FEATURE ARTICLE

Biocomplexity: Aligning an "NGSS-Ready" Curriculum with NGSS Performance Expectations

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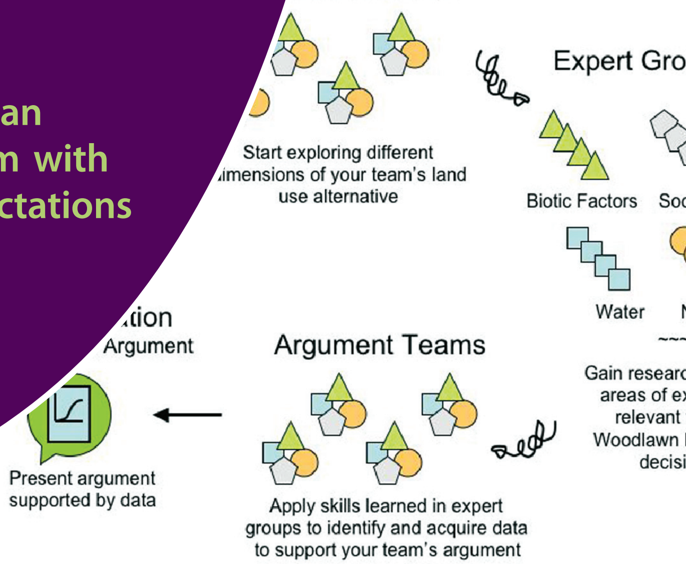

Abstract

Until new materials are available that reflect the conceptual shift in teaching required by the Next Generation Science Standards, teachers will need to evaluate existing materials and consider strategies for adaptation. In this article, we demonstrate one strategy for evaluating pre-NGSS curricula to bring them into alignment with the NGSS Framework. To do this, we retrospectively analyzed materials from a high school capstone course in ecology that were developed prior to the advent of the new standards. Based on this analysis, we recommend some general steps to help teachers consider how to adapt materials they are currently using. We believe that this evaluation and adaptation process can also strengthen teachers' understanding of the Framework and its implications for teaching, for student learning, and for assessment.

Key Words: *NGSS alignment; high school; ecology; curriculum adaptation.*

The National Research Council's *Framework for K-12 Science Education* for the Next Generation Science Standards (NGSS) calls for a conceptual shift in teaching and learning (NRC, 2013). The Framework advocates a "knowledge-in-use" perspective on curriculum and instruction articulated in terms of three dimensions of science: Science and Engineering Practices, Crosscutting Concepts, and Disciplinary Core Ideas. The Science and Engineering Practices describe "what scientists do to investigate the natural world and what engineers do to design and build systems" (students engage in practices to build, deepen, and apply their knowledge of core ideas and crosscutting concepts), and the Crosscutting Concepts "help students explore connections across the four domains of science, including Physical Science, Life Science, Earth and Space Science, and Engineering Design".

A fourth dimension, the Nature of Science (NOS), is also an important theme for the NGSS. However, though linked to the other three dimensions in the standards as published, important elements of NOS are largely represented in an Appendix. The articulation of NOS as a fourth dimension represents an area where further development is needed. McComas (2016) argues that NOS is conspicuously absent in current efforts to align curricula with the NGSS. He states, "There can be no more important goal of science teaching than for students to understand how science develops, generates, tests, and validates scientific knowledge" (p. 707).

Performance expectations described in the NGSS integrate the three dimensions, and represent what should be assessed at the end of a grade level or grade band. This knowledge-in-use model is intended to ensure that students see that social implications and systemic consequences are intrinsic parts of the making, understanding, and deployment of scientific knowledge. Indeed, the approach is considered so central that one leading scholar, who has written extensively on implementation of the NGSS, has said that it provides a decisive criterion by which to differentiate materials that are worth working with from those that should be passed over. He writes, "Elements of the science and engineering practice(s), disciplinary core idea(s), and crosscutting concept(s), blend and work together to support students in three dimensional learning to make sense of phenomena or to design solutions. If the lesson or unit you are judging don't meet this criteria [*sic*], there is no need to go on with an evaluation to discern if the materials align with NGSS or not" (Krajcik, 2014).

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Education researchers and policy makers have published general articles on the vision of the standards and their capacity to transform science education (e.g., Penuel et al., 2015), misconceptions related to the NGSS (e.g., Huff, 2016), and guides for

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district and school leaders, and teachers, either to develop plans to implement the standards (e.g., NRC, 2015), or to evaluate curricula to align them with the NGSS (Achieve, 2014). Yet others attempt to support teachers by publishing exemplars, with recommendations for how to adapt curricula that teachers currently use (Krajcik, 2015), or personal narratives that illuminate how to plan NGSS-based instruction (Colson & Colson, 2016).

However, until new materials are available, teachers will need to evaluate existing materials to consider strategies for adaptation. Given the different way of thinking represented by the standards, teachers will also need to develop strategies for formatively assessing student progress toward the Performance Expectations. For example, the NextGen Science Assessment project is addressing the goal of formative assessment toward the Performance Expectations by designing Learning Performances that are smaller in scope than a given Performance Expectation and represent some key aspect of the Performance Expectation (NextGen Science Assessment Project, 2016). In this model, *related sets of Learning Performances represent student progress toward achieving given Performance Expectations at the end of each grade*.

Although many of the articles above, as well as other resources (e.g., Berk, 2014; Krajcik, 2014) provide suggestions for how this might be done, worked examples based on a specific piece of curriculum are rare. Therefore, this paper examines *Environmental Science and Biocomplexity*, a curriculum that was designed before the publication of the NGSS but is, however, "NGSS-ready." [Funded by the National Science Foundation as *Biocomplexity and the Habitable Planet* (DRL-0628171), *Environmental Science and Biocomplexity* is now available in digital and print-on-demand format from Its About Time Publishers (iat.com).]

In what follows, we demonstrate how to identify Learning Performances in the curriculum that are smaller in scope than the Performance Expectations of NGSS. Identifying these and determining how they build toward the Performance Expectations, if successfully completed by students, can be used to judge to what extent a curriculum can be fully aligned with the NGSS. In this way, the article provides and illustrates some practical guidelines for how teachers might approach this task.

○ What Do We Mean by NGSS-Ready?

By this term, we mean that the curriculum meets Krajcik's decisive test cited above (Krajcik, 2014). That is, although not having been written to NGSS specifications directly, it was originally designed to enable teachers and students to address many of the *core ideas* in ecology through student use of various *science practices*. In addition, several of the *concepts* that are now NGSS Crosscutting Concepts, such as Systems, were included as well.

Materials that are "ready" in this sense must facilitate a teaching approach based on the Performance Expectations orientation of the NGSS, and it is in this arena that analysis and adaptation will often need to focus, as we show in what follows. Moreover, since the Performance Expectations are open to a variety of interpretations, the materials should allow the teacher to translate these general rubrics into more concrete and fine-grained Learning Performances, which will be usefully applicable to the students for whom the teacher is preparing. Indeed, we suggest that this secondary analysis of potential Learning Performances may be the critical ingredient in making an NGSS-ready curriculum truly NGSS-aligned. Learning Performances may already be developed in the curriculum, or only latent and requiring additional teacher curriculum development, or may be superfluous to the Performance Expectations and can therefore be cut.

○ Analyzing (and Adapting) Your Instructional Materials

The steps we applied to our pre-NGSS materials are detailed in Table 1. We believe that you may find them useful in identifying materials to support your teaching within the Framework, and in mapping out a path for their effective use. This adaptation process can also be a way to strengthen your own understanding of the Framework and its implications for your teaching, for student learning, and for assessment.

Although perforce presented as a sequence in Table 1, this process will likely be iterative as you go about analyzing, and most likely adapting, the curriculum at hand.

○ What is Biocomplexity?

Biocomplexity differs from traditional ecology/environmental science in several respects (Figure 1).

1. It draws from a relatively new scientific focus on "coupled natural-human systems," which sees human social institutions and patterns of behavior as integral parts of ecosystems.
2. It draws on landscape ecology, which studies how landscape structure affects the abundance and distribution of organisms, including humans, and dictates the movement of abiotic factors across the landscape. A fragmented suburban landscape, for example, may include several interacting ecosystems—such as a pond, a park, housing, and a highway with manicured verges—and processes in each affect the others.
3. It incorporates a focus on ecosystem services, which take into account, and try to place a value on, the benefits that ecosystems confer on humans.

○ The Biocomplexity Curriculum

A partnership between TERC (see Acknowledgments) and the Cary Institute was funded by the National Science Foundation to develop *Biocomplexity* as a capstone high school curriculum that introduces a new way for students to look at their world, through the integration of ecology, environmental science, geography, social science, physical science, and math. It was grounded in best practices exemplified in TERC's curriculum work of the previous two decades, for example, in inquiry-based learning (Drayton & Falk, 2001; Wiser et al., 2012), and in research on learning environments and school contexts for curricular innovation (e.g., Drayton et al., 2010; Asbell-Clarke & Rowe, 2014; Puttick et al., 2015a, 2015b; Drayton & Puttick, 2016; Rosebery et al., 2016).

The full curriculum engages high school students in exploring the complex fabric of relationships between humans and the environment at all spatial and temporal scales. It consists of inquiry-based investigations designed around cases in urban, suburban/agricultural, tropical, and polar systems, in which students

Table 1. Dimensions of adaptation.

Analysis	Strategy for Adaptation
1. Identify learning expectations and expected learning outcomes or "Learning Performances."	Recast learning goals in terms of expected Learning Performances to determine if students understand the learning goal (i.e., recast as "Students will be able to. . .").
2. Identify the driving question for students' inquiry in each instructional activity.	Make the driving questions explicit, and use them to direct and constrain the inquiry.
3. Identify resources and activities that relate to Learning Performances (#1) and driving questions (#2) directly.	Ensure that resources and activities are all related to #1 and #2, by identifying the learning performances that should result from each activity, and ensure that they build toward the Performance Expectation. Eliminate those that are not directly related! Ensure that resources provided can support the performances.
4. Clarify how students will make meaning, and how you will use the Learning Performances formatively.	Look for opportunities for students to make meaning through the Learning Performances, e.g., by analyzing data, reflecting on observations, discussing and synthesizing the implications of their work.
5. Identify what evidence students will use to draw and communicate conclusions.	Students can derive evidence from several types of data; remember that students learn when transferring knowledge from one representation to another.
6. Assemble the revised instructional activities.	Now examine the sequence for pedagogical coherence between Learning Performances, and for the best use of materials and resources.
7. Prepare your own inquiry: What questions are you left with about the clarity, sequence, and depth of the unit as you've adapted it?	Identify two or three areas or elements that seem particularly important to observe, and decide what will count as evidence to you that the materials and their sequence support students' successful Learning Performances.

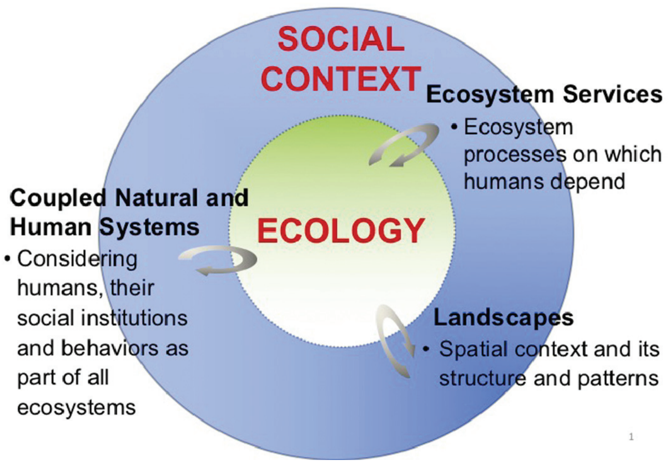

Figure 1. Biocomplexity integrates a focus on coupled human-natural systems, and ecosystems services across landscapes.

Figure 2. The Sprawl unit. (*Top left*) Greater Prairie Chicken (*Tympanuchus cupido*); © iStockphoto.com / Michael Zurawski. (*Bottom left*) Suburban sprawl: © 2012 Jupiterimages Corporation. (*Top right*) Prairie grasses; © iStockphoto.com / dpenn. (*Bottom right*) Agricultural fields; © 2012 Jupiterimages Corporation.

address land use and resource use challenges increasingly confronted by society.

For example, in the Sprawl unit, students must consider tradeoffs among different options for land use that include conservation to support native prairie biodiversity, agriculture, housing development, or a combination of all three (Figure 2). To design a land use plan, they apply a systems approach to consider biotic factors such as conservation and biodiversity, abiotic factors such as water use or carbon flow, and human factors such as quality of life and aesthetics. Using evidence they gather themselves, students marshal arguments in support of their chosen land use plan.

In doing so, they learn about several important disciplinary core ideas, and go into the crosscutting concepts in some depth. For example, the energy models they develop are based in *systems thinking*. They look for *patterns* in the distribution of organisms in the landscape, and relate these to the patchy structure of prairie ecosystems. Disciplinary core ideas, crosscutting concepts, and science practices are each intrinsic to student progress through the unit, and each is essential to student learning. In conducting investigations, students also engage with NOS as they generate, test, and validate their scientific knowledge.

○ How do Learning Performances in Biocomplexity Build Toward Performance Expectations?

For the purpose of demonstration in this article, we examined the learning sequences in the Sprawl unit, applying the Learning Performances lens to instructional activities to determine if they were aligned with the NGSS Performance Expectations. This allowed us to identify sets of Learning Performances that build toward the Performance Expectations (Table 2). The Learning Performances, all relevant to the final land use plan that students must construct, all proved to build toward the two Performance Expectations shown in Table 2.

○ Implications

The states are in varying readiness to adopt the NGSS; 16 have adopted them as of February 2016 (Heitin, 2016). However, many districts across the country are using the NGSS to reshape curricula and teaching in science, technology, and engineering (Heitin, 2015),

Table 2. Related sets of Learning Performances in the Sprawl unit that build toward meeting the two NGSS Performance Expectations indicated.

Instructional Activity	Learning Performance	Performance Expectation
Students investigate succession in their area, and at a prairie site.	Students are able to arrange images of successional stages in prairie ecosystems through analyzing the levels of biodiversity shown.	**HS-LS2-6. Evaluate the claims, evidence, and reasoning that the complex interactions in ecosystems maintain relatively consistent numbers and types of organisms in stable conditions, but that changing conditions may result in a new ecosystem**.
Students investigate biodiversity in their area, as a "way in" to analyze patterns in biodiversity data related to patchiness in prairie ecosystems.	Students are able to demonstrate understanding that biodiversity in prairie ecosystems is distributed in patches.	
Students analyze graphical data on the interaction of fire and grazing in determining prairie biodiversity	Students are able to attribute biodiversity patterns in the data to the interaction of grazing and fire.	
Students analyze natural history data for prairie species such as bison and prairie chicken.	Students are able to identify the resources required to sustain a population of the selected species.	
Students analyze satellite images to investigate the impact of different suburban designs on the environment, on biodiversity, and on human well-being.	Students are able to identify patterns of impact related to conventional, sustainable, and new urbanist neighborhood designs.	**HS-LS2-7. Design, evaluate, and refine a solution for reducing the impacts of human activities on the environment and biodiversity**.
Students explore numerical data on the energy subsidies required for different agricultural land uses.	Students are able to compare the energy subsidies required by traditional and sustainable agriculture.	
Students use microcosms to investigate the impact of different environmental conditions on plant net primary productivity, and translate this into carbon uptake.	Students are able to identify how varying abiotic conditions impact plant productivity.	
Students examine and analyze plant productivity in an agricultural field and in native prairie.	Students are able to develop models of the inputs and outputs of energy required to support farming versus native prairie.	
Students use their energy input and output models to choose particular kinds of land use.	Students are able to use evidence to support their chosen land use plan.	

and teachers are feeling pressure to align their curricula and instruction with NGSS. Some states, and some districts too, expect teachers to accomplish this over the course of one or two years, and some (e.g., California) expect to be administering NGSS-aligned state assessments in 2017.

The continuity of NGSS ideas with many principles from prior waves of science education reform means that some curricula are probably already NGSS-ready. Such materials provide a head start to bringing them into full alignment, if they already address many of the core ideas, if they incorporate student use of some science practices, if the design of the curriculum is structured around some of the unifying concepts that are now NGSS Crosscutting Concepts, and if students engage with the NOS through their investigations. These were all existing characteristics of the Biocomplexity curriculum.

As we have attempted to show here, in discussing what we learned from the process of analyzing the Sprawl unit for the purposes of this article, such units can be brought into full NGSS alignment through careful review and adaptation. Review involves recasting learning goals for each instructional activity as Learning Performances, and checking the extent to which each activity and associated Learning Performance builds toward an NGSS Performance Expectation. This may result in one of several actions in the units that need adapting, as follows: An activity may need to be revised if it does not recognizably lead to an identifiable Learning Performance. An activity may need to be supplemented so that students are empowered to use specific Science and Engineering Practices. Finally, an activity may need to be omitted altogether if it does not directly build in a sequence toward a desired Learning Performance.

Determining to what extent the Learning Performances build toward the Performance Expectations of the NGSS can help teachers to judge whether or not the curricula they currently use can be aligned with the NGSS. We hope that the example of this process applied to the Sprawl unit illustrates some practical guidelines for how teachers might approach the task.

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