to the updated PD program outlined in Table 4, below. Feedback from the second field test will be used in a second round of revisions to prepare the final version of the curriculum.

Based on feedback from the teachers, we are planning a revised professional development program, as shown in Table 5.

Table 5: PD program outline for 2016–2017 field test

5 days: August 22-26	Teachers will learn about the NGSS and the BSCS 5E Instructional Model using experiences from Chapter 1
2 day: September	Ch. 2
1 day: October	Ch. 3
2 days: November	Ch. 4
1 day: December	Ch. 5
1 day: February, 2017	Teachers will reflect on their use of the Tools from the unit, the Literacy strategies, the 5E model & the NGSS.

Conclusion

We have used a backward design process to develop a middle school ecology curriculum to support a bundle of NGSS PE related to MS-LS2 (Ecosystems: Interactions, Energy, and Dynamics), MS-ESS3 (Earth and Human Activity), and MS-PS1 (Matter and Its Interactions). We have also developed an immersive and reflective professional development program to support teachers who field tested the curriculum during the 2015–2016 school year. Results obtained from expert reviewers and the field test teachers indicate we have made substantial progress in development of curriculum and professional development that support three-dimensional teaching and learning. However, we have also learned that there are a number of steps we can take to further support the vision of the NGSS. We are currently revising the curriculum and professional development plan to provide more explicit support for teachers and students, including strategies for diverse learners and educative elements to support teachers S-CK and PCK.

References

Bybee, R. W. (1997). *Achieving scientific literacy: From purposes to practices*. Portsmouth, NH: Heinemann.

Bybee, R. W., Taylor, J., Gardner, A., Van Scotter, P. Carlson, J., Westbrook, A., & Landes, N. (2006). *The BSCS 5E instructional model: Origins, effectiveness, and applications.* Colorado Springs, CO: BSCS.

Bybee, R. W. (2013). *Translating the NGSS for classroom instruction.* Arlington, VA: NSTA Press.

Cobb, P., & Gravemeijer, K. (2008). Experimenting to support and understand learning processes. In A. E. Kelly, R. A. Lesh, & J. Y. Baek (Eds.), *Handbook of design research methods in education: Innovations in science, technology, engineering, and mathematics learning and teaching* (pp. 68–95). New York: Routledge.

Cohen, D. K., Peurach, D. J., Glazer, J. L., Gates, K. E., & Goldin, S. (2013). *Improvement by design: The Promise of Better Schools*. Chicago, IL: University of Chicago Press.

College Board. (2009). *Science College Board standards for college success*. Retrieved from http://professionals.collegeboard.com/profdownload/cbscs-science-standards-2009.pdf.

Collins, A., Joseph, D., & Bielaczyc, K. (2004). Design research: Theoretical and methodological issues. *Journal of the Learning Sciences*, *13*, 15–42.

Darling-Hammond, L. (2010). Teacher education and the American future. *Journal of Teacher Education*, *61*(1-2), 35–47.

Davis, E. A. & Krajcik, J. S. (2005). Designing educative curriculum materials to promote teacher learning. *Educational Researcher*, *34*(3), 3–14.

Desimone, L. M. (2009). Improving impact studies of teachers' professional development: Toward better conceptualizations and measures. *Educational Researcher, 38*, 181–199.

Lauffer, H. B. (2010). SIMPL: A framework for designing and facilitating professional development to change classroom practice, *Science Teacher Education*, *58*, 13–28.

Loucks-Horsley, S., Stiles, K., Mundry, S., Love, N., & Hewson, P. (2010). *Designing professional development for teachers of science and mathematics*. Thousand Oaks, CA: Corwin.

Mikeska, J.N., Wilson, S.M., Short, J.S., Bills, P., Dibner, K., Elgendy, S., Helmsing, M., McClure, D., Meyer, A., Shattuck, T., Holmes, J. & Roditi, H. (2013, April). *Examining urban, middle school science teachers' intellectual, social, and conventional resources in a science professional development program.* Paper presented at the Annual Meeting of the American Educational Research Association, San Francisco, CA.

National Governors Association Center for Best Practices and Council of Chief State School Officers (NGA-CSSO). (2010). *Common core state standards in english language arts and mathematics* (CCSS). Retrieved from *http://www.corestandards.org/the-standards.*

National Research Council. (1999). *How people learn: Brain, mind, experience, and school.* Committee on Developments in the Science of Learning. J.D. Bransford, A.L. Brown, and R.R. Cocking (Eds.). Washington, D.C.: National Academy Press.

National Research Council (NRC). (2005). *How students learn: Science in the classroom*. Committee on *How People Learn*, A Targeted Report for Teachers, M. S. Donovan & J. D. Bransford, (Eds.), Division of Behavioral and Social Sciences and Education. Washington, D.C.: The National Academies Press.

National Research Council. (2007). *Taking science to school: Learning and teaching science in grades K-8*. Committee on Science Learning, Kindergarten through Eighth Grade. R.A. Duschl, H.A. Schweingruber, & A.W. Shouse (Eds.). Board on Science Education, Center for Education. Division of Behavioral and Social Sciences and Education. Washington, DC: The National Academies Press.

National Research Council. (2009). *Learning science in informal environments: People, places, and pursuits*. Committee on Learning Science in Informal Environments. P. Bell, B. Lewenstein, A.W. Shouse, & M.A. Feder (Eds.). Board on Science Education, Center for Education. Division of Behavioral and Social Sciences and Education. Washington, DC: The National Academies Press.

National Research Council. (2012). *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas*. Committee on a Conceptual Framework for New K-12 Science Education Standards, Board on Science Education. Division of Behavioral and Social Sciences and Education. Washington, DC: The National Academies Press.

NGSS Lead States. (2013). *Next generation science standards: For states, by states.* Washington, D.C.: The National Academies Press.

Osborne, J., Simon, S., Christodoulou, A., Howell-Richardson, C., & Richardson, K. (2013). Learning to argue: A study of four schools and their attempt to develop the use of argumentation as a common instructional practice and its impact on students. *Journal of Research in Science Teaching, 50*, 315–347.

Robelen, E. W. (2013, May 14). Common science standards face capacity issues, *Education Week Online*.

Rowan, B., Correnti, R., Miller, R., & Camburn, E. (2009). School improvement by design: Lessons from a study of Comprehensive School Reform programs. In B. Schneider & D. Sykes (Eds.), *AERA handbook on education policy research* (pp. 637–651). New York: Routledge.

Wiggins, G. & McTighe, J. (2005). *Understanding by design*. Alexandria, VA: Association for Supervision and Curriculum Development.

Wilson, S. M., Rozelle, J., & Mikeska, J. N. (2011). Cacophony or embarrassment of riches: Building a system of support for teacher quality. *Journal of Teacher Education, 62,* 383–394.

Wilson, S.M., Short, J.B., Mikeska, J.N., Bills, P., Dibner, K., Elgendy, S., Helmsing, M. & Shattuck, T. (2012, April). *Teaching teachers to teach science: The case of Urban Advantage.* Paper presented at the Annual Meeting of the American Educational Research Association, Vancouver, BC.