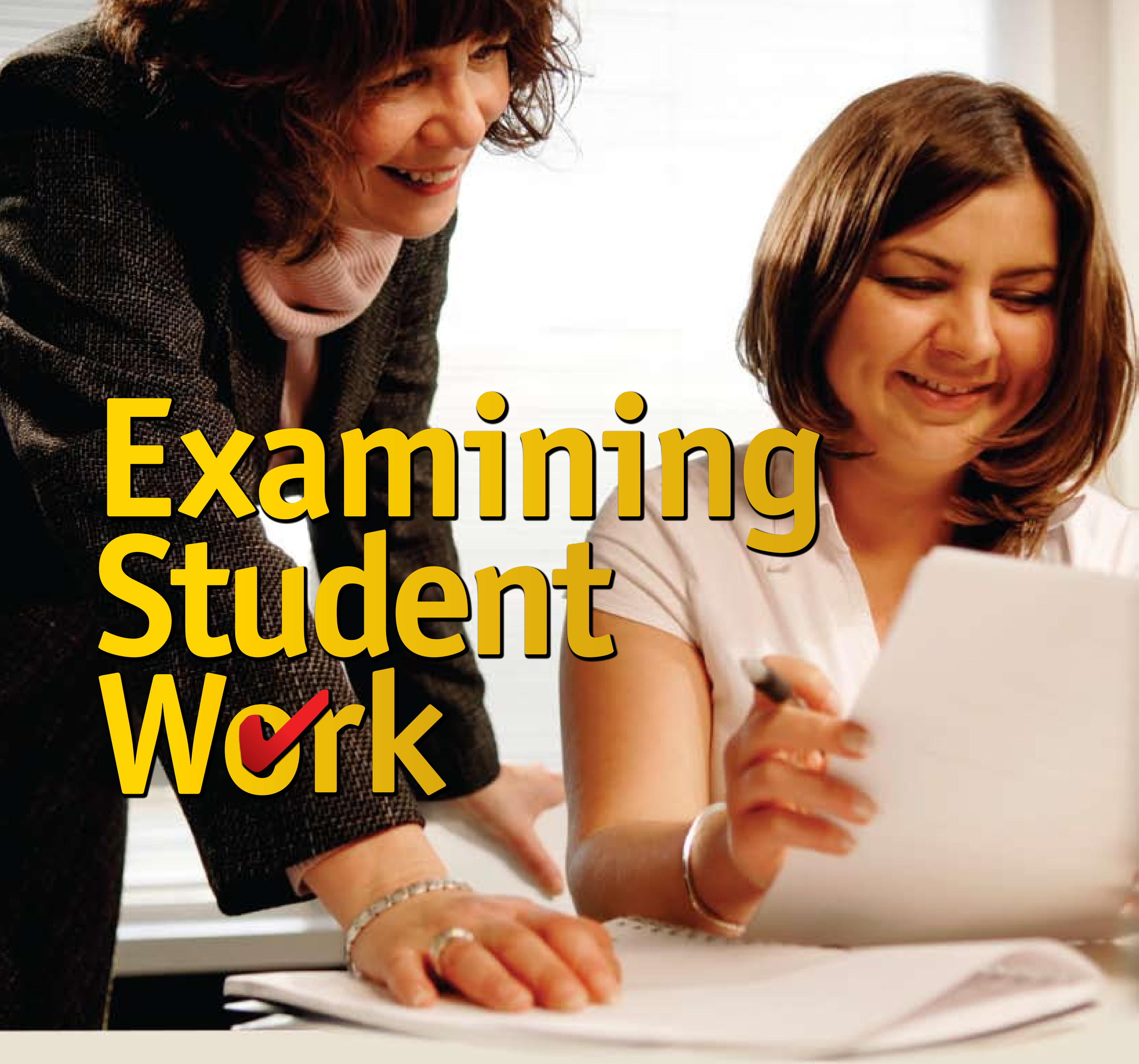


Examining Student Work

Evidence-based learning for students and teachers

— **Jessica Thompson, Melissa Braaten, Mark Windschitl, Bethany Sjoberg, Margaret Jones, and Kristi Martinez** —

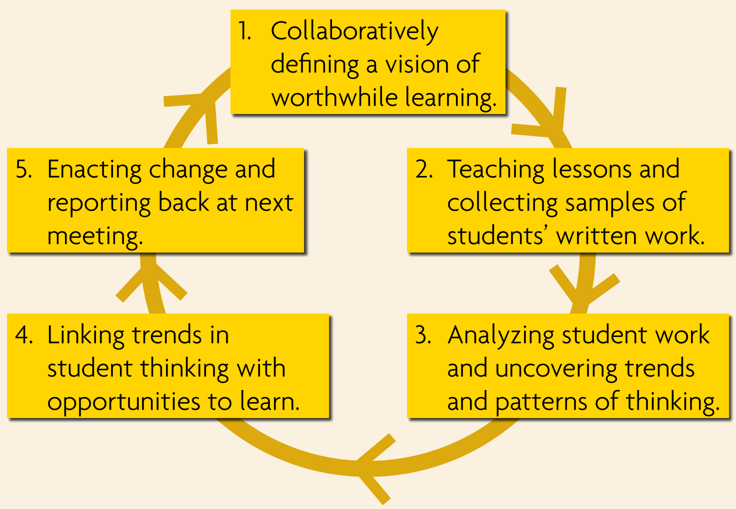
Across the nation, teachers gather regularly to examine student work and uncover how their students are thinking about science. These teacher groups aim to improve both their instructional methods and the effect these methods have on student learning. Achieving positive outcomes, however, requires teachers to use thoughtful, intentional methods to design instruction, select student work, analyze these artifacts, and make evidence-based changes to instruction (Bray et al. 2000; NRC 1996; Wood 2007).

This article presents a model of collaborative inquiry for groups of science teachers who want to systematically improve their practice through analyses of student work. The five-phase APEX[ST] (Advancing High-Leverage Practices by Examining Student Thinking) model (Figure 1) is appropriate for students of all achievement levels. It focuses on high-leverage practices (e.g., pressing for evidence-based explanations) and longitudinal learning for both students and teachers over the course of a year.

Critical Friends Groups

We have designed and tested the APEXST model of collaborative inquiry for Critical Friends Groups (CFGs). A CFG is a learning community of 8–12 educators who gather for about two hours a month to discuss improving their practice through collaborative learning. In collegial CFG meetings, teachers engage in a cycle of inquiry, reflection, and action to promote adult growth that is directly linked to student learning (Curry 2008; NSRF 2009). The APEXST model provides a structure and focus for these groups to engage in meaningful examination of student work. There are five phases of the APEXST model that support the improvement of teaching and student learning. These are described in the following sections.

FIGURE 1
APEXST model of collaborative inquiry.



Phase 1: Defining a vision of worthwhile learning

Perhaps the most important decision CFGs can make is to identify some aspect of student learning that is important enough to focus on for a full academic year (Ball et al. 2009; Curry 2008; Windschitl, Thompson and Braaten Forthcoming). We recommend teacher groups choose a core scientific practice they can develop across different topics and courses. In our most recent project, we chose students' "construction of evidence-based explanations." This type of scientific thinking is critical to understanding the more conceptual ideas in science and is a valued scientific practice (NRC 2000; Windschitl 2008). It is important that CFGs do *not* choose topics that can change from meeting to meeting—this will make it difficult to analyze any one scientific practice's development over time.

Creating lessons that press students for evidence-based explanations can be difficult work. The challenge is that lessons from standard curriculum materials are often organized around narrow topics or processes, not big ideas with underlying explanations. Big ideas have complex causal stories, composed of a web of events and concepts that help explain why observable phenomena occur. An example of one observable phenomenon is the diffusion of materials across a membrane. The causal explanation for why this occurs has to do with core concepts such as equilibrium, concentrations of solutions, and permeability of membranes.

Once a big idea is selected, teachers can work together to identify a lesson or series of lessons that aim to explain observable phenomena. Lessons that ask students to gather information through investigation or already existing evidence help them understand both the development of an explanation and the use of evidence. One such example would be a pulley investigation in which students use ideas about forces, work, and energy to explain why a single person can lift a very heavy load using simple machines.

"What-how-why" explanation

After the teachers have selected a lesson, the next step is to construct a full explanation for the phenomena (i.e., a causal story or stories describing *why* a phenomenon occurs). To connect this explanation to evidence from an investigation, it is helpful to first draw a diagram of the phenomenon under study and then draw in features and processes that are not observable—thus creating a scientific model for the phenomenon (Windschitl 2008; Windschitl, Thompson, and Braaten 2008).

Once the "why" is outlined, the team of teachers can then write a rubric that details a "how" and "what" explanation that students might provide when asked for a "why" explanation (see "On the web"). Figure 2 (p. 50) is an example of the "what-how-why" explanation framework that a group of teachers developed for a cellular respiration investigation in which students were asked to explain why respiration increased after exercise. Students breathed into a Bromothymol Blue (BTB) solution before and after exercising. (**Safety note:** Students were strictly supervised and cautioned not to accidentally inhale or swallow the solution.)

CAUTION

In the example provided in Figure 2, students were asked to use multiple forms of evidence and to coordinate the evidence with a scientific explanation. They collected three types of data before and after exercising: heart rate, number of breaths per minute, and amount of time (in seconds) it takes for BTB to change from blue to yellow. After collecting the data, *students* used the "what-how-why" framework to analyze their results. The teachers

FIGURE 2

"What-how-why" explanation.

	Level 1: What	Level 2: How	Level 3: Why
Depth of explanation	◆ Student describes what happened. ◆ Student describes, summarizes, or restates a pattern or trend in data without making a connection to any unobservable or theoretical components.	◆ Student describes how or partially why something happened. ◆ Student addresses unobservable or theoretical components tangentially.	◆ Student explains why something happened. ◆ Student can trace a full causal story for why a phenomenon occurred. ◆ Student uses powerful science ideas that have observable or theoretical components (e.g., kinetic molecular theory) to explain observable event.
Example explanation	The BTB changed from blue to yellow after the exercise because the body exhaled more carbon dioxide than when it was stationary.	When exercising, the body requires more oxygen. As oxygen intake increases, so does carbon dioxide output.	When exercising, the body requires more oxygen, which is taken from the lungs to muscle cells (via the circulatory system and diffusion). The cells use the oxygen to break down glucose into energy and carbon dioxide. Muscles use the energy to do work. The carbon dioxide diffuses into the blood and then the lungs and is exhaled. Cellular respiration happens at a faster rate when a person is exercising, so more carbon dioxide is produced. The exhaled carbon dioxide reacts with water to produce carbonic acid, causing the BTB indicator to change color.

used the rubric to design questions for students and evaluate their written work.

Phase 2: Collecting student work samples

A key feature of the APEXST model is that attention is given to students of all achievement levels. We recommend selecting nine students to track throughout the school year—three high-performing students, three average students, and three underperforming students. The amount of student work you analyze can be small (e.g., a 3–5 sentence response to an explanation-type question asked on a quiz) or large (e.g., an evidence-based claim students made following an investigation).

Many of the teachers we worked with found it helpful to collect video samples as a way to share images of rich classroom conversations. Recording and editing video samples can be time consuming, but if available, this can be done by a district-level science coach, an administrator, or a research partner from a university. For video segments, try to capture student-to-student conversation as a way to provide insight into how students wrestle with evidence or scientific explanations.

Phase 3: Analyzing student work

Most assessments will tell you *if* students have learned, but close examinations of student work can reveal *why* some students have learned something and others have not. The analysis phase of the APEXST model is usually completed individually by teachers. The first step is to use the rubric (see "On the web") you developed in Phase 1 (p. 49) as a reference to detect what "partial understandings" students might have compared to the intended understanding. This provides clues about different paths to understanding, rather than simply making judgments about whether students' responses were correct or incorrect.

Partial understandings by students may take several forms:

- Student is familiar with a scientific idea, but uses it in the wrong context.
- Student understands part, but not all, of an idea.
- Student recognizes when a vocabulary term should be used, but does not provide evidence that he or she understands what it means.
- Student can go through the motions of a scientific prac-

tice (e.g., interpreting data or creating a model), but does not know when or how to apply this practice in a new situation.

Another important aspect of the analysis phase is to look carefully at the full range of high-performing, average, and underperforming students in your classroom. This will provide a foundation for addressing how different groups of students are learning. One of the teachers working with us found that her underperforming students were having difficulty writing scientific conclusions—not because they comprehended the task differently from their peers, but because they did not know how to respond to feedback the teacher had given them a few weeks earlier on this type of writing. The teacher realized she had to help her underperforming students not only understand scientific writing practices, but also how to use her feedback more productively.

When analyzing student work, sticky notes and highlighters can be used to mark places where students show elements of understanding the target idea. Students who have similar responses to one another can be grouped together, and teachers can then look for one of two types of patterns in student thinking:

- An *unexpected trend* is when many students responded to instruction in an unpredicted way. It signals a learning situation that did not present students with an opportunity to process ideas in the way a teacher thought it would.
- A *relationship* is when groups of students, who share similar characteristics, perform similarly on a feature of the task or question. In one of our cases, the English Language Learners (ELLs) in a classroom were able to draw sophisticated models of air pressure during small-group work, but during whole-class discussions, they were unable to communicate their thinking to others.

Phase 4: Linking trends with opportunities to learn

When CFG meetings occur, the following materials are needed:

- *Student work*: At each meeting, one teacher serves as the presenter. The presenter should bring copies of three to four students' work that are particularly illustrative of the patterns he or she noted. The assignment questions that were analyzed should be circled and any necessary notes included. There should be one set of papers for each group member.
- *Rubric* (see "On the web"): The presenter should bring copies of the rubric that the group constructed in the first meeting and notes about all nine students' thinking.
- *Patterns and questions*: The presenter should bring written reflections on his or her analysis, summarizing both the patterns seen in the data and the questions peers should focus on during the session (see "On the web").

In the APEXST model of collaborative inquiry, the CFG meeting should be characterized by three kinds of accountability: accountability to peers, to the science itself, and to understanding student work. Being accountable to peers means each presenter collects and analyzes student work, makes copies for everyone, and is ready for an in-depth discussion (typically at least 50 minutes). For other participants, being accountable means reserving the time to engage in this process with others and using constructive criticism.

The second type of accountability is to the science itself. At each meeting, everyone is asked to present a scientific explanation of the phenomenon present in the student work sample. This helps participants to see certain indications of students' scientific understanding in their work. It also forms the basis of a common language that can be used during the session.

The third type of accountability is to understanding the student work. During the meeting, a segment of time is devoted to a generous review of student work. Teachers look for important clues in every paper—no matter how sparse—that provide insight into the workings of a student's mind. Participants need to resist glossing over a sample of work, only to dismiss it as "wrong," and should look not only within the work of each student, but also across the samples of student work.

During these meetings, it is helpful to avoid "repair talk" (i.e., talk of how one would fix the instructional activity). This talk can be contagious; a skilled facilitator should instead steer participants toward an understanding of student thinking.

The rubric and the CFG protocol (see "On the web") are tools that are especially important for maintaining accountability. The facilitator should bring copies of the protocol for all members so it can be used to structure the peer conversations that take place. The three most important parts of this science-specific CFG protocol, based on our research, are:

1. the invitation to come to a group understanding of the best possible scientific explanation of the focal phenomenon;
2. the prompt to have participants seek out evidence of partial understandings; and
3. the practice of hypothesizing how, based on evidence, changes in instruction could positively impact learning.

Phase 5: Enacting change and reporting back

For the APEXST model of collaborative inquiry, groups will want to leave about 30–60 minutes at the end of each CFG meeting to return to Phase 1 (p. 49). After the presentations, the strategies that were discussed are labeled and recorded. Each teacher can choose one idea to try prior to the next meeting. Teachers can then work in pairs to discuss exactly which practices might be applied to an upcoming lesson and work through the activities listed in Phase 1.

Conclusion

We have worked with CFGs who meet once a month and others who have negotiated three full professional development days per year for these meetings. Regardless of structure, most teachers made significant gains in how they conceptualized which ideas were worth teaching, how they posed "why"-level questions in the classroom, and how they identified and responded to students' partial scientific understandings. Through collaborative inquiry, teachers were able to greatly improve students' opportunities to engage in rich forms of scientific reasoning. Over time, teachers formed a community of "critical colleagues" who were willing to hold each other accountable, take intellectual risks, and open up windows into each other's classrooms.

The principled and collaborative analysis of one's practice for the purposes of improvement is the work of professionals. This inquiry itself is scientific—it involves the generation of questions, the production and collection of evidence, and the coconstruction of theories about how and why students respond to instruction in particular ways. Through the APEXST model of collaborative inquiry, it is entirely possible for committed groups of science educators to understand their students' thinking in new and deeper ways, and to eventually make evidence-based changes that bring science achievement within the grasp of all students. ■

Jessica Thompson (jjthomps@u.washington.edu) *is a research associate, Melissa Braaten* (mbraaten@u.washington.edu) *is a research assistant, and Mark Windschitl* (mwind@u.washington.edu) *is an associate professor, all at the University of Washington in Seattle; Bethany Sjoberg* (bethany.sjoberg@gmail.com) *is a science teacher at Evergreen High School in Seattle, Washington; Margaret Jones* (mjjones@seattleschools.org) *is a science teacher at Rainier Beach High School in Seattle, Washington; and Kristi Martinez* (kmartinez@lwsd.org) *is a science teacher at Eastlake High School in Sammamish, Washington.*

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On the web

Analysis of student work record sheet: *www.nsta.org/highschool/connections.aspx*

Critical Friends Group protocol: *www.nsta.org/highschool/connections.aspx*

Rubric for analysis of student understanding of evidence-based explanations: *www.nsta.org/highschool/connections.aspx*

Tips for identifying patterns in the data and devising a question for a follow-up CFG meeting: *www.nsta.org/highschool/connections.aspx*

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