PROJECT-BASED SCIENCE

Engaging students in three-dimensional learning

Joe Krajcik

The biggest shift in the *Next Generation Science Standards* (NGSS Lead States 2013) is the focus on students making sense of phenomena or designing solutions to problems by using *three-dimensional learning* (NRC 2014). The three dimensions are disciplinary core ideas, scientific and engineering practices, and crosscutting concepts. Three-dimensional learning is the first criterion described in the EQuIP rubric used for judging if lessons and materials align with the *NGSS* (Achieve and NSTA 2014).

The *NGSS* include student performance expectations that incorporate all three dimensions. Figure 1 (p. 26) shows two examples of performance expectations. The performance expectations describe what students should be assessed on at the end of instruction but do not describe how to support students in realizing them. Three-dimensional learning challenges educators to rethink the inquiry approach to teaching science content.

Project-based science

What instructional approach better aligns with three-dimensional learning? Project-based science (PBS) encompasses driving questions, investigations, and collaboration. First, at the core of PBS, is asking (Practice 1) and investigating real-world questions, a concept that dates back to John Dewey (1938), who promoted teaching about topics relevant to students' lives.

The various genres of PBS share other fundamental features as well (Krajcik and Czerniak 2013). Second, to answer the meaningful questions raised in PBS, students plan and perform investigations, consistent with the *NGSS* Science and Engineering Practice 3, "planning and carrying out investigations." As part of the investigations, students analyze and interpret data (Practice 4) and support their claims with evidence and reasoning to explain phenomena and design solutions (Practice 6). Third, students, teachers, and members of society collaborate on the question or problem to find solutions and make sense of the data (Practice 8: obtaining, evaluating, and communicating information). Fourth, students develop a series of artifacts or products that address the question or problem, often by constructing models (Practice 2) and developing explanations (Practice 6). Fifth, as students engage in investigations or construct artifacts, they use various technological tools when needed to obtain, evaluate, and communicate information (Practice 8). Figure 2 (p. 26) presents a summary of these features. Let's look at them more closely.

Solving relevant questions

I have referred to the meaningful questions students explore in PBS as *driving questions.* An example is "Why do some things stick together and other things don't?" (Mayer, Damelin, and Krajcik 2013), which focuses on electrical interactions, helping students build understanding toward two performance expectations: HS-PS2-4 and HS-PS2-5 (Figure 1).

Developing understanding of electrical interactions helps students explain and predict various cross-disciplinary phenomena, including phase changes, chemical reactions, protein structure, and the energy in hurricanes. Being able to explain and predict these phenomena would involve students using disciplinary core ideas from PS1.A: Structure and Properties of Matter, PS3.A: Definitions of Energy, and PS3.C: Relationship Between Energy and Forces along with crosscutting concepts such as cause and effect, patterns (recognizing that macroscopic patterns are related to the microscopic and atomic level structure of materials) and structure and function; and scientific practices such as engaging in argument from evidence, constructing explanations, and analyzing and interpreting data.

In PBS, it's important to engage students in the phenomena they need to explain. In the case of "Why do some things stick together and other things don't?" students should experience phenomena like socks clinging to other clothes as they're taken out of the dryer or of plastic bags sticking together.

The driving question needs to be broad enough to allow students to explore *subquestions*. For example, if a teacher starts a project with the driving question, "How clean is our water?" students might explore such subquestions as "Is our water safe to swim in?" "Is our water safe to drink?" and "What can live in our water?" Asking questions is a central scientific practice identified in the *NGSS*.

FIGURE 1

Example Performance Expectations in the interactions curriculum.

Building toward Performance Expectations

- HS-PS2-4. Use mathematical representations of Newton's law of gravitation and Coulomb's law to describe and predict the gravitational and electrostatic forces between objects.
- HS-PS3-5. Develop and use a model of two objects interacting through electric or magnetic fields to illustrate the forces between objects and the changes in energy of the objects due to the interaction.

*Ideas in color are not developed in this project.

FIGURE 2

Features of project-based science.

- Seeking solutions relevant to learners' lives
- Planning and performing investigations to answer their questions
- Collaborating with other students, teachers, and members of society
- Producing artifacts that respond to their questions
- When appropriate, using technology tools

Planning and carrying out investigations

The driving questions set the stage for students to use various scientific practices like planning and carrying out investigations (Practice 3) and developing and using models (Practice 2) to make sense of phenomena and justifying one's position using evidence (Practice 7). For the question "Why do some things stick together and other things don't?" students might need to explore the energy it takes to change a substance from a liquid to a gas. Why does water boil at 100°C and carbon dioxide far below the freezing point of water? Students might then use technology to further examine the question. For example, they might use a computer simulation to visualize, observe, and manipulate patterns of what occurs at the molecular level when these two substances boil. Concord Consortium's Next Generation Molecular Workbench offers free simulations to explore these ideas (see "On the web").

In PBS, students investigate a question over an extended period of time rather than doing short-term activities that are out of context. Driving questions such as "Why do some things stick together and other things don't?" and "How clean is our water?" provide learners with opportunities to design investigations, make sense of data, and build models that explain.

Collaborating to find solutions

PBS involves students, teachers, and members of society collaborating to investigate questions. Collaboration is central to the doing of science and is essential to finding solutions to the most challenging science and engineering questions and problems. Seldom in science and engineering does a single individual make a major breakthrough. Diverse and collective expertise, creativity, and ideas from various individuals are needed to solve complex problems. Often collaboration engages students in arguing from evidence as students try to make sense of phenomena (Practice 7).

PBS creates a classroom environment that becomes a community of learners in which students collaborate with others and with their teacher to make sense of phenomena and design workable solutions to problems. Communication technologies allow learners to communicate with knowledgeable individuals, to take advantage of more extensive resources, and to share data and explanations. For instance, students in the water quality project could share data with other students in the same watershed to see if the water quality in the different locations varies.

Use of technology tools

In PBS, students can use digital tools to engage in various scientific practices. Technology tools can support students in carrying out investigations (Practice 3) by collecting real-time data and accessing data on the web. They can help students obtain and communicate information by expanding interaction and collaboration with others via networks (Practice 8). Technology tools can support students in analyzing data and engaging in mathematical thinking by employing graphing and visualization tools (Practice 5). Technology allows students to create multimedia artifacts with such tools as drawing software, word processing, videos, and digital images. These capabilities make information more accessible, both physically (providing easy access to information) and intellectually (helping students incorporate new information into their understanding).

Technology tools let students actively construct knowledge, using temperature and pH probes, for example, to gather data about the local watershed. Students can collect water quality data throughout a watershed by connecting digitally to students at other schools nearby, and they can use Google Maps to visualize the watershed and track how the water changes. They can also digitally photograph the various organisms that live in the steam as evidence of the water quality. In the project in which students investigate why things stick together, students can explore interactive simulations of electrical fields that help them build understandings of why charges attract.

Creation of artifacts

Artifacts can be used to help assess student understanding. This aligns with recommendations made by the NRC committee on *Developing assessments for the Next Generation Science Standards* (2014). I refer to products that students construct in project environments as artifacts because they are similar to historical artifacts, serving as records of a culture as well as records of students' engagement in science.

Artifacts serve as tangible products that can be shared and critiqued. Creating them provides opportunities for students to engage in scientific practices such as constructing models, engaging in argument from evidence, and communicating scientific information and ideas about a phenomenon. For example, constructing a model to show why socks cling to clothing when removed from the dryer demonstrates students' understanding of an everyday experience. The creation and sharing of artifacts approximates the activities of scientists, who frequently communicate their ideas by sharing what they learn with colleagues through text or oral presentations (Practice 8). Presenting an artifact for classmates to critique lets students communicate with others about their work and receive helpful comments. Learners can reflect on their work, present evidence and argue for their ideas, and revise their artifacts, if needed. For instance, students in the water quality project can develop models to propose causal mechanisms of what factors influence the quality of their water and receive helpful comments from others in their class. When students construct models, a critical scientific practice, the model is a representation of what they know.

Conclusion

Project-based science is an exciting way to teach science that aligns with the *NGSS*. By focusing on core ideas along with practices and crosscutting concepts, classrooms become learning environments where teachers and students engage in science by designing and carrying out investigations and making and debating claims supported by evidence and reasoning. A project-based approach allows learners to engage in making sense of phenomena or designing solutions to problems by the three dimensions working together. As students seek solutions to their questions and problems, they explore the meaning of disciplinary core ideas, take part in scientific practices, and use crosscutting concepts, thereby building understanding toward meeting performance expectations. In the explorations of real-world questions, the content cannot be separated from the doing of the science. Because of its approach, PBS supports all students engaging in science as they become involved in personally relevant projects. Science is for all students, not just those embarking on scientific careers. To make important decisions regarding their own lives and society, all learners need to have a useable knowledge of science so they may make informed decisions throughout their lives on issues of individual scientific and community importance. ■

Joe Krajcik (krajcik@msu.edu) *is a professor of science education at Michigan State University and director of the Institute for Collaborative Research for Education, Assessment, and Teaching Environment for Science, Technology, Engineering, and Mathematics (CREATE for STEM).*

On the web

Concord Consortium's Next Generation Molecular Workbench: *http://mw.concord.org/nextgen/*

References

Achieve and National Science Teachers Association. 2014. EQuIP rubric for lessons and units: Science. *http://bit.ly/1t6DJ3m*

Dewey, J. 1938. *The school and society. Dewey on education.* New York: Teachers College Press.

Krajcik, J. S., and C. Czerniak. 2013. *Teaching science in elementary and middle school classrooms: A project-based approach*, 4th edition. London: Routledge.

Krajcik, J. S., and N. Shin. 2014. Project-based learning. In *The Cambridge handbook of the learning sciences,* 2nd edition, ed. R. K. Sawyer, chapter 14. New York: Cambridge University Press.

Mayer, K., D. Damelin, J. S. Krajcik. 2013. Linked in: Using modeling as a link to other scientific practices, disciplinary core ideas, and crosscutting concepts. *The Science Teacher* 80 (6): 57–62.

National Research Council (NRC). 2014. *Developing assessments for the* Next Generation Science Standards. Washington, DC: National Academies Press.

NGSS Lead States. 2013. *Next Generation Science Standards: For states, by states.* Washington, DC: National Academies Press.