



AUTHENTIC SCIENCE INVESTIGATION IN THE CLASSROOM

TOOLS FOR CREATING ORIGINAL, TESTABLE
QUESTIONS AND GRAPHICAL HYPOTHESES

*by L. Max Tarjan, Kristin de Nesnera,
and Robert Hoffman*

As teachers begin to align curricula with the *Next Generation Science Standards (NGSS)* (NGSS Lead States 2013), they must increasingly engage students in classroom science that mirrors authentic research. One of the more difficult aspects of science research is the initiation of an original investigation. Doing so requires a strong understanding of how to formulate scientific questions and hypotheses. These practices are particularly challenging for students and difficult for teachers to distill (Flannagan and McMillan 2009; Graves and Rutherford 2012). Most resources we have encountered do not promote active student engagement in these science practices or oversimplify them, leading to student misconceptions. For example, resources for developing student investigations often emphasize tweaking existing questions, resulting in “cookbook” projects (Linn, Bell, and Hsi 2010). Hypotheses are either incorrectly defined as an “educated guess” (McComas 1996) or are forced into an “if ... then” format, which can be misused (Baxter and Kurtz 2001), is inflexible, and does not resemble how practicing scientists communicate hypotheses in their work.

Our goal was to incorporate teaching tools that provide students a stronger foundation for understanding and using *NGSS Science and Engineering Practice 1, Asking Questions and Defining Problems* (NGSS Lead States 2013). In this article, we present a tool that we developed to help students practice asking testable questions (Question Sorting and Flowchart, see Figure 1–3) and an existing tool that we modified to facilitate forming hypotheses (Inquiry Boards, see Figure 4). These tools are flexible and useful for any scientific investigation and help science teachers of any discipline implement three-dimensional instruction in their classrooms. For example, the Question Sorting activity can be used as a model to sort student-generated questions for a class investigation. Also, the Inquiry Boards can be used for any hypothesis-driven investigation, either to guide the whole process or to focus on a particular element of an investigation by using a subset of boards.

This article describes how we used these activities as students conducted science-fair projects during the 2014–2015 academic year. Worksheets for these activities are available with this article’s online supplements at www.nsta.org/middleschool/connections.aspx.

Teacher preparation

Before implementing these activities, we found it helpful to give students

FIGURE 1 Sorting Activity worksheet

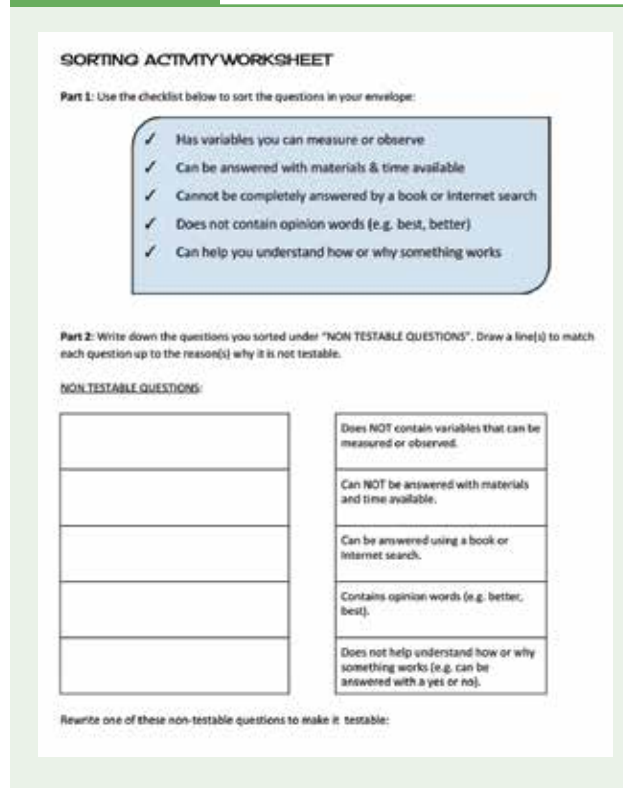
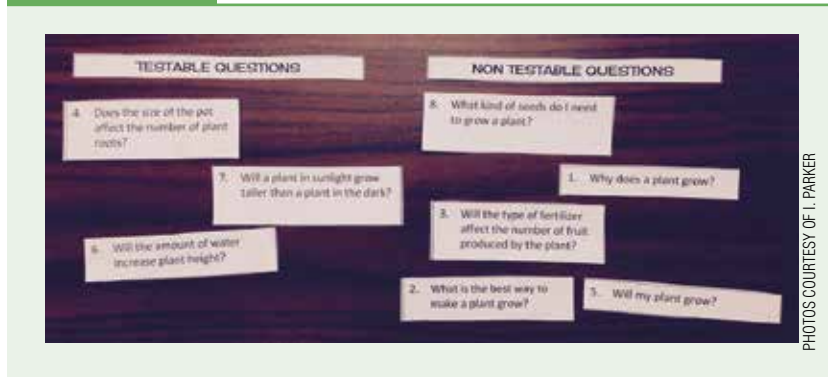


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a homework assignment to identify a topic of interest for their science-fair investigation and to propose three questions about their chosen topic. Teachers can use this homework assignment to formatively assess student proficiency at asking testable questions. We assessed student-generated questions using the testable-questions checklist (blue box in Figure 1). The degree to which student questions were testable or nontest-

FIGURE 2 Question strips



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able helped us identify the amount of support students needed. Because most of our students were unable to generate testable questions, we used the Question Sorting activity followed by the Inquiry Board activity to support student development of this practice.

We began both activities by teaching the class how to use the tools (Question Flowchart and Inquiry Boards) with the common example of plant growth. Student pairs then used these tools to develop their own science-fair investigation. Our students live in a community dominated by agriculture, so they were familiar with plant growth and were thus able to focus on the tools rather than on understanding the content. If this topic is unfamiliar to your students (i.e., they do not understand that plants require sunlight, water, and nutrients to grow), then you should prepare for this activity in the following ways: (1) select a topic with which your students are familiar, (2) revise the question strips, and (3) generate sample data to use during the Inquiry Board example.

The concept of scientific variables is an important feature in both activities. Students will gain a deeper understanding of variables and the role they play in science investigations, but teachers should preface instruction by reviewing the definitions of independent and dependent variables.

Additional preparation includes printing hard copies of the materials. Each student should receive a printed copy of the following handouts (available with this article's online supplements): Question Strips, Sorting Activity Worksheet, Testable Question Flowchart, and Inquiry Boards. The teacher can either provide scissors for students to cut out the question strips or pre-cut the question strips and secure each set together using paperclips, rubber bands, or envelopes.

Activities

Question Sorting and Flowchart

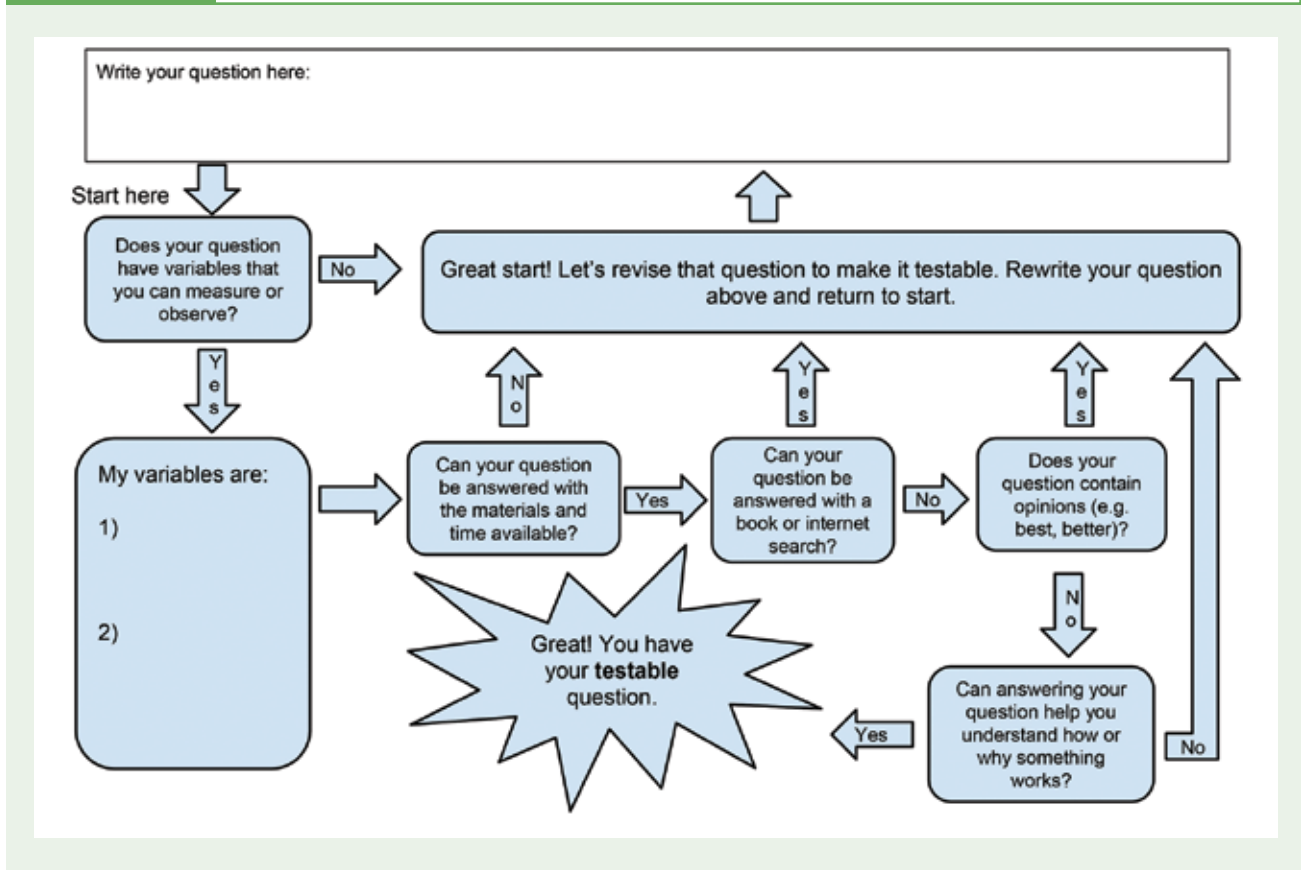
The middle school students with whom we worked were comfortable asking questions, but most did not understand that testable questions for science investigations should meet a specific set of criteria. We found that few students were able to generate testable questions during the preclass homework assignment. We designed the Question Sorting activity to help students grapple with this practice and created a list of criteria for testable questions based on our experience as scientists. Student pairs were provided envelopes containing question strips (small strips of paper with sample questions, which were printed and cut into strips by the teacher prior to class) (Figure 2), along with the Question Sorting activity work-

sheet (Figure 1). We used question strips about plant growth, a topic familiar to all of our students, to allow them to focus on the format of the questions without being confused by the content. Students worked for 10 minutes and used the criteria for testable questions (see the blue box in Figure 1) to sort questions into two categories: testable questions and nontestable questions. For nontestable questions, students identified which criteria were not met and indicated them on Part 2 of the worksheet (Figure 1).

After students finished sorting, we reviewed their answers as a class. Students volunteered to share how they sorted each question and provided explanations for why they chose to sort them under testable or nontestable. We asked the rest of the class if they agreed or disagreed with the classification and to elaborate if they sorted differently. We then modeled how to refine a nontestable question to make it testable (e.g., "What makes a plant grow?" became "Does the amount of water affect the height of the plant?"). Students then spent five minutes rewriting one nontestable question to make it testable. Finally, students used the Testable Question Flowchart (Figure 3) to guide the development of their own testable questions on the topic that they chose as part of the preclass homework assignment. This flowchart contained the testable question criteria and reinforced the fundamental concepts of scientific questioning.

During the sorting activity, we were careful to emphasize that nontestable questions are not "bad" questions; they just can't be tested using an investigation. We explained that nontestable questions for investigations are often starting points and can be refined and further developed to test a specific idea. We also encouraged students to underline the *variables* (factors, traits, or conditions that can be altered, measured, or observed) on the question strips and on the questions they developed themselves. Underlining variables helped students who were struggling to correctly categorize questions that lacked variables, as they were able to use the checklist of criteria (see blue box in Figure 1) to confirm that the question was nontestable by an investigation.

At the end of this activity, students showed improvement in their ability to ask testable questions, and some had formulated a testable question for their science-fair project. Other students were still developing and revising their questions. We found that following the Question Sorting activity with the Inquiry Board activity helped support students as they continued to develop their investigation. Students with testable questions were able to use the Inquiry Boards more quickly to develop a hypothesis, while other students began using the boards to revise their scientific question.

FIGURE 3 Testable Question Flowchart


Inquiry Boards

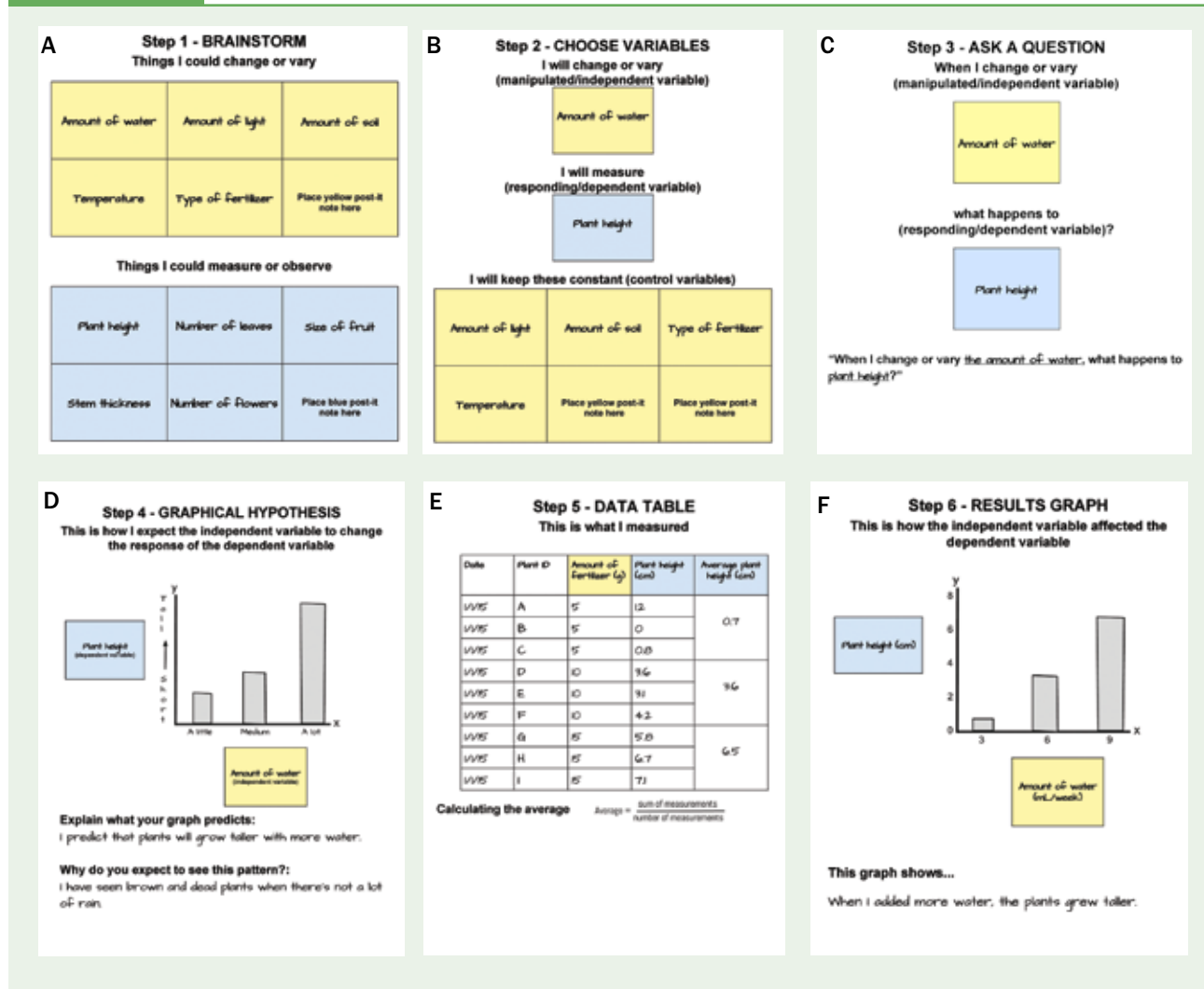
Inquiry Boards show students how to conduct a scientific investigation through the fundamental role of variables. Students write variables on sticky notes and physically move them across six boards that represent stages of an investigation (Figure 4; see worksheets and blank Inquiry Boards with this article's online supplements). The boards appeal to multiple learning styles, simplify how to conduct an investigation enough for students to grasp the essential parts of the process, and can be used with any science content. These boards were modified from "Inquiry on Board!" (Buttmer 2006), with the addition of (1) built-in opportunities for students to translate the sticky notes into scientific writing, such as written testable questions and interpretations of graphs, and (2) a *graphical hypothesis*—a graphical representation of predicted results that support a given hypothesis. The graphical-hypothesis board gives students a flexible method for making predictions, requires them to use a graphical model to represent their thinking

(Bryce et al. forthcoming), and offers a basis for comparison for a graph of their final results.

In the classroom, student pairs began using the boards to continue developing their question of interest from the end of the Question Sorting activity. To first teach students how to use the boards, we provided the example of exploring plant growth (this example and use of the boards are illustrated in an online video; see Resource). We walked the class through the plant-growth example (30 min.), and students then used Inquiry Boards as a tool to begin their own science-fair investigation (steps 1–4; 30 min). Students continued to use the remaining boards (steps 5–11) as they developed their investigation over the course of the next two months.

To initiate an investigation about plant growth, students wrote variables they could change on yellow sticky notes and placed them on the first Inquiry Board (Figure 4a). For example, some students thought that the amount of water, amount of sunlight, and type of fertilizer could affect plant growth. Students then identified variables they could measure to describe plant

FIGURE 4 Inquiry Boards



growth (e.g., plant height, stem thickness, number of leaves, number of flowers) and wrote them on blue sticky notes. As facilitators, we made sure that students only wrote one variable per sticky note.

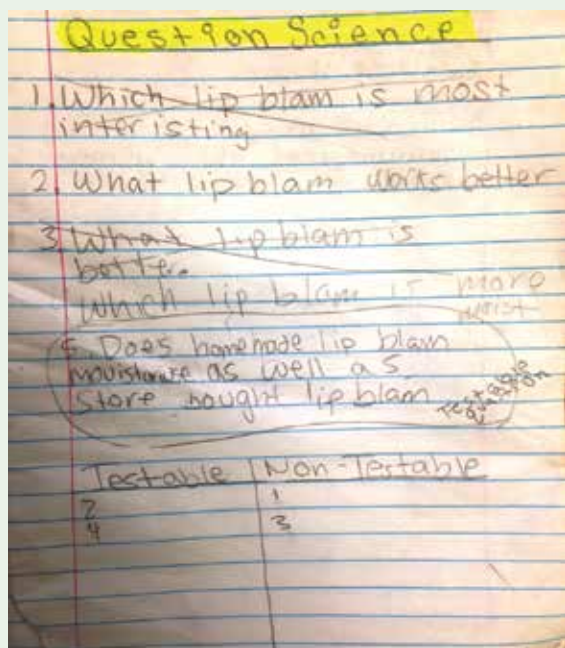
Students moved on to the next board to select variables to use in their investigations (Figure 4b). Students selected one of the yellow sticky notes, which became the independent variable, and one of the blue sticky notes, which became the dependent variable. As there was one space for each type of sticky note, students were limited to only changing one variable at a time, a practice that many students previously found difficult when designing their own investigations. All other variables on yellow sticky notes were kept constant across trials as control variables. Although experimental design was not directly addressed by the

Inquiry Boards, we found this emphasis on changing only one independent variable to be helpful during later investigation stages.

On the next board, students moved their sticky notes to form their testable question (Figure 4c). They then wrote their question in the fill-in-the-blank spaces at the bottom of the board. On the graphical-hypothesis board (Figure 4d), students stated their prediction as a graph. If they chose a categorical independent variable, they drew a bar graph of their prediction. Many continuous variables were expressed as categories (e.g., amount of water was written on a bar graph as 3, 6, and 9 mL/week of water) if students were not prepared to draw and interpret line graphs. Students who chose a continuous independent variable and were familiar with line graphs drew a line graph of their prediction.

FIGURE 5

Refining testable questions



Students then interpreted their graph into words and wrote their prediction on the bottom of the board. In addition, they provided a reason for why they expected to find the pattern they drew.

Note that the graphical-hypothesis board requires both a clear hypothesis and a graphical prediction. We did not make the distinction because these two ideas are so tightly linked. We found that this board gave students multiple ways of showing their understanding, unlike a rigid “if ... then” statement. In addition, we found that when students were required to state why they made a prediction, they were less likely to think of a hypothesis as a guess (where students lack a reason or mechanism for their expectation).

After they recorded their graphical hypothesis, students moved into their investigation (either hypothetical, in the case of the plant-growth example, for which we provided students with data, or authentic, in the case of their science-fair projects) and used their sticky notes to identify the columns of their data table. As data tables often vary widely, we provided an example table that made use of the sticky notes (Figure 4e), which should be tailored to the particular student or class investigation.

Once their investigation was complete, students used the last Inquiry Board (Figure 4f) to identify the placement of the independent and dependent variables

in their results graph and to visually represent their data. Students were also required to interpret their results graph and to express their pattern in writing. We then encouraged students to make a direct comparison of their results graph to their graphical hypothesis to determine whether the data supported or did not support their initial hypothesis. This comparison offers a visual way for students to make sense of their data and lays the groundwork for the concept of statistical reasoning by comparing their observed data to an expectation.

Conclusion

With the support of these tools, students were able to generate an original, testable question for their science-fair project and provide a graphical hypothesis with a logical explanation of their prediction. As a result, these projects were unique and students displayed a strong sense of ownership and pride for their work. Students who had struggled in the classroom, either due to learning disabilities or language barriers, were engaged and successfully navigated difficult practices, such as identifying independent and dependent variables. Following students' completion of their projects, teachers also noticed a difference in the perseverance of some students in the face of difficult assignments.



Generating and refining questions and hypotheses for science investigations are quite difficult, even for practicing scientists. Students will likely struggle at first and should be reminded that this is a normal part of doing science. Almost all of our students had to go through several iterations to refine their questions and hypotheses (Figure 5; see this article's online supplements for tips on refining testable questions). We believe this is an essential aspect of practice development, so these tools (in particular the Question Flowchart and the Inquiry Boards) can be used in an iterative manner as students settle on an investigation path.

We also recognize that these tools are designed specifically to facilitate hypothesis-driven science investigations. This is not meant to constrain the kinds of science that students engage in in the classroom and we caution teachers against this; there should be continued support for other types of science engagement. In particular, teachers should seek support for the parallel process of generating problems and designing solutions for engineering.

We saw considerable benefits to using these tools in the classroom. Students generated written work that made their thinking visible at each stage of the process. This record allowed teachers to more easily support individual students as they progressed through the investigation at their own pace. Students were also able to reflect on their own thinking and develop an appreciation for the iterative nature of scientific investigations. Finally, we saw that by developing their own research questions, students felt a sense of ownership over their work and were proud to share their ideas and results. This may be the most enduring benefit of using these tools, since ownership can increase student participation and engagement with science (O'Neill and Barton 2005). By providing additional support for the science practices at the early stages of investigations, these activities will help teachers continue to align their curricula with the NGSS. ■

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Resource

Inquiry Boards video—www.youtube.com/watch?v=2RuXjrGrggY

L. Max Tarjan (ltarjan@ucsc.edu) and **Kristin de Nesnera** (kdenesne@ucsc.edu) are PhD candidates in the Department of Ecology and Evolutionary biology at the University of California, Santa Cruz, in Santa Cruz, California, and are Graduate Fellows of the National Science Foundation GK–12 program, Santa Cruz–Watsonville Inquiry-Based Learning in Environmental Science (SCWIBLES). **Robert Hoffman** (robert_hoffman@pvusd.net) is a science and NGSS curriculum coach for Pajaro Valley Unified School District in Watsonville, California, and Teaching Fellow of SCWIBLES.