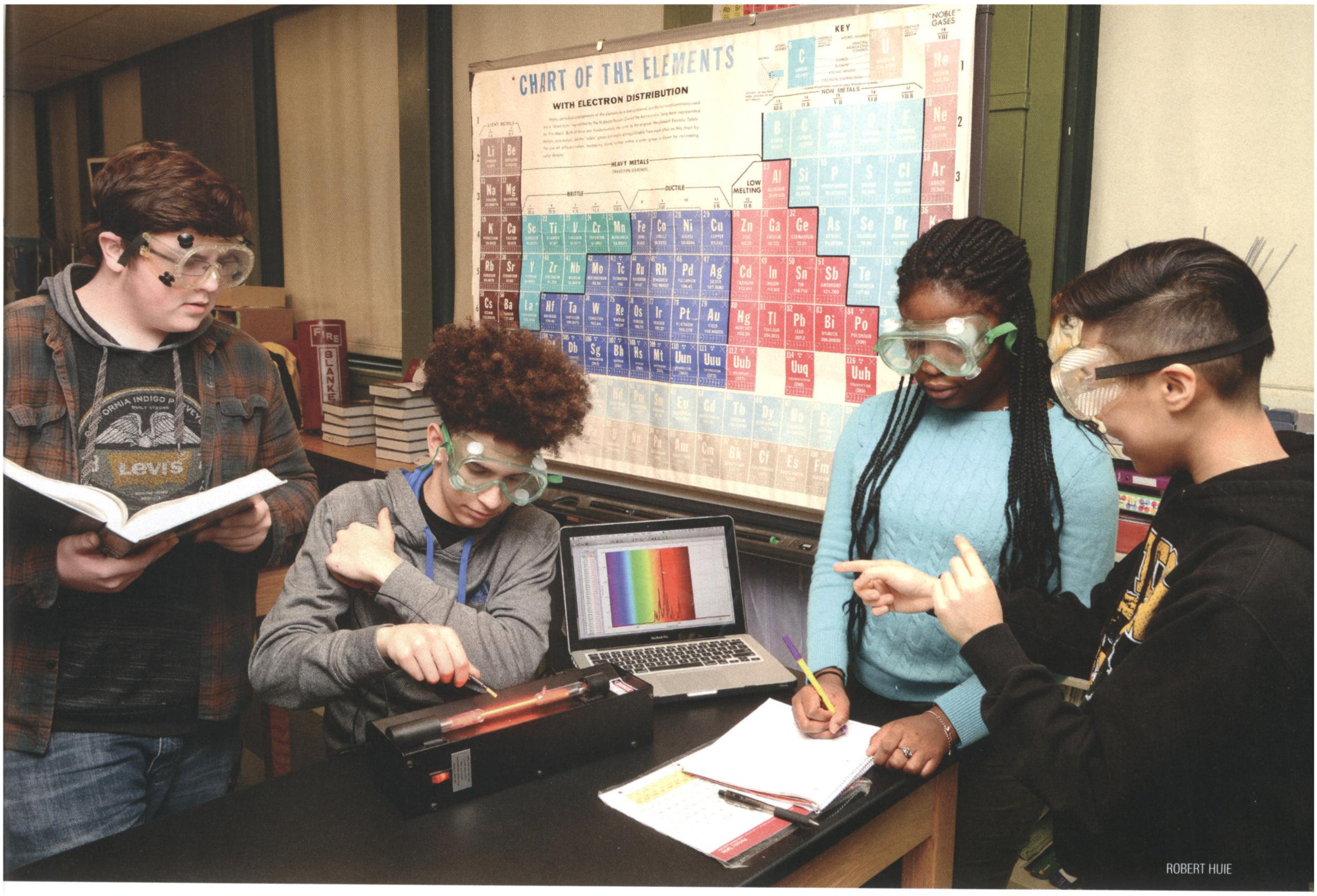



ROBERT HUIE

# Better Formative Assessment

*Making formative assessment more responsive to student needs*

**Michael Clinchot, Courtney Ngai, Robert Huie, Vicente Talanquer, Jennifer Lambertz, Gregory Banks, Melissa Weinrich, Rebecca Lewis, Pamela Pelletier, and Hannah Sevian**

Formative assessment has been defined as the process "to recognize and respond to student learning to enhance that learning during the learning" (Bell and Cowie 2001, p. 536). Formative assessment helps teachers identify strengths and weaknesses in their students' understanding, focuses students' attention on relevant information and ideas, and provides scaffolds that guide and support student progress (NRC 2011).

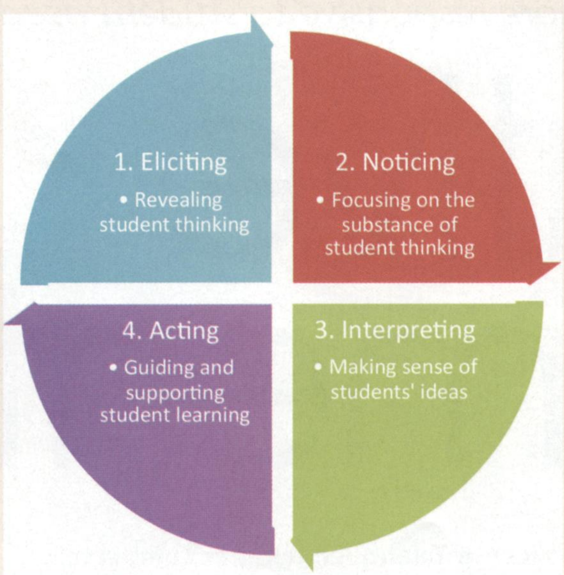
Formative assessment is an ongoing process (Figure 1) in which teachers typically engage in multiple cycles of

- *eliciting* students' ideas,
- *noticing* the substance of students' thinking,
- *interpreting* to make sense of students' ideas, and
- *acting* to guide and support student learning (Levin et al. 2012).

How teachers approach formative assessment influences students' conceptual understanding, as well as their attitudes, motivation, and effort (Ruiz-Primo et al. 2010), particularly among underperforming learners (Stiggins and Chappuis 2005). Research indicates that meeting the new vision of the *Next Generation Science Standards* (NGSS Lead States 2013; see box, p. 75) requires shifting teaching practices from more *prescriptive* approaches that emphasize "discrete facts with a focus on breadth over depth" (NRC 2011, p. 1) toward more *responsive* approaches that provide "time for students to engage in scientific investigations and argumentation and to achieve depth of understanding of the core ideas presented" (NRC 2011, p. 11).

**FIGURE 1**

**Cycle of core teacher practices in formative assessment.**




In each of the four dimensions listed above, a teacher's practices can be characterized along a continuum from more prescriptive to more responsive. This article, using results from our investigations of chemistry teachers' practices, suggests ways to implement more responsive approaches to formative assessment in the science classroom.

## A formative assessment example

For a formative assessment probe of chemistry students studying chemical reactions, we showed a video (see "On the web") of a student preparing a chemical demonstration for second graders. The student depicted in the video intends to create a display of a "volcano" eruption. From among many available substances, she chooses to use sodium bicarbonate (baking soda) and citric acid for the demonstration. She measures 5 g of each, places both in a test tube with a red triangle (a "volcano" shape) behind it, and then adds 20 ml of water to the test tube. A fizzing "eruption" occurs.

After watching the video, the chemistry students are given a handout that describes the video activity and lists the materials that were available for the demonstration (see "On the web"). The chemistry teacher then asks the chemistry students to propose three ideas for how the student in the video could create a bigger eruption and to justify their answers.

Figure 2 shows the answers of three representative high school students: Albert, Reinaldo, and Sonia (pseudonyms). Nearly all of the hundreds of students whom we tested with our "volcano probe" assessment proposed increasing the amounts of baking soda and citric acid (Albert's ideas are a common variation). Reinaldo and Sonia also gave common suggestions. Other frequent responses included constricting the opening of the test tube, using a skinnier test tube, heating the water, using several more chemicals simultaneously, and shaking the test tube.

We invite readers (as we have many other teachers) to analyze the student responses in Figure 2 and consider: What did you pay attention to? How do you make sense of it? Do you notice any patterns? Imagine these are students in your own classroom and you have a limited amount of class time to follow up on this formative assessment. What actions would you take to help these students develop a better understanding of the subject matter? How could the volcano probe be improved to better assess students' understanding?

## Four common formative assessment approaches

We did this exercise with various teachers who had from three to 28 years of teaching experience. We classified their responses into four common approaches to formative assessment (see "On the web" for sample responses). We then built composite descriptions (Figure 3, p. 72) of the motivations that teachers in each category expressed for why they said what they did. We gave the composites pseudonyms so we could refer to them more easily. Each approach can be thought of as a formative assessment "personality" that a given teacher may adopt under different circumstances.

Some teachers in our studies (the Mr. Clark personality type) were rather *prescriptive* in their noticing, interpreting, and acting. They took a descriptive and evaluative approach, focusing on describing what students said, categorizing students' responses as correct or incorrect, and suggesting remediative actions to correct misunderstandings. Others (the Ms. Koczat personality type) were considerably more *responsive* in all formative assessment practices. They approached assessment by focusing on the disciplinary (chemistry, in this case) substance of students' responses, seeking to make sense of their ideas and creating opportunities for students to publicly express their thoughts, engage in argument with their classmates, and reflect on their thinking. We also encountered teachers (the Mr. Aguiar and Ms. Ripley personality types) who were more *prescriptive* in some practices but more *responsive* in others.

Each of the assessment approaches described in Figure 3 may be effective, depending on the circumstances. Wise teachers will use the best assessment "personality" for a particular moment. That suggests being proficient in all four approaches and using them as appropriate, thereby basing instructional decisions on student needs informed by assessment, making assessment "formative." Getting trapped in just one or two of the approaches may constrain our ability to best support student learning.

Research in science education suggests that students' ability to generate sound explanations of natural phenomena and engage in argument based on evidence is fostered when teachers adopt more responsive approaches to formative assessment in all four formative assessment practices (Levin et al. 2012). Next, we suggest some strategies to strengthen the use of more responsive formative assessment approaches ("personalities") in the classroom.

**FIGURE 2**

### Students' responses for three ideas for making a bigger chemical 'volcano' eruption.

***Albert:***

My three things are I would add (1) more citric acid, (2) more baking soda, and (3) more water.

These three things will make the volcano eruption bigger because when the chemicals mix, there will be more chemicals mixing. If they add more citric acid and more baking soda, there needs to be more water for the chemicals to mix and create a substance.

***Reinaldo:***

She could use hydrochloric acid, sodium hydroxide, and water to make a bigger eruption. I'd use hydrochloric acid and sodium hydroxide because they contain hydrogen, and if there was a lot of hydrogen in the air, we would explode. They also contain sodium and chloride, which are both soluble, so I chose water as the last ingredient to make a bigger eruption.

***Sonia:***

One thing that she could do is increase the amount of each reactant to increase the amount of product produced. If there are more reactants reacting with each other, then the amount of product will increase.

Another thing that she could do is perform the experiment over a hot plate. The extra heat will cause the citric acid particles and the baking soda particles to collide at a greater speed. The fast collision of particles will cause the product to be produced at a greater force, making a bigger eruption.

Finally, she could also add acetic acid and more baking soda to the system. Since vinegar is known for reacting with baking soda, there will be two reactions occurring in the test tube, creating an even bigger explosion.

## Responsive formative assessment

The assessment approach that we adopt in a given situation is likely influenced by various factors, including our teaching goals, standardized test outcomes, past experiences, knowledge of current students, and depth of our own content knowledge, together with our interpretation of what the assessment task assesses. However, we can implement concrete strategies to make assessments more responsive to student thinking and to better scaffold their learning. These strategies, summarized in Figure 4, follow.

### *Eliciting student thinking*

More responsive formative assessment calls for probes that uncover how students make sense of ideas and reason through problems rather than only measure whether students know particular facts or can carry out certain procedures. The *Ambitious Science Teaching* project (see "On the web") describes two main characteristics of *rich tasks* that do this: They are accessible to students and can reveal consequential ideas. Rich formative assessment tasks elicit student thinking with questions that draw on their prior knowledge. The assessment

**FIGURE 3**

**Common formative assessment approaches in composite "personalities."**

| | **Prescriptive noticing and interpreting** | **Responsive noticing and interpreting** |
|---|---|---|
| **Prescriptive acting** | **Mr. Clark**<br>When teachers use this assessment approach, they follow *more prescriptive noticing, interpreting, and acting*. For example, Mr. Clark focuses on evaluating the correctness of students' statements, as well as their ability to apply procedures to problem solving. This approach enables him to quickly gather detailed information on student mastery. He might then provide additional opportunities for students to gain exposure to and practice the content again. Strategies consistent with this approach could include segmenting topics into small sets of skills and ideas and providing scaffolded worksheets that ensure all students become successful at them. | **Mr. Aguiar**<br>In this assessment approach, teachers follow *more responsive noticing and interpreting but prescriptive acting*. When Mr. Aguiar uses this approach, for example, he allows students to explore, discuss, and test their ideas with each other to uncover their thinking. He listens to student conversations and contemplates what assumptions may be constraining how students think. After a period of sharing and exploration, he uses his observations to create an activity that reinforces the scientific ideas intended in the activity. He typically shows the class an exemplar response or has students edit their responses following a prescribed method. He does this so that all students know the correct answer. |
| **Responsive Acting** | **Ms. Ripley**<br>When teachers choose the assessment approach of Ms. Ripley, they are *prescriptive in their noticing and interpreting but more responsive in their acting*. They tend to treat student responses as straightforward, measurable data representing student understanding. Ms. Ripley's lesson-planning design identifies key understandings students should be able to express in order to have mastered key content. She regularly checks to find out if most students have reached the appropriate level of proficiency before moving on. If not, Ms. Ripley adjusts her instructional approach to build on the class's current understanding to empower students to explore the ideas they voiced in creative ways, such as multimedia projects, physical models, or student-designed labs. | **Ms. Koczat**<br>When following the assessment approach of Ms. Koczat, teachers are *more responsive in all areas*. They focus less on whether students answer correctly and more on what ideas they bring forth. Ms. Koczat focuses on how students make sense of investigations when she looks at their answers. Instead of telling the student the right answer, she designs a customized new problem or investigation to give the student more data and an opportunity to further develop ideas. Students then discuss how this information ties into previously learned chemistry principles. Students use this new insight to explain how and why chemical phenomena occur in a specific manner. |

probes in the NSTA book series, *Uncovering Student Ideas in Science* (Keeley, Eberle, and Farrin 2005), have these characteristics. Rich formative assessments often ask students to make predictions, identify possible causes for a phenomenon, create initial models to explain an event, design a solution to a problem, or choose the best product for a particular purpose from among several options.

### Noticing the substance of student thinking

Noticing productive ideas or reasoning strategies is particularly difficult when we have set answers in mind when we ask a question or pose a problem. Adopting a more responsive approach requires us to better attend to what students say and do, noticing productive elements in their thinking and acting that we could use to develop scientific understandings. When practicing responsive noticing, wrong answers are not dismissed but analyzed, and right answers are not accepted without justification. When we pay closer attention to how students talk and communicate ideas, we can better help them transition from everyday language to the scientific language we want them to master. When we recognize the personal experiences that shape how students think about a phenomenon, we can better challenge their current understandings and allow them to construct more accurate scientific knowledge.

### Interpreting to make sense of students' ideas

A responsive approach to assessment requires teachers to analyze students' answers to understand the reasoning behind them, regardless of whether the responses are correct. This is easier when teachers know what ideas often guide novice thinking about phenomena in a specific scientific discipline. Teachers should hypothesize about the prior knowledge, reasoning, problem-solving strategies, and partial or alternative understandings that may be guiding students' explanations and possibly constraining their thinking and actions.

### Acting to scaffold learning

Acting typically restarts a cycle of formative assessment. It can occur quickly, such as with follow-up questions to responses we receive during a class discussion. Or it can occur over a longer timeframe, as we analyze student responses to a written probe and plan follow-up activities to build on student thinking.

FIGURE 4

**Strategies for shifting our formative assessment practices to meet the *NGSS* vision.**

| Formative Assessment Practice | From<br>More prescriptive | To<br>More responsive |
|---|---|---|
| *Eliciting student thinking* | Using formative assessments that differentiate among ability levels and/or identify known misconceptions. | Recognizing, adapting, and designing formative assessments that are accessible to all students and capable of revealing students' thinking. |
| *Noticing the substance of student thinking* | Describing students' statements, focusing on students' behaviors, and/or only considering ideas that align with accepted scientific knowledge. | Attending and highlighting ideas that students' express about targeted phenomena, the language that they use to communicate those ideas, and the strategies they propose to tackle problems. |
| *Interpreting to make sense of students' ideas* | Taking an evaluative stance, assigning students' responses as correct or incorrect and/or tagging specific misconceptions. | Taking an interpretive stance, identifying productive underlying thinking and misapplied assumptions that constrain students' thinking and may limit learning. |
| *Acting to scaffold learning* | Planning remedial actions (e.g., relecturing main points, providing worksheets that drill skills, modeling correct procedures). | Planning responsive actions that build upon students' productive ideas in deliberate directions, fostering a classroom culture that values exploring which knowledge is relevant, using multiple sources of data and outcomes predicted by different models, constructing new understanding. |

*When using formative assessment in our own teaching, we have found it productive to ask ourselves: What is this task intended to reveal about students' thinking?*

Teachers should also consider how responsively they redirect student ideas during class discussion (Lineback 2015). More prescriptive redirections include asking questions that steer the student in a particular direction, signaling an incorrect student answer. More responsive redirections reveal the students' ideas, including inaccurate ones. This may include asking students to propose or elaborate on a mechanism underlying an explanation, connecting two students' responses, inviting students to weigh the pros and cons of different ideas that have emerged, requesting that students interpret another student's comment, or challenging students to form a relevant hypothesis and test it in the laboratory. Such responsive questions launch students' ideas into the class discussion, giving us opportunities to find productive ones.

## Conclusion

Teacher judgments of student understanding affect many classroom decisions, including future instructional plans (Stiggins and Conklin 1992). Prescriptive formative assessment can miss opportunities to value students' productive ways of reasoning. Responsive formative assessment, on the other hand, can elicit students' ways of thinking and make sense of how students solve problems. Responsive teachers reveal and highlight the substance of students' ideas, recognize disciplinary connections, and take actions that productively scaffold student learning (Robertson, Scherr, and Hammer 2016).

When using formative assessment in our own teaching, we have found it productive to ask ourselves: "What is this task intended to reveal about students' thinking?" As we consider the answer, we reflect on other questions such as: "What do students cue on and what do they not pay attention to?" "Which issues are worth opening discussion about and which are better approached by repeated practice?" These questions have helped us to identify teaching strategies that move us toward more responsive modes of formative assessment. ■

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### On the web

Ambitious Science Teaching project: *http://ambitiousscienceteaching.org*
Examples of teachers' responses: *www.acctproject.org/FA-personalities*
Video of student preparing a demonstration: *http://bit.ly/volcano-probe*
Volcano probe resources: *www.acctproject.org/volcano-probe*

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## Connecting to the *Next Generation Science Standards* (NGSS Lead States 2013).

**Standards**
**HS-PS1 Matter and Its Interactions**

**Performance Expectations**
The chart below makes some of the most direct connections between the Volcano Probe formative assessment described in the article and the *NGSS*. The intended goal of the Volcano Probe is to elicit students' ideas about how to control chemical reactions. Other valid connections are possible besides the ones listed below; however, space restrictions prevent us from listing all of the possibilities.

**HS-PS1-2.** Construct and revise an explanation for the outcome of a simple chemical reaction based on the outermost electron states of atoms, trends in the periodic table, and knowledge of the patterns of chemical properties.

**HS-PS1-5.** Apply scientific principles and evidence to provide an explanation about the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs.

| Dimension | Name and *NGSS* code/citation | Specific connections to classroom activity |
|---|---|---|
| **Science and Engineering Practices** | **Using Mathematics and Computational Thinking**<br>Use mathematical representations of phenomena to support claims.<br><br>**Constructing Explanations and Designing Solutions**<br>Construct and revise an explanation based on valid and reliable evidence obtained from a variety of sources (including students' own investigations, models, theories, simulations, peer review) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future. (HS-PS1-2) | In the formative assessment probe described in the article, students are challenged to identify and justify three ways that would make the "volcano" eruption bigger. Students can draw upon multiple ideas and practices in physical sciences to do this.<br><br>Students use mathematical representations to identify the limiting reagent, given the starting conditions presented, and could propose to increase the amount of the reactant that is limiting. |
| **Disciplinary Core Ideas** | **PS1.B: Chemical Reaction**<br>• Chemical processes, their rates, and whether or not energy is stored or released can be understood in terms of the collisions of molecules and the rearrangements of atoms into new molecules. (HS-PS1-5)<br>• In many situations, a dynamic and condition-dependent balance between a reaction and the reverse reaction determines the numbers of all types of molecules present.<br>• The fact that atoms are conserved, together with knowledge of the chemical properties of the elements involved, can be used to describe and predict chemical reactions. (HS-PS1-2)<br><br>**ETS1.C: Optimizing the Design Solution**<br>• Criteria may need to be broken down into simpler ones that can be approached systematically, and decisions about the priority of certain criteria over others (trade-offs) may be needed. | Students identify outcomes that would be affected by changing design conditions of the reaction, including rate (how fast a gas is evolved), and explain the effect on the outcomes in terms of molecular-level processes (collisions, rearrangements).<br><br>Students justify why a gas-evolving reaction is driven toward products by the removal of the gas.<br><br>Students predict the products that could result, based on reaction models.<br><br>Students design investigations that could systematically test claims about how to make a bigger "volcano" eruption, identifying which factors are more relevant in altering the desired outcome. |
| **Crosscutting Concept** | **Patterns**<br>• Different patterns may be observed at each of the scales at which a system is studied and can provide evidence for causality in explanations of phenomena. (HS-PS1-2), (HS-PS1-5) | Students make and defend claims for how various factors (physical constraints, external parameters, internal parameters) would affect different outcomes (reaction rate, amount of products, types of products) of a chemical reaction. |