Supporting the NRC Framework: Educator Resources for K-12 Science Education

GLBRC 2012

Summary

The Great Lakes Bioenergy Research Center (GLBRC) is one of three bioenergy research centers established in 2007 by the U.S. Department of Energy to perform the basic research that generates technology to convert cellulose from plants to ethanol and other advanced biofuels. The GLBRC is leading the way in multi-disciplinary research, involving over 400 scientists, students, staff, and education and outreach specialists. GLBRC research epitomizes the intersection of science and engineering described in the new *Framework for K-12 Science Education* and in the *Next Generation Science Standards*, which are scheduled for release in early 2013. These documents will require a significant shift in how science is taught in U.S. classrooms. Changes will include student engagement in science and engineering practice, covering fewer core concepts in greater depth, and linking crosscutting concepts between scientific disciplines. GLBRC educational materials and professional development support teaching and learning aligned with the new Standards.

In this report, we help teachers understand and prepare for the expected changes in science education described in the Framework and Standards. We examine more closely the dimensions and new emphases in the expectations for K-12 science laid out in these documents and describe how GLBRC educational materials and professional development help teachers meet these new demands.

National Research Council Framework for K-12 Science Education

The National Research Council (NRC) *Framework for K-12 Science Education* (NRC, 2012) identifies expectations for K-12 students of science built around three dimensions: scientific and engineering practices, crosscutting concepts and disciplinary core ideas. The scientific and engineering practices define components of scientific inquiry and engineering design that mirror the practices of scientists and engineers. The crosscutting concepts are broadly applicable in many scientific disciplines. Finally, the disciplinary core ideas have explanatory power in the physical, life, earth, and space sciences as well as engineering and technology.

The *Next Generation Science Standards* are scheduled for release early in 2013, and are based on the Framework. The Standards will define what students in different grade levels should be able to do, and are designed to integrate the components of the Framework. Each Standard describes a practice and crosscutting concept that students should use when explaining a disciplinary core idea.

The following is an example of a middle school standard from the first public draft of the *Next Generation Science Standards.* The scientific practice is highlighted in yellow, the crosscutting concept in green, and the disciplinary core idea in turquoise:

Use evidence to support an explanation that matter is conserved when molecules from food react with oxygen in the environment and cycle repeatedly between living and non-living components of ecosystem.

New Demands Placed on Teachers by the Framework

Perhaps the biggest change described in the Framework is the **emphasis on scientific and engineering practices,** such as constructing explanations and designing solutions. First, engineering practices have not previously been elevated to the level of the scientific practices. *The Benchmarks for Science Literacy* (AAAS, 1993, 2009) described ways in which humans have used technology to control their world during pursuits such as agriculture and energy use. However, students were not expected to design solutions to engineering problems. In addition, the inclusion of science and engineering practices in each standard gives the practices a much more prominent place in the Standards document. The implication is that the teaching of the practices and content cannot be compartmentalized. Rather the expectation is that, at least in part, students use scientific and engineering practices to make sense of the disciplinary core ideas.

The inclusion of seven crosscutting concepts in the Standards is another new feature. These concepts can act as "an organizational framework" (NRC, 2012, p. 83) that applies to many disciplines. They include cause and effect, structure and function, and matter and energy conservation. *The Benchmarks for Science Literacy* described common themes similar to the crosscutting concepts as useful ways of approaching many disciplines. However, their connection to specific disciplinary ideas was not delineated. Building the crosscutting concepts into multiple topics within the curricula requires a deep and coherent understanding of the content rather than a view of the content as a combination of individual stories.

The disciplinary core ideas most closely resemble the content in previous national documents (AAAS, 1993, 2009; NRC, 1996). Interdependent relationships in ecosystems, forces and motion, and plate tectonics are examples. However, the new Framework emphasizes covering fewer key ideas and including those of societal concern, most notably global climate change.

The effect of developing Standards by integrating scientific or engineering practices and crosscutting concepts with disciplinary core ideas is to define a deeper, more powerful understanding as the goal for students' learning. Not only do students need to understand major concepts, but they also have to connect those ideas to supporting evidence. For example, rather than describing or explaining that "the atoms and molecules on the earth cycle among the living and nonliving components of the biosphere" (*National Science Education Standards,* NRC, 1996), they now need to "use evidence to support an explanation" that this is the case. Students also need to include the crosscutting concepts in justifications of their explanations. In this way, the practices and the crosscutting concepts can help students connect ideas, hopefully combating the tendency to learn science as a disparate collection of ideas and facts.

Unfortunately, very few curricula support teachers in integrating these different facets of science (see for example, Project 2061 Textbook Analyses). The scientific method is often relegated to a single introductory chapter or sprinkled haphazardly throughout. Engineering design is often not included. Crosscutting concepts, if included, are treated as ideas comparable to the rest of the content rather than as unifying approaches that can be used in multiple content domains.

GLBRC Research Activities Model the Dimensions of the Framework

GLBRC research epitomizes the intersection of science and engineering described in the *Framework for K-12 Science Education*. The overall goal of Great Lakes Bioenergy Research Center (GLBRC) research is to develop and implement sustainable bioenergy technologies. This means: (1) studying biofuel crops in order to optimize production of useful cellulosic biomass, (2) finding efficient ways to process plant material in order to extract useable sugar, (3) improving methods of converting those sugars into ethanol using microbial enzymes and chemicals, and (4) studying the environmental effects of growing biofuel crops in order to identify sustainable agricultural practices.

GLBRC researchers use the whole array of science and engineering practices identified in the Framework. Some GLBRC research leads to the generation of new information, such as an understanding of how newly discovered microbes break down plant matter. Some research yields new designs that represent "the best solution under the given constraints and criteria" (NRC, 2012). For example, researchers have developed equipment to efficiently treat plant material with ammonia so that nearly all, rather than about 30%, of the sugar is available for fermentation into ethanol.

The crosscutting concepts of energy and matter conservation are at the heart of GLBRC research. The key to understanding carbon footprints is the concept that matter, in particular carbon, is conserved. After combustion, carbon in fossil fuels and biofuels ends up in atmospheric carbon dioxide. However, the carbon in biofuels also came from the atmosphere and does not represent transfer from a different carbon pool. Conservation of matter is also important for considering how to grow biofuel crops sustainably. The crops require water, as well as nutrients such as nitrogen, potassium, and phosphate. How much of each do they need? Where will they come from? How can we maximize how much of each stays in the system? The idea of energy conservation leads to energy accounting. In energy accounting, the energy demands of growing biofuels crops and producing usable biofuels are weighed against the energy yields of biofuels.

GLBRC researchers come from and use the core ideas from many disciplines including the physical, life, and earth sciences, applied sciences and engineering. They apply chemists,' biochemists' and engineers' knowledge of matter and energy to study the chemical reactions involved in converting plant sugars to biofuels. They use biologists' and biochemists' knowledge of plant molecular structure and genetics to improve biomass by increasing useful hydrocarbons and developing strategies to more easily degrade cell walls. They combine biologists' and earth scientists' knowledge of earth systems and ecosystems to optimize biomass yields from crops while minimizing environmental costs.

GLBRC Classroom Materials and Professional Development Support Teachers' Implementation of the Framework

The GLBRC has funded two sets of curriculum materials that support the goals defined in *The Framework for K-12 Science Education.* GLBRC Education and Outreach classroom materials use the rich problems that form the basis of the Center's research to create authentic opportunities for students to work toward the goals defined in the Framework. The ultimate goal of the *Carbon TIME* curriculum materials is to contribute to an informed citizenry who can understand the reasons for and the work of the GLBRC, as well as use scientific information in decision making. Examples of these two sets of materials and their connections to the dimensions of the Framework are described below.

Plant biomass contains large amounts of cellulose, which stores simple sugars. Thus, plant material must be processed before the sugars it contains can be released and fermented into ethanol. To develop new approaches to plant deconstruction, GLBRC researchers are exploring how newly discovered microbes from unusual environments break down cellulose. In the GLBRC's *Bioprospecting* classroom materials, students **design and perform similar investigations** by growing and isolating microbes (from leaf mold, termites, etc.) and testing their enzymatic activity by looking at their ability to grow on cellulose-rich growth media. Students then **analyze and interpret data** to uncover **patterns** of where cellulose-degrading microbes are most likely to be found in the environment.

As part of the quest to sustainably grow biofuels crops, GLBRC researchers are investigating the benefits of growing perennial biofuels crops such as switchgrass. These include an increase in local insect diversity, which can reduce the amount of pesticides needed in other crops grown nearby, increase pollinations rates, and increase weed seed predation. Students using the GLBRC curriculum materials, *Field investigations of bug biodiversity and ecosystem benefit*s, **ask questions about and investigate** insect **diversity** in schoolyard biofuel plots, agricultural fields, existing natural communities, or even potted plants. Students can study different cross sections of the insect community by choosing from a suite of six field-sampling methods. These investigations allow students to uncover **patterns** of plant and insect diversity and develop **explanations for the mechanisms** by which insect communities affect ecosystem benefits such as pollination and predation.

GLBRC engineers design and test engines to efficiently burn different biofuels generated in the fermentation labs. Understanding combustion efficiency presupposes an understanding of matter and energy transformations. Students using the *Carbon TIME* unit, *Systems and Scale,* apply these **crosscutting concepts** to the combustion of ethanol. They investigate changes in mass and use soda water to detect changes in CO_2 concentrations. Students **use molecular models** and chemical equations to answer the "three questions" that frame each *Carbon TIME* unit: What happens to the matter? Where do the carbon atoms go? What happens to the energy?

Energy-rich plant oils used to generate biodiesel are restricted to seeds, such as soybeans, which are used for food and animal feed. GLBRC researchers are developing bioenergy crop plants that have oil in their vegetative tissues such as leaves, stems, and tubers, increasing the energy content of these crops and allowing for the production of biodiesel. In the *Carbon TIME* unit on *Plants,* students **investigate** the same triad of carbon transforming processes that affect the amounts of oils present in plant matter: photosynthesis, biosynthesis, and cellular respiration. Students plant radish seeds in vermiculite to study the increase of biomass without soil. Additional investigations include use of soda lime or Bromothymol blue to study CO_2 production and use by *Elodea* in the light and dark and study of types of different macromolecules found in different types and parts of plants using food nutrition labels.

GLBRC professional development activities for educators provide opportunities to work with GLBRC classroom materials and researchers to see firsthand how they reflect the science described in the Framework*.* The Bioenergy Institute for Educators is a one-week event where educators explore core areas of GLBRC research and experience and adapt the inquiry-based education materials. The Research Experience for Teachers program allows teachers to spend six weeks on the University of Wisconsin-Madison campus working with a mentor scientist conducting bioenergy or educational research and developing a related classroom activity.

New Opportunities

While the *Framework for K-12 Science Education* places new demands on teachers of science, it also creates new opportunities by necessitating the development of active science classrooms that reflect the power of science and engineering. Students must go beyond learning a collection of unconnected ideas to understanding how many areas of science use a few **crosscutting concepts** and generate new ideas and designs using similar **scientific and engineering practices**. These skills and knowledge mean that students are able to appreciate, understand, emulate, and even participate in cutting-edge research. The GLBRC's work is one example of ongoing research that directly impacts our way of life. GLBRC classroom materials, *Carbon TIME* curriculum, and professional development activities support teachers' efforts to bring this science directly to students.

For more information, please visit the GLBRC website, or contact GLBRC education and outreach staff at (608) 890-2828, education@glbrc.wisc.edu.