Assessment for Learning

Using formative assessment in problem- and project-based learning

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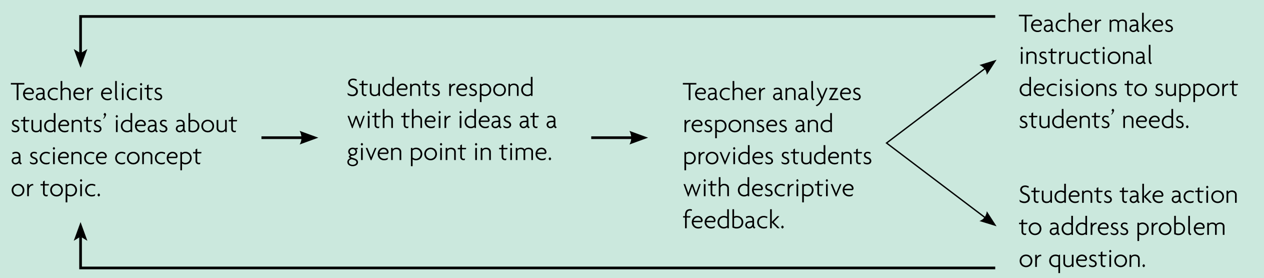
Problem-based learning (PBL) and project-based science (PBS) are increasingly popular approaches for engaging students in scientific inquiry. Though these approaches have different origins, they are similar in practice. Both PBL and PBS are centered on authentic problems or meaningful questions that serve to organize learning. Both are student-oriented and experiential—students solve a problem by practically applying science concepts (Hmelo-Silver 2004).

FIGURE 1

A cyclic model of formative assessment.

Adapted from Sadler (1989) and Otero and Nathan (2008).



During PBL and PBS, students conduct research on a science topic and gather relevant information to devise a solution or create a product (Barrows 1996; Marx et al. 1997). They develop knowledge and understanding of scientific ideas by planning investigations, gathering evidence, using previous research, proposing possible explanations or hypotheses, and communicating their findings—hallmarks of authentic science inquiry (NRC 2000).

Due to the student-centered nature of PBL and PBS, it is easy for teachers *not* to provide students with adequate feedback or enough support to promote critical thinking. However, research has shown that PBL and PBS are most effective when appropriate learning goals are defined, embedded supports and feedback are part of instruction, and there are multiple opportunities for self-assessment and revision (Barron et al. 1998).

Instructional supports for student learning come in many forms. In this article, we describe how formative assessment can be used to support PBL and PBS to maximize student achievement.

Formative assessment: A primer

Formative assessment is assessment *for* learning, not assessment *of* learning, which is common in end-of-unit tests (Black and Wiliam 1998). Formative assessment is any pedagogical strategy used to elicit student understanding at any point during instruction. For formative assessment to be most successful, teachers must use the outcomes to make instructional decisions and provide feedback that directs learning. In fact, formative assessment should be a cyclical activity that occurs several times in a PBL or PBS unit (Figure 1).

Embedding formative assessment

Beginning with the end in mind

Planning a PBL or PBS unit can be daunting. However, through formative assessment, a teacher can more readily identify students' interests, which can be used as the starting point for planning instruction. Teachers can begin by identifying a general focus area (e.g., the rock cycle, genetic engineering, space exploration) that aligns with state content standards and use it to probe students' prior knowledge and personal interests.

Several common pedagogical strategies can be used to formatively assess students' knowledge and interests. For instance, a KWL chart—What I *K*now, What I *W*ant to Know, What I *L*earned—is often modified for the project-based classroom. In this version, students answer a set of need-to-know questions at the beginning of a project (Chin and Chia 2008), such as

- What do I know about this problem?
- What do I need to know to provide a solution? and
- How can I find out what I need to know?

These questions provide students with necessary direction and provide the teacher with valuable insights

FIGURE 2

Example T-chart.

This chart is used to elicit students' prior knowledge and interests in science topics.

Topic: Stars and their life cycle	
What I know about stars and their life cycle	**Questions I have about stars**

FIGURE 3

Background knowledge probe example.

It is estimated that 99% of the species that have lived on Earth are extinct (Cowen 2000). However, only a small number of these organisms have been found as fossils. Why are there so few fossils from all the plants and animals that have lived on Earth? Read the statements below and circle the best answer.

A. Most dead plants and animals decompose slowly. For fossils to form, dead organisms must decompose rapidly.

B. Dead plants and animals must be made of special materials to form fossils.

C. Fossils are made from the bones of dead animals. Therefore, animals that have bones can produce fossils; other animals (and plants) cannot.

D. Fossils form when conditions in the environment are right. Because the best conditions for producing fossils are rare, the number of fossils produced from dead organisms is small.

Explain why you chose your answer. Describe the reasoning you used to come up with this answer.

FIGURE 4

Example formative assessment prompts.

These prompts help students metacognitively reflect on the problems or driving questions central to problem-based learning (PBL) and project-based science (PBS).

Writing prompts

Which gases contribute to global warming? Where do they come from or how are they made? What can be done to reduce the emission of these gases?

What are the environmental conditions on Mars? Given these conditions, does extraterrestrial life seem likely or unlikely? Explain.

Journal entries

Each day, write in your journal what you have learned about the science topics related to the problem statement. Consider how the science you have learned will determine how you approach the project or problem.

Minute paper

In the last five minutes of class, explain what you have learned about comets and asteroids. What questions do you still have about comets and asteroids? How do comets and asteroids relate to the problem statement?

about their prior knowledge, their alternative conceptions about science content, and potential problem areas during learning.

We have also found that the Think-Pair-Share strategy works well. This strategy requires students to individually consider a concept or topic and write what they know about it, then share their ideas with a peer before engaging in a whole-class discussion.

A whole-class discussion using a T-chart (Figure 2, p. 35) is also effective. On the board, the teacher writes down what students know and the questions they have about a topic. Then—using the information gathered from this discussion—he or she plans a unit centered on a problem or question that is tailored to both students' interests and learning needs. For example, we used a T-chart to help identify students' questions about stars and their life cycles (Figure 2). We found that students had limited background knowledge about the Sun and constellations and wanted to know more about the composition of stars and how they form. Based on this discussion, we formulated a problem-based unit on the life cycle of stars.

Formative assessment is assessment for learning, not assessment of learning.

Ultimately, teachers should use outcomes of an opening activity to make instructional decisions that will support and engage students during PBL and PBS. The type of opening activity or strategy used is left to the teacher's discretion.

During the learning

When designing a PBL or PBS curriculum, it is often useful to divide the unit into smaller parts based on the science concepts being covered. Doing so makes it easier to plan activities that target those specific concepts, and allows teachers to probe students' understanding.

Students' prior knowledge and ideas about the natural world greatly influence their learning, and their conceptions can be difficult to change (Scott, Asoko, and Leach 2007). Therefore, it is just as important to understand the knowledge and conceptions students bring with them to the science classroom as it is to assess their learning after instruction. By probing students'

FIGURE 5

Addressing misconceptions.

The following student misconceptions relate to the Andromeda (M31) Galaxy.

Your task: Determine if you can you see the Andromeda Galaxy from Earth.

To gather information on this topic, explore the following websites. Based on the information collected, respond to the writing prompt below.

- *www.skyhound.com/sh/archive/oct/M_31.html*
- *www.smokymtnastro.org/Seasons/Winter/Winter%20Sky%20Tour%20Andromeda.htm*
- *http://astronomy2009.nasa.gov/observe_oct.htm*
- *www.solstation.com/x-objects/andromeda.htm*
- *www.sciencedaily.com/articles/a/andromeda_galaxy.htm*

In your earlier research, many of you claimed that other galaxies were not visible from Earth. Based on this new information, have your ideas changed? Explain.

FIGURE 6

Student progress report.

Topic or question being investigated: ______________________
Describe what you have learned about the topic above from the activities and research you have conducted.
List your sources of information.
How have your ideas changed as a result of your research? What were your ideas before? What are your ideas now?
What questions do you still have about the topic or question?

conceptions before and during instruction, teachers are better able to help students confront their alternative conceptions of science.

We have found formative assessment probes to be useful in targeting students' ideas about specific science concepts. Publications such as the *Uncovering Student Ideas in Science* series (Keeley, Eberle, and Farrin 2005) provide ready-made formative assessment probes on a wide variety of topics. Or, teachers can formulate their own probes based on common student misconceptions. For instance, during a PBL unit on evolution, a teacher may want to probe students' understanding of how fossils are formed to address misconceptions about the fossil record (Figure 3). These probes can be used to gather information from individual students about their learning or as a prompt for a small-group or whole-class discussion.

In our research on PBS and PBL, we found that students often lose sight of the purpose of learning activities as a unit progresses. Regular reflection on the problem statement or driving question can help. Teachers can encourage students to metacognitively reflect using one of many strategies, such as writing prompts, journal entries, minute papers, or open class discussions (Figure 4). During metacognitive reflection, students think about

FIGURE 7

Sample rubric.

Criteria	Advanced (16–20 pts.)	Proficient (11–15 pts.)	Basic (6–10 pts.)	Unsatisfactory (1–5 pts.)
Position	Position is clearly stated and consistently maintained. Clearly stated references relate to hypothesis.	Position is clearly stated and mostly maintained throughout letter. Some references made to hypothesis.	Position is not clearly stated or maintained throughout letter. Few references made to hypothesis.	Position is neither clearly stated nor maintained throughout letter. It is unclear which hypothesis was chosen.
Scientific concepts used to defend position	Uses science concepts to clearly and fully explain the position. Provides at least three reasons why chosen hypothesis is most plausible.	Uses science concepts to explain position, but not completely. Provides two to three reasons why chosen hypothesis is plausible.	Does not always use science concepts to fully explain position. Provides fewer than three reasons for why chosen hypothesis is plausible.	Completely lacking the use of science concepts to support position. Provides one or fewer reasons for why hypothesis is plausible.
Scientific concepts used to reject other hypotheses	Uses science concepts to clearly and fully explain one reason why the two rejected hypotheses are less plausible.	Uses science concepts to explain one reason why the two rejected hypotheses are less plausible. These reasons are not fully elaborated.	Does not always use science concepts to fully explain one reason why the two rejected hypotheses are less plausible.	Completely lacking science concepts to provide reasons why the two rejected hypotheses are less plausible.
Suggestions for further research	Includes and fully describes at least two suggestions for further research on chosen hypothesis.	Includes but does not fully describe at least two suggestions for further research.	Lacking suggestions for future research or suggestions are not explained.	Completely lacking suggestions for future research and no explanations are provided.
Writing conventions	Correct spelling, grammar, and punctuation are used throughout the letter. Essay is well organized and easy to read.	Minimal spelling, grammar, or punctuation errors. Essay is mostly organized and easy to read.	There are consistent errors in spelling, grammar, or punctuation. Essay contains minimal structure and organization.	Errors in spelling, grammar, or punctuation make reading difficult. Essay lacks structure and organization.

science content they have learned and how it relates to the statement or question at hand. Students' responses reveal the effectiveness of learning activities and identify those areas with which they are struggling.

For formative assessment to be effective, the teacher must take action or make instructional decisions that support students' needs at that time. In our PBL unit on the life cycle of stars, for example, we found that students thought only stars in the Milky Way Galaxy were visible with a regular telescope. To help them confront this misconception, we provided them with additional web-based activities and then followed up with a writing prompt to determine what they had learned (Figure 5, p. 37). After students responded to the prompt, we facilitated a whole-class discussion so they could share their newly formed ideas.

Daily or weekly reports are another good way to hold students accountable and gather formative information about their learning (Figure 6, p. 37). Individually or as a group, students can report the outcomes of investigations and inquiries. This provides valuable insight about students' progress and timely information about learning needs, allowing teachers to make instructional decisions before students get too far off-track.

Close to the end

For students to successfully complete a PBL or PBS unit, they must have a clear understanding of the learning goals and performance standards. Providing a rubric with clearly stated evaluation criteria is a crucial step in helping students achieve their best. Near the end of the unit, teachers should provide time for students to reflect on their work using criteria outlined in the rubric (Figure 7).

Students should be asked to self-assess their work and identify aspects they have done well and those they can improve. They can also act as critics to provide positive comments and constructive feedback for their peers. Based on the self- or peer-assessment, students can then devise a plan of action to improve their work prior to final submission. Peer- and self-assessment does not have to occur at the end of a PBL or PBS unit, but can be done several times within the unit, while students are still learning.

Making formative assessment effective

For formative assessment to be most effective, students need ongoing encouragement to share their thinking. It takes time and support for students to develop rich understandings of science content. Formative assessment is not about evaluating achievement; it is about eliciting what students do or do not understand about a topic. If students think they will be penalized, they will not disclose their confusion about a subject, which, in turn, truncates the formative assessment process.

Teachers should provide feedback to direct students toward the goals of the PBL or PBS unit. This should be positive and specific and focus on students' progress, not judge their capabilities (Brookhart 2008). Feedback gets misguided students back on track, clarifies learning goals for confused students, focuses students who are drowning in information, and probes all students to think more deeply about the problem or driving question. ■

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