Planning for Success

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How to design and implement project-based science activities

I nquiry, a prominent feature of the National Science Education Standards, is the instructional keystone that connects doing and learning science (NRC 2000). Because it is integral to the Standards, inquiry is also emphasized in science curriculum standards adopted at state and local levels. Inquiry-based classes allow for scientific learning through investigation, which develops the abilities students need to design and conduct scientific studies (NRC 2000). Project-based science (PBS) instruction addresses these criteria for inquiry. This article highlights ways to design and incorporate substantive PBS activities in the classroom.

Why PBS instruction?

The emphasis on inquiry in science instruction is not new. Dewey (1933) proposed inquiry-based projects as a means of instruction in the early 20th century. Reform efforts in the 1960s focused on inquiry as well (Bruner 1962). Although the reforms showed promise in terms of student motivation and achievement (Bredderman 1983), they were not widely adopted and only sporadically successful.

While PBS had its roots in these reforms, it emerged as a result of two fairly recent advances in learning theory. First, learning is a social process. It takes place in the context of culture, community, and past experiences and is enhanced when students work together on challenging tasks (Vygotsky 1986). Second, knowledge is constructed as students actively engage with their world and struggle to understand concepts (Driver et al. 1994). Students enter our classrooms with well-developed, but often inaccurate, notions of how the world works. In order to challenge preconceived notions, classroom activities need to be both hands-on and minds-on (Driver et al. 1994).

PBS differs from other inquiry methods in that it emphasizes cooperative learning and student construction of artifacts that demonstrate what is being learned. Among the many methods proposed to address reform, PBS uniquely addresses the calls for greater inquiry and depth, while also addressing current views of cognition and learning.

In the current atmosphere of high-stakes testing, addressing core content is particularly critical. PBS investigations result in a deeper understanding of the underlying core concepts (Baumgartner and Zabin 2008; Boaler 2002), but they also take more time than traditional instruction. Boaler, in a three-year longitudinal study of British math students, found that even though students taught in a project-based environment covered less material, they performed significantly better on national assessments than their peers taught in a traditional environment (Boaler 2002). Baumgartner and Zabin (2008) found students in PBS classes learned science concepts more deeply. Projects that address tested standards in deep ways are likely to satisfy administrators, engage and motivate students, and as a result, multiply teacher benefits.

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The improved student understanding also results in improved student achievement (Boaler 2002; Baumgartner and Zabin 2008; Cognition and Technology Group at Vanderbilt 1992).

What is PBS?

We define PBS as an instructional method that uses complex, authentic questions to engage students in long-term, in-depth collaborative learning, resulting in a carefully designed product or artifact. This definition permits a broad range of teacher control and curricular focus. Project-based units share key characteristics. The units

- are central to the curriculum and address a significant number of required concepts;
- relate to real-world problems;
- allow students to design and conduct their own investigations;
- are designed so that students work autonomously in groups; and
- are centered on answering a driving question that is sustainable over weeks or months (Thomas and Mergendoller 2000; Krajcik, Czerniak, and Berger 2002).

Planning a project

Good planning assures that key characteristics of PBS are embedded in the unit design. In our experience, failure to address one or more key characteristics of PBS reduces the impact of the project.

The framework in the following sections can be used to guide the design of projects. Once a decision has been made on the curricular focus of the project, the next step is to craft a driving question that is open-ended, relates to real-world problems, motivates students to grapple with core curricular concepts in a meaningful way, and sustains interest over the project period.

Design of a driving question

A good driving question—central to a PBS curriculum—allows students to explore areas of interest to them while requiring them to develop core skills and knowledge. It is important to have a project that addresses enough core concepts that multiple weeks are required to give adequate attention to each concept and produce deep understanding. A classic science fair project that answers the question, "Which antibiotic kills the most bacteria?" could be transformed into a project-based unit by asking, "How are emerging diseases transforming healthcare?" Refined driving questions transform simple questions with predictable answers into complex questions about issues that are multifaceted and relevant to students. Driving questions may be revised multiple times to ensure they meet the established parameters, connect to teaching standards, and produce the desired learning outcomes.

Good driving questions are also meaningful to students. For example, water-quality projects are popular in many areas. While water-quality monitoring has inherent value, it becomes more meaningful when students contribute data to a larger group or contribute to the solution of a problem. (**Editor's note:** See "Making Science Relevant" [Eick et al.] in the April/May 2008 issue of *The Science Teacher*.) (**Note:** PathFinder Science [see "On the web"] offers multiple projects through which students can contribute to national databases.)

Designing the final assessment

Once there is a good driving question, the teacher should consider

- what artifacts students will produce as a result of answering the driving question (e.g., a poster session, paper, website, video, or letter);
- who will be the audience for the final project (e.g., fellow students, parents, community activists, or city government); and
- how the product will be graded.

Meaningful projects can be created by having students generate products that will be used by a larger audience. For example, a study of biodiversity in city parks will have more impact if it results in a plan for reducing nonnative species and is presented to local stakeholders and decision makers. The product can also be tailored to meet different ability levels of students within and among classes.

Research shows that breaking down the final product into manageable pieces that are graded and revised before the final version results in better final products (Petrosino 1998; Barron et al. 1998). In our classes, we usually design a detailed rubric to guide students as they progress through the project activities, as well as to assess the final product. This also forces us to think through all project components, clearly define our expectations for student work, and give formative feedback so students can revise their work and improve the quality of the final product. (**Note:** Rubistar [see "On the web"] is an excellent tool for developing rubrics.)

We typically give our students a rubric that has three performance criteria for each assignment. The assignment

- meets expectations and is on time,
- needs revision, or
- needs a conference and is late.

Students are required to bring work up to the "meets expectations" level before moving on to the next steps in their project.

We sometimes use self-assessment to help students internalize expectations and develop critical-thinking skills. We also recommend that the grading include both individual and group components. This makes individual students accountable and encourages the group to work together. For example, each person in the group may be responsible for collecting three data sets, but the group is responsible for analyzing the data as a whole.

Planning the activities

Some proponents of PBS advocate student involvement in all aspects of the unit (i.e., design, implementation, and assessment). We have seen varying degrees of student involvement and teacher control in successful projects. Teachers in project-based classrooms facilitate, guide, and manage the process of learning in ways that are consistent with their management styles. The key is to keep project activities and outcomes open-ended enough for students to experience some degree of autonomy.

Project activities must build students' ability to work in a project-based environment while, simultaneously, addressing core content. Teachers need to scaffold activities carefully to provide a bridge for students as they transition from traditional environments to project-based classrooms. We have found that students respond best to a purposeful transition from structured to guided to open inquiry.

For example, in addressing the driving question, "How do you design an earthquake-proof building?" students may begin with a well-defined research assignment investigating earthquakes. This would be followed with a class session in which students present their findings and discuss factors that cause structural damage during earthquakes. Small groups would then explore different materials, shapes, and structural-design principles in guided inquiries. Finally, students might work as competing architectural firms to design and build a new city hall that meets building codes for a defined site in an earthquake-prone area. The building is then tested on an earthquake simulator (see "On the web"). Students write a final report and present it to a mock city council or, if appropriate, the real city council.

Tips for success

Projects should start small, working from mini-projects to larger scale projects. Smaller projects are easier to manage and fit into tightly packed curricula. Piloting a smaller version allows the teacher to identify and fix major problems before committing to a longer time frame and greater investment of resources. We have found that it generally takes three project implementation cycles to work out most of the kinks. It helps to keep a reflective journal to record the progress through the project and note the successful elements while revising things that did not work well.

When planning and implementing the project, collaboration with fellow teachers, community members, parents, and administrators, for example, provides moral

support, reduces the individual workload of the teacher (Thomas and Mergendoller 2000), and connects students with stakeholders in an authentic way.

Thomas and Mergendoller (2000) also found that successful PBS teachers effectively use technological resources and establish a classroom culture that stresses student self-management. Furthermore, the following time-management principles facilitate projects:

◆ Adding 20% more time than anticipated to account for unexpected developments
◆ Coordinating major deadlines between courses and within courses
◆ Introducing alternative instruction when student projects needed direction
◆ Encouraging a quick start by having students think about the project well before implementation

Keeping a selection of student products from year to year provides future students with examples of quality work and guides project activities.

Reaping the benefits

In our experience teaching in and observing project-based classrooms, well-designed and implemented projects offer significant rewards for both students and teachers. Students learn concepts more deeply and are able to use the knowledge gained in authentic applications. PBS also motivates students who do not perform well in traditional settings (Wurdinger et al. 2007; Tretten and Zachariou 1995). Motivating students to produce high-quality work is deeply rewarding for teachers and well worth the additional effort it takes to transition from traditional instruction to PBS. ■

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On the web 🖱

(**Note:** all resources listed are freely available.)
Earthquake simulator: *http://school.discoveryeducation.com/lesson plans/programs/earthquakeproof*
PathFinder Science: *http://pathfinderscience.net*
PBS resources:
    Edutopia: *www.edutopia.org/project-learning*
    The Buck Institute for Education: *www.bie.org/index.php/site/PBL/web_resources*
    Northwest Regional Educational Laboratory: *www.nwrel.org/request/2002aug*
    Rubistar: *www.rubistar.4teachers.org*
    Student projects: *www.ci.txstate.edu/faculty/dickinson/pbi/sp_previous.htm*

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