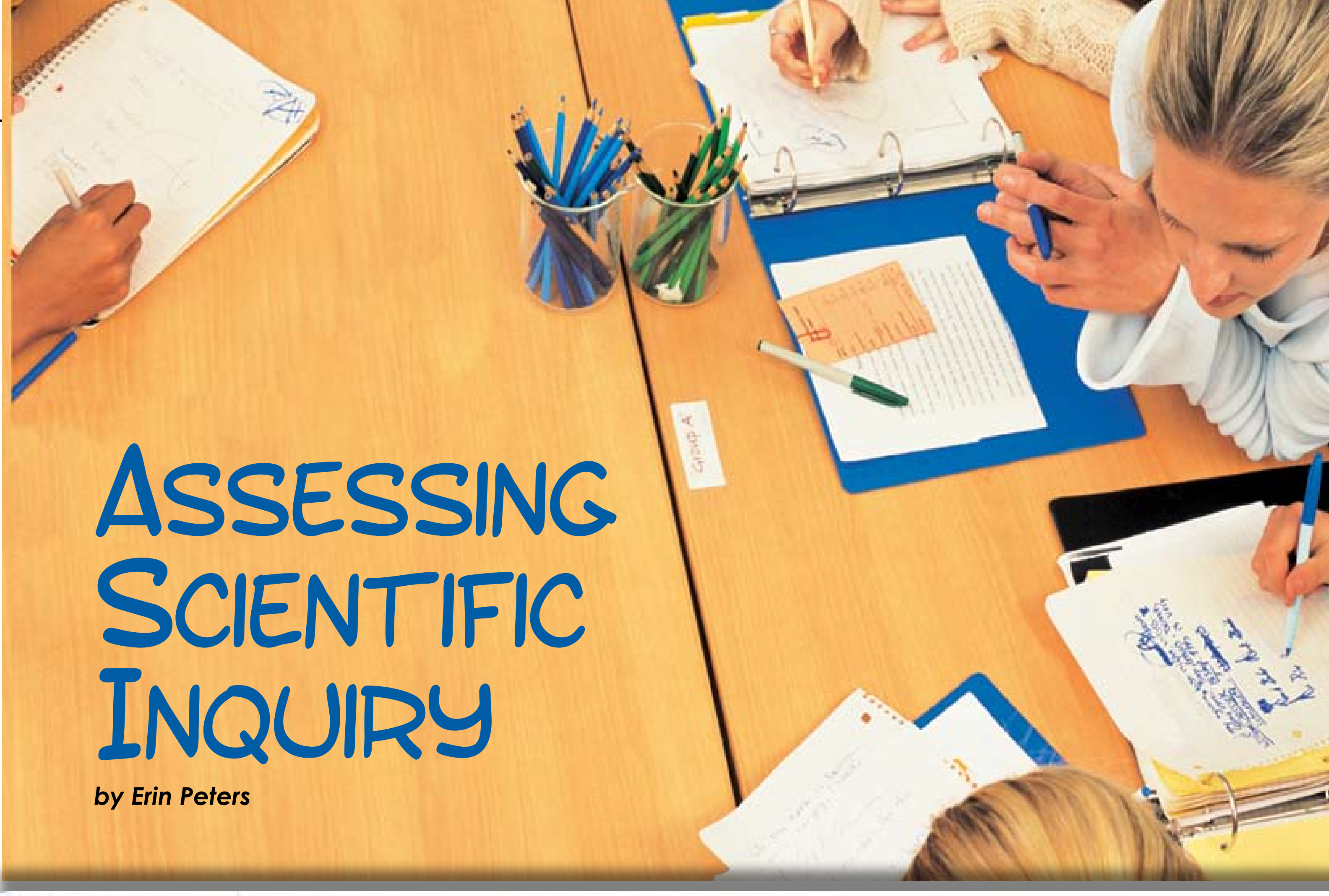

Assessing Scientific Inquiry

by Erin Peters

Assessing student-led, open-ended scientific inquiry holds a unique problem for classroom teachers because of the diverse skills and content that emerge from student work. This article provides tangible strategies for teachers to assess divergent student-generated inquiry in a manner that is manageable for teachers, informative for students, and that demonstrates measurable academic growth. Using strategies illustrated in this article, teachers can improve inquiry assessment by developing a culture of assessment as information rather than judgment, developing relevant criteria for assessment of scientific thinking, and including vital elements in planning lessons in order to effectively inform instruction through assessment.

Information, not judgment

Establishing an environment where students are not afraid of getting feedback is fundamental in assessing inquiry. In the current atmosphere of standards-based education and assessment, students are often left with the impression that the outcome of assessment is a final evaluation of their work in the form of an irrevocable grade. But assessment's main function is actually to determine the extent of student learning in order to inform future instruction, not to place a judgment on the value of work. Effective inquiry, because of its fluid nature, requires an environment where students welcome assessment.

To accomplish the massive task of changing the culture of the classroom in terms of assessment, it is helpful for teachers to assign students ways to communicate informally. One way to provide informal assessment in inquiry is to have a two-way journaling activity from the beginning to the end of an inquiry project. This gives students a private way to discuss difficulties and to express their progress. Journals also give teachers a way to provide feedback to students to help guide their work

However, most middle school teachers face a time constraint when journaling with students. One suggestion to make this assessment technique more manageable is to have students record their concerns and successes with their inquiry once a day from Monday through Thursday. On Friday, students should summarize their concerns and successes for the week and the teacher can respond. This gives students the chance to reflect on their own work, synthesizes their progress, and condenses the workload for the teacher. Another method to make journaling more manageable is to have students jot down ideas as a group. If a teacher has 100 students and there are four members in each group, this process reduces the number of journals read by the teacher from 100 to 25. Having students jot down ideas as a group helps them to refine their ideas because the group has to collectively express their ideas. The main idea in the two-way journaling is to have students feel comfortable expressing their ideas without the fear of judgment. Establishing an environment where students feel that they can freely describe their work without fear of failing opens the channels for communication that are necessary in the learning process.

Another way to create an environment where assessment is not seen as a judgment is to develop methods of peer assessment and self-assessment. During the development of inquiry studies, students in different groups can sit beside each other and discuss their progress as well as their difficulties. This process gives students a chance to summarize their work and to identify any difficulties they may have. As an added bonus, students will often clarify complex issues when they talk out loud about their work. Figure 1 provides some sample questions that students can ask when conducting a peer review. Self-assessments are a way to help students clarify their work to date, and teachers can gather information about students' perceptions of their progress. Figure 2 shows a sample of a student self-assessment instrument. Since students are pursuing divergent topics and processes, it is imperative that they feel free to discuss their learning with others.

Criteria for assessing inquiry

Quality student inquiry often results in divergent directions of study within each class, which makes the creation of assessment tools difficult. Another complication of assessing inquiry includes the pursuit of topics for which teachers may not have content expertise. How can you possibly assess each diverse project fairly? Three concepts that are essential to the construction of scientific knowledge can be used to help with this dilemma: ways of knowing in science, processes of science, and science content. All three concepts are necessary in scientific inquiry, so they should be an integral part of assessment.

Ways of knowing in science

Education researchers have identified some aspects of the nature of science that are appropriate for use in the K–12 arena (Abd-El-Khalick, Bell, and Lederman 1998; Lederman 1992; McComas 2005). The nature of science includes the ideas that science is durable yet tentative, empirical evidence is required to back up ideas, historical and social factors influence the development of scientific ideas, science is a creative endeavor, science and technology influence each other but are not the same, laws and theories are two different ways of knowing, and habits of mind of science incorporate accurate record keeping and peer review. Aspects of the nature of science, such as the need for empirical evidence and the habits of mind of science, can be assessed in a practical way during student inquiry.

In assessing students' understandings of the need for evidence, teachers should look for student use of empirical evidence in gathering data during inquiry. That is, students should avoid using ambiguous or relative terms such as "colorful" or "big" in describing their observations. Instead students should use precise descriptions like "green, blue, and red" or standard units such as "27 centimeters" so that the descriptions could be understood by others. Another factor in assessing student orientation toward evidence is the ability to back up ideas using empirical evidence. Student work can be reviewed for the extent that each idea is justified by using empirical evidence gathered during the inquiry. A third factor that can be used to assess student inquiry work in terms of evidence is the willingness to change ideas in the face of evidence (Harlen 2007). Often students cling to their preconceived notions even when the evidence gathered during the inquiry refutes their prior ideas.

Habits of mind in science have always been difficult to assess, but identifying important aspects of behavior in science may make this venture more tangible. Three important facets of habits of mind in science consist of the ability to construct meaningful questions, to choose tools that gather consequential data, and to infer from evidence. As students develop original questions for their initial inquiry, teachers can determine if students know the outcome of the inquiry by assessing prior knowledge. If students are aware of the outcome, they have not generated a meaningful question and the time spent on the inquiry could be used in more fruitful pursuits.

Student choice of tools can be assessed for their appropriateness in gathering the most precise and reliable data. For example in an inquiry unit, students may choose to use a meter stick to measure the thickness of a dime although a Vernier caliper is available. Teachers can provide feedback to students to introduce the use of a Vernier caliper in order to measure small distances.

Habits of mind can also be assessed in terms of students' ability to infer from evidence. Students can demonstrate their ability to engage scientific habits of mind by explaining all possible inferences that can be made about their study and tightly linking their inferences to the evidence found in the inquiry. Assessing scientific habits of mind in three distinct

FIGURE 1 Peer-review sample questions

	Meets expectations	Could use some improvement	Comments (must be filled out by reviewer)
Ways of knowing in science			
Are all ideas backed up with evidence from the inquiry?			
If the group changed their way of thinking about the inquiry, could they explain why? Was there a point in the inquiry where the group got stuck? How did they get over that barrier?			
Did the group go back to improve on their procedures and data? Could the group explain or document how their processes changed as they learned more about the topic?			
Did the group try to find out what scientists already know about their topic? Is there evidence that the group researched what is already known about this topic?			
Processes of science			
Did the group record observations that everyone, even if they weren't involved in the inquiry, could understand?			
Did the group think about other ways to measure in their inquiry?			
Did the group try to predict what might happen in their inquiry?			
Did the group begin with a general question that was testable?			
As the group went through the inquiry, did more questions come out of the study?			
Did the group have a plan for their inquiry that made sense?			
Did the group follow the plan? If not, can they explain why they didn't follow the plan?			
Did the group make decisions about their conclusions that were based on their evidence?			
Are there better ways for the group to communicate ideas, procedures, or results?			
Science content			
Note to teachers: Use local standards to indicate student understanding of content.			

FIGURE 2 Self-assessment sample questions

	Meets expectations	Could use some improvement	Comments (must be filled out)
Ways of knowing in science			
Can you connect all of your ideas with evidence found in the inquiry?			
Did you change your mind about the inquiry? Can you document how this happened?			
Would you make any changes in your procedure based on what you know now?			
How much research did you do to find out about your topic?			
Processes of science			
Are your observations as detailed as you can make them?			
Did you use the best tools to make measurements in the inquiry? Did you do research to find other tools that measure the same quantities? Could your data be more precise when you use these other tools?			
How did you know that your question that guided the inquiry was testable?			
Did you think of other questions as you progressed through the inquiry?			
Can you explain why your plan for inquiry was the best one for you?			
Could you communicate your processes, ideas, or results differently?			
Content			
Note to teachers: Use local standards to indicate student understanding of content.			

forms—forming meaningful questions, choosing appropriate tools, and inferring from evidence—gives both teachers and students a solid framework.

Peer review plays a large part in the development of scientific ideas, so it is important that it has a role in the assessment of inquiry. Two factors that can be assessed in peer review are students' ability to communicate scientific ideas effectively to other groups, and the ability to look at other projects critically. Often students are afraid of hurting each other's feelings by making corrections on peer work, so teachers can provide students with assessment tools (such as the one described in Figure 1) in order to ensure suitable communication between peer groups.

Processes of science

Some of the processes of science that can be assessed are observing, explaining, predicting, formulating questions, measuring, planning investigations, conducting investigations, and interpreting evidence. Not all processes are appropriate for all science inquiries, so teachers should choose which processes are useful for the particular inquiry unit students choose to follow. For example, if students are examining the food choices of meal worms, observation may be more useful than measurement in describing the results. Assessors of the inquiry unit could comment on the amount of detail that goes into the process of observing and make appropriate suggestions.

Science content

Of course, content that is constructed during the inquiry unit is important to assess. Teachers can gauge their assessment of content in terms of the breadth and depth of content that is constructed during the unit. For example, if students are investigating the types of rocks that are found in the schoolyard, the breadth of the information can be measured in terms of completeness of the accounting of rocks. The depth of information can be assessed in terms of the research that goes into describing the rocks, identifying the rock formations, and describing the possible origin of the rocks. Helpful descriptions of core content information can be found in the *National Science Education Standards* (NRC 1996) or the *Benchmarks for Science Literacy* (AAAS 1993). Figure 3 presents a journaling tool that illustrates the use of the three major concepts, ways of knowing in science, processes of science, and science content, in assessing inquiry work.

Effectively informing instruction

Teachers can set the stage for effective assessment in inquiry by planning lessons that include three factors: (1) providing mechanisms to allow students to show what they know, (2) building multiple types of assessment into inquiry units, and (3) planning assessments for multiple audiences. Students should be given open-ended assignments so that teachers have complete and accurate information about students' conceptions and misconceptions. Since forced-choice assessments, such as multiple choice or fill in the blank, do not allow students to express their understandings, multiple types of assessments, such as oral reports, diagrams, or role playing, can be used to help students find a variety of ways to express their ideas effectively to a variety of audiences.

Let students show what they know

Meaningful learning goals that can have more than one answer and open-ended questioning techniques are two characteristics that allow students to show what they know. It is difficult to aspire to deep student understanding of concepts if learning goals in inquiry units are superficial. Meaningful learning goals, for example essential understandings (Wiggins and McTighe 1998), provide students the opportunity to explore and connect new knowledge with prior knowledge. A mixture of open-ended communication processes like written portfolios, oral presentations, flowcharts of ideas, and student-kept records help teachers to ascertain what knowledge students value and what they accurately comprehend.

Multiple types of assessment

Knowledge is difficult to assess accurately if it is not communicated well. Students can demonstrate their strengths and weaknesses in communication styles when offered multiple forms of assessment, such as written, oral, and diagrammatic. A variety of assessment types offers students a chance to write their understandings, speak about their understandings, and represent their understandings using symbols. Examples of student work products that can be assessed are as varied as student-kept records, portfolios, journals, rubrics, anecdotal notes, student-teacher conferences, and student-student conferences. Figure 4 shows some examples of how these products can be used to elicit student communication of their knowledge.

Frequent feedback loops

Students who receive frequent feedback about their ideas during the inquiry process tend to develop more complete understandings of science (Donovan and Bransford 2005). However, it is difficult for a teacher to provide frequent feedback to students due to time constraints. One solution to this problem is to assign students the task of presenting the information to a variety of audiences, using tools such as peer assessment and self-assessment. Peer feedback can give students multidimensional perspectives on work, which will lead to increased quality in student knowledge. Frequent peer assessment and self-assessment can result in the perception that assessment is not a judgment of students, but rather a method of providing important information to improve their work, resulting in increased understanding. (For information on peer and self-assessment, see "Assessing Student Presentations From Three Perspectives," in this issue.)

Assessment is important in guiding open-ended inquiry in productive directions. Frequent two-way communication of knowledge and skills, otherwise known as content and process, learned through inquiry is necessary in the construction of valid conceptions about phenomena. By developing a culture of assessment as information, planning lessons that allow open-ended communication, and establishing tangible criteria for scientific thinking, teachers can be well informed about student growth and can demonstrate measurable academic achievement. ■

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FIGURE 3 Assessment journal

	Date #1		Date #2		Date #3	
	Teacher comments	Student comments	Teacher comments	Students comments	Teacher comments	Student comments
Ways of knowing in science • Respect for evidence • Willingness to change ideas in the face of evidence • Willingness to critically review procedures, observations, and inferences • Willingness to use available knowledge						
Processes of science • Observing • Explaining • Predicting • Formulating questions • Planning and conducting investigations • Interpreting evidence • Communicating						
Science content (example) • Sediments of sand and smaller particles (sometimes containing the remains of organisms) are gradually buried and are cemented together by dissolved minerals to form solid rock again.						

FIGURE 4 Student work products

Student products	Types of communication	How they could be used in assessment
Student-kept records	Written and diagrammatic	Teachers can establish benchmarks to be reached at certain points in the inquiry. When students reach a benchmark, teachers read the student-kept records of the inquiry and provide feedback on completeness of ideas, misunderstandings, scientific processes, and further study.
Portfolios	Written and diagrammatic	Instead of assessing the portfolio of work at the end of the project, teachers could assess the products as they are chosen for the portfolio. At the end of the project, teachers look at the totality of the work in the portfolio for an additional assessment of work.
Journals	Written	Students can write to teachers about the progression of learning goals and teachers can comment on their progress and offer suggestions for additional study.
Rubrics	Written	Students can create their own rubrics to show what they consider to be quality work.
Anecdotal notes	Written	Teachers can observe learning in lab groups and write field notes on student progress, which are shared with students individually to enhance the learning experience in inquiry.
Student-teacher conferences	Oral	Teachers can interview students in a one-on-one setting using the three indicators for inquiry: ways of knowing in science, processes of science, and science content. The assessment journal in Figure 3 can be adapted for this type of assessment.
Student-student conferences	Oral	Students can interview students from other groups in a one-on-one setting using the three indicators for inquiry: ways of knowing in science, processes of science, and science content. The assessment journal in Figure 3 can be adapted for this type of assessment.

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