Using Formative Assessment to Uncover How Students Think About Science

By Joyce Tugel

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Introduction

> *Firm evidence shows that formative assessment is an essential component of classroom work and that its development can raise standards of achievement. We know of no other way of raising standards for which such a strong prima facie case can be made.*
>
> Paul Black and Dylan Wiliam, *Inside the Black Box* 1998

It has been more than twenty years since Black and Wiliam's "Inside the Black Box" was published in the Phi Delta Kappan. (Black and Wiliam, 1998). The exciting news is that this work continues to grow, and as teachers integrate formative assessment practices into daily activities, schools are realizing that they can substantially increase the rate of student learning (Wiliam, 2018).

Formative assessment is the process of collecting evidence about student thinking to inform instruction and provide feedback to students. It is a keystone to best practices in K–12 education. This is equally true in science classrooms where it is critical to understand how students are absorbing, retaining, and connecting scientific concepts and theories.

This paper offers suggestions for formative assessment techniques that can support comprehension in the science classroom and help students overcome challenges while continuing to enjoy the learning process.

Why Formative Assessment?

An assessment is merely diagnostic if evidence is gathered but not used to inform the teacher and his or her students during the learning process. For an assessment to be considered formative, it must be used to make decisions about next steps, to plan instruction, and to help learners reflect upon their thinking.

Formative assessment is a feedback process that promotes learning and engages the learner. It is frequently described as assessment *for* learning rather than assessment *of* learning. Dylan Wiliam has synthesized five strategies from his decades of experience that he believes are core to successful formative assessment practice in the classroom (Wiliam 2018):

1. **Clarifying, sharing, and understanding learning intentions and criteria for success**
   Students should know what to expect from their classroom experience and understand how their success will be measured.

2. **Engineering effective classroom discussions, activities, and learning tasks that elicit evidence of learning**
   Teachers must develop effective classroom instructional strategies that allow for the measurement of success.

3. **Providing feedback that moves learning forward**
   Teachers work with students and provide them with the information they need to better understand problems and solutions.
4. **Activating learners as instructional resources for one another**
   Getting students involved with each other in discussions and working groups can help improve student learning.
5. **Activating learners as owners of their own learning**
   Self-regulation of learning leads to improved performance.

Page Keeley is well known in the field of science education as a leader and expert in science formative assessment. She began developing formative assessment probes in the early 1990's, and she continues to develop and publish assessment probes (uncoveringstudentideas.org) and formative assessment classroom techniques (Keeley 2015, 2016) for science and mathematics educators.

Keeley's ability to translate theory into concrete practice has been enthusiastically received by classroom teachers, curriculum coordinators, and administrators as a means to transform classrooms across the K–12 continuum. Keeley points out that formative assessment classroom techniques (FACTs) can be used for multiple purposes (Keeley 2016):

- Elicit and Identify Preconceptions
- Engage and Motivate Students
- Activate Thinking and Promote Metacognition
- Provide Stimuli for Discussion
- Initiate Inquiry and Idea Exploration
- Formal Concept Development and Transfer
- Improve Questioning and Quality of Student Responses
- Provide Teacher-to-Student Feedback
- Peer and Self-Assessment
- Reflection

Embedding multiple purposes within the same assessment strategy results in a rich teaching and learning environment.

Formative Assessment and the "New Standards"

The release of the *Framework for K–12 Science Education* (NRC, 2012) and *Next Generation Science Standards* (NGSS Lead States, 2013) has provided an additional layer of complexity and opportunity for science education. The NGSS were developed with the goal of improving science education for ***all*** students. Every NGSS standard has three dimensions, consisting of: disciplinary core ideas, science and engineering practices, and crosscutting concepts.

The integration of content and application reflects how science and engineering are practiced in the real world, and many states have adopted the NGSS as their state standards. For states and districts who have not, the vast majority choose to adapt components of the three dimensions, particularly the core ideas and science & engineering practices.

The implications of working towards the vision of the NGSS are profound. The emphasis is now on making sense of science through exploring and explaining phenomena, and teachers are being asked to shift from some commonly-used teaching approaches to a more learner-centered approach (NRC 2015, p. 11):

IMPLICATIONS OF THE VISION OF THE NGSS

THE TRADITIONAL APPROACH TO TEACHING SCIENCE	THE NGSS APPROACH TO TEACHING SCIENCE
Science education will involve less	Science education will involve more
Rote memorization of facts and terminology	Facts and terminology learned as needed while developing explanations and designing solutions supported by evidence-based arguments and reasoning
The learning of ideas is disconnected from questions about phenomena	Systems thinking and modeling are used to explain phenomena and give context to ideas being presented
Teachers provide information to the whole class	Students conduct investigations, solve problems, and engage in discussions with the guidance of their teacher
Teachers pose questions with only one right answer	Students discuss open-ended questions that focus on the strength of the evidence used to generate claims
Students read textbooks and answer questions at the end of the chapter	Students read multiple sources, including science-related magazines, journal articles, and web-based resources, and they develop summaries of information
Preplanned outcomes for “cookbook” laboratories or hands-on activities	Multiple investigations driven by students’ questions with a range of possible outcomes that collectively lead to a deep understanding of established core scientific ideas
Students complete worksheets	Students keep journals, write reports, create posters and/or media presentations that explain and argue
Teachers oversimplify for students who are perceived to be less able to do science and engineering	Teachers provide supports so that all students can engage in sophisticated science and engineering practices

These transformative shifts lend themselves to the integration of formative assessment strategies that support the science and engineering practices of:

- Asking questions and defining problems
- Developing and using models
- Planning and carrying out investigations
- Analyzing and interpreting data
- Using mathematics and computational thinking
- Developing explanations and designing solutions
- Engaging in argument from evidence
- Obtaining, evaluating, and communicating information

Formative Assessment in Science: Examples and Suggestions

As we shift towards learner-centered classrooms that place high priority on learning science through asking questions, developing explanations, and engaging in argument from evidence, educators need formative assessment techniques that can support this transformation and help students persevere in a manner that is enjoyable and rewarding.

The following strategies have shown to engage and motivate students, encourage student discussion, and provide the feedback needed to promote thinking and inform instruction.

P-E-O (Predict-Explain-Observe)

P-E-O is a strategy that lays the foundation for the science practices of developing explanations, as well as planning and carrying out investigations. It can be used to provide stimuli for scientific discussion and initiate scientific inquiry, idea exploration, and reflection.

P-E-O begins with the teacher presenting a phenomenon. For example, students are shown an apple floating in water. Students are asked to make a (P) prediction or select a prediction from a set of responses that best matches their ideas about the question: “What will happen if a hole is drilled all the way through the apple?”

Students are asked to (E) explain their predictions by sharing what they think they will see and why they think this.

The teacher and/or students will then carry out the experiment and (O) observe what happens. At this point, students should analyze and discuss the results to see if they match their original predictions. The teacher uses the information to inform instruction, and after investigating, students are provided an opportunity to revise their earlier explanations based on the results and class discussion.

Sticky Bars

The sticky bars strategy provides an opportunity for teachers to publicly share student responses while allowing students to remain anonymous. Creating a safe environment encourages the sharing of a range of ideas and promotes metacognition (students thinking about their own thinking).

To begin, students are asked a question that has multiple answer choices, such as: "Will a stick of butter weigh more, less, or the same when the butter is cut into small pieces?" Their possible responses are: A. The butter cut into small pieces will weigh more; B. The butter cut into small pieces will weigh less; C. The butter cut into small pieces will weigh the same.

Each student is given a sticky note of the same size and color and is asked to write their prediction using a letter response (in this example: A, B, or C). The notes are then collected and arranged on a wall or easel chart as a bar graph that represents the range of student responses.

The sticky bar strategy becomes formative as the teacher and students analyze the bar graph data. The teacher uses the information to inform the next steps in instruction, and the graph promotes learning as students discuss the responses. The sticky bar graph can be revisited during or after instruction, allowing students to confront earlier ideas with their current thinking, based on new evidence from the lessons they have explored.

Commit, Fold, and Pass

Commit, fold, and pass is another engaging, anonymous, formative, assessment strategy that can be used to elicit and identify preconceptions and promote thinking as students compare their own ideas with others in the class. For example, each student can respond to a prompt on a sheet of paper, asking, "If you have a battery and a bulb, what is the smallest number of wire strips you would need to make the bulb light up: a) One strip; b) Two strips; c) Three strips; or d) Four strips?

Ask students to draw a picture that explains how they would light the bulb. Remind students not to write their names on their papers. After committing to their answer by writing it down, students fold their papers in half. When the teacher gives a signal, students begin to move around the room, exchanging papers multiple times until the sheets have been "shuffled."

Students are then asked to set aside their own thinking, open the paper in their hands, and share the ideas and thinking that are described on this paper rather than their own ideas. This leads to a group discussion in which students can decide which ideas seem most plausible. The teacher can quickly identify the different ideas students may have about a concept, and students suspend their current thinking to consider another student's ideas. The ideas can be re-examined during and after instruction, allowing students to reflect on how and why their thinking has changed.

Card Sorts

Card sorts are a formative assessment strategy that can be used to access prior knowledge and activate thinking. Students work in pairs or small groups and are provided a set of cards related to a category associated with a specific concept or idea. For example, they may receive 15 cards with words and/or pictures such as squirrel, bird, fish, seed, fire, and river. Students are then asked, "Is it living?". As students discuss each card one at a time, they sort them into two categories: "It is living" or "It is not living."

During the sorting process, students must justify their thinking and develop rules or reasons for their decisions. The card sort strategy becomes formative as the teacher observes where the group is placing their cards and listens to the small- and subsequent whole-group discussions to inform the next steps in instruction. This strategy promotes learning as students discuss their ideas, listen to the ideas of their peers, and modify their thinking accordingly.

For further descriptions and over 100 additional strategies, see *Science Formative Assessment,* Vol. 1 and 2 (Keeley, 2015, 2016).

Conclusion

Formative assessment is used to inform instruction and promote student thinking, not to grade students. Students should be reminded that there are no right or wrong answers during a formative assessment exercise. There will be time for that at the end of the learning cycle.

The power of reflection is at the heart of best practices in teaching and learning science. Students need opportunities to revisit their initial ideas after the learning experience, so they can confront their prior thinking and explain how their thinking has changed.

If you are a teacher leader, curriculum coordinator, or administrator, consider how you might help teachers uncover student thinking (and their own) by establishing professional learning communities centered on looking at student work from formative assessment prompts.

Formative assessment promotes learning for all students in grades K–12, across the continuum of struggling learner to high achieving learners, in all content areas. Formative assessment is truly assessment for learning!

Additional Resources

The *Uncovering Student Ideas in Science* series by Page Keeley et. al. provides a set of grades K–12+ formative assessment probes that link key concepts in science to commonly held ideas described in the research on learning. These probes can be used to reveal the variety of conceptions students bring to their learning, including misconceptions and scientific ideas.

Keeley's probes inform pathways needed to build a conceptual bridge from where students are at any point in the instructional cycle to where they need to be scientifically. For descriptions of each of the *Uncovering Student Ideas* publications, visit: uncoveringstudentideas.org

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