Using Assessment as a Guide in Teaching for Understanding: A Case Study of a Middle School Science Class Learning about Sound

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ABSTRACT: The incorporation of assessment practices embedded in instruction is critical in addressing both researchers’ and practitioners’ concerns about ways to improve teaching and learning in science for understanding. This article, the result of such concerns, examines the work of one teacher who taught a topic of sound to grade 8 students over a period of three weeks. Using an interpretive research methodology, the findings of the study are presented as five assertions. The research showed that ongoing embedded assessment was used by the teacher to inform her teaching, that nearly every activity had an assessment component integrated into it, that students had a wide range of opportunities to express their knowledge and understanding through writing tasks and oral questioning, and that individual students responded to and benefited from the different assessment techniques in various ways. The article concludes with discussion about the current reforms, which support the notion that the integration of teaching with assessment does lead to improvement of science learning.

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INTRODUCTION

Recent research implies that learning can be improved when teachers use curricula and instructional strategies that allow for frequent and ongoing assessment of students’ understanding as it develops and is restructured over time during learning (Black, 1993; Black & Wiliam, 1998; Champagne, Lovitts, & Calinger 1991; Duschl & Gitomer, 1997; Simpson, 1993; Kyle, 1997; Wiggins, 1998). The premise is that teachers should utilize information from ongoing assessment to make adjustments in their teaching in response to their students’ ideas and reasoning. These adjustments will aid students in learning and understanding scientific concepts more thoroughly.

However, ongoing assessment is not the norm. According to Duschl and Gitomer (1997), much classroom research shows that the main emphasis in many classrooms is focused on the activity structure of lessons, including time, materials, and students’ behavior. Assessment of cognitive goals in these lessons is often ignored or only addresses lower levels of learning behavior. Research data and practical knowledge from working with teachers show that the common model of teaching and assessment in secondary schools involves teaching a topic, testing students to assign grades on their achievement pertaining to the content, and continuing on to the next topic. In common practice employed in secondary school science classes, assessment data are not used systematically by teachers to alter their instructional plans (Gallagher, 1987; Salish, 1997). Instead, assessment is used mainly to assign students their grades in a summative manner.

This state of affairs has not gone unnoticed, and a wide variety of educators are beginning to critically examine and experiment with alternative approaches to assessment that allow teachers to analyze the development of students’ scientific understanding and reasoning. These alternative approaches go beyond forms of assessment that only serve to appraise students’ ability to recall information and assign grades. In this vein, the National Science Education Standards (National Research Council, 1996) contain several recommendations:

Assessment processes that include all outcomes for student achievement must probe the extent and organization of students’ knowledge. Rather than checking whether students have memorized certain items of information, assessments need to probe for students’ understanding, reasoning and the utilization of knowledge.

Assessment and learning are so closely related that if all the outcomes are not assessed, teachers and students likely will redefine their expectations for learning science only to the outcomes that are assessed. (p. 82)

But what should the alternative assessment look like and how will it help? First, the assessment should match our models of best teaching practice. Kulm and Stuessy (1991) state that:

When learning is individualistic and dependent upon experience and motivation, assessment must be continuous, sensitive to individual differences, and open-ended enough to be capable of reflecting deep and broad understanding. Although some separate testing may be necessary, most assessment should be non-intrusive and integrated with learning activities. (p. 74)

This type of assessment combined with teaching is called embedded assessment (Gallagher, Parker, & Ngwenya, 1999; Wiggins, 1998) because the assessment is embedded...
in and is an integral part of the teaching. Embedded assessment is defined as an ongoing, cyclical process which teachers can use to:

1. gather information about their students’ understanding and reasoning about any particular content knowledge in science
2. make sense of that information
3. use it to guide instructional decisions including making adjustments to teaching plans in response to the character of students’ conceptual understanding (Simpson, 1993; Wiggins, 1998)

The process tends to be informal, but well organized. Moreover, effective teachers gather information as students work on learning or assessment tasks that expose their ideas and reasoning. Effective teachers also do this as part of their normal teaching when they observe and listen to students engaged in the task, talk to them, ask probing questions, involve students in whole class discussions following work on the task, and examine written and graphic work that are products of the task (Virginia Education Association, 1992).

Research also supports the idea that assessment and effective teaching should involve students in writing and use of other representations. Writing can play a powerful role in the learning of science (see, e.g., Glynn & Muth 1994; Hand & Prain, 1995; Holliday, Yore, & Alvermann, 1994; Keys, 1994, Rivard 1994). When students write about their observations and findings from experiments, they organize their thoughts better, and they sharpen their interpretations and arguments. Further, writing enables students to express their intellectual and emotional reactions to science phenomena in a variety of forms (Glynn & Muth, 1994, pp. 1065 – 1066). These same authors recommend that writing is effective when it involves a real audience and is written in such a way that the writing can inform the uninformed.

Less is known about the utility of oral and graphic presentations by students as vehicles to inform teachers about students’ understanding and reasoning. Nevertheless, oral presentations are an effective way to assess students’ knowledge if they are accompanied by means of interpreting responses similar to a scoring rubric. The use of drawings, diagrams, and models constructed by students in conjunction with oral or written descriptions or explanations appears to be another powerful tool which can be used to gain insights into students’ understanding of scientific ideas and reasoning.

The outcome of effective use of ongoing or embedded assessment as an integral part of teaching should be a more focused approach to teaching in which adjustments are made in response to students’ ideas. Wolf, Bixby, Glenn, and Gardner (1991) claim that such a shift in the direction of assessment might enable teachers to develop sophisticated clinical judgments about students’ understanding of significant ideas and processes and encourage educators to discuss, rather than simply measure educational progress. (p. 33)

This is consistent with the goals of the National Science Education Standards (National Research Council, 1996, p. 87) which describe “teachers [as being] in the best position to put assessment data to powerful use.” Some of the ways that the Standards advocate that teachers use these data include improving classroom practice, planning curricula (and lessons), developing self-directed learners, reporting students’ progress, and researching teaching practices.

The change from the common assessment practices to those just described requires a change in the basic epistemology of teaching and learning from a testing culture to an
assessment culture (Wolf et al., 1991) or portfolio culture (Duschl & Gitomer, 1991). Broadly defined, assessment using performance tasks requires students to write, read, and solve problems in genuine, rather than artificial, ways. Portfolio-based assessment involves a structured sampling of a student’s work over time on selected science activities and tasks, taken from different topics. This is a systemic change requiring a change in thinking by teachers, educational institutions, testing agencies, and parents. The major outcome of this study is to help educators make the change by providing a detailed illustration of what assessment integrated into teaching looks like.

PURPOSE OF THE STUDY

This case study is a detailed investigation of one experienced teacher’s use of embedded assessment as a tool for improving instructional effectiveness and student learning in middle school science; the teacher, Roberta Jacobowitz (a co-author of this paper) is hereafter called Roberta. The goal of the study is to document and describe how embedded assessment plays out in a real classroom and explores the effects of this approach on students and the classroom environment. During the case study, we explored and documented how Roberta, an acknowledged exemplary teacher, incorporated assessment tasks as an integral component of her teaching about the topic of sound. The outcomes of the study, which are reported as five assertions, illustrate how this teacher’s use of assessment was compatible with students’ expectations of how they felt they best learned science and also led them to a deeper understanding of scientific concepts about sound.

DESIGN OF THE STUDY

The Context

This research was part of a larger project of cooperation between university faculty members in education and several local school districts that incorporated the notion of Professional Development Schools as sites for research and professional development in real schools (Holmes Group, 1990). On a regular basis from 1992 – 1999, university faculty met with middle school (grades 6 – 8) science teachers in various schools to identify ways of using assessment to improve teaching effectiveness and student learning. Six resource booklets and a process for staff development were used as a guide for teachers in making changes in their teaching based on assessment of students’ understanding of and reasoning about the subject matter being taught (Gallagher, 1996). Roberta had been involved in the cooperative project since its inception and was considered to be proficient in the teaching approaches being described.

The Grade 8 class was composed of 23 students representing diverse ethnic backgrounds, being approximately one-third Caucasian, one-third African-American, and one-third Hispanic-American, with a small percentage of Asian-Americans and Native Americans. The students, who were from a working class neighborhood of a medium-sized midwestern city where parental involvement in the school was minimal, had a range of abilities and aptitudes for school and for science. The working class socioeconomic status of the school community was confirmed by the following data: 62% of students were eligible for free or reduced lunch, one-third of students transferred in or out of the school during the school year, and, according to the 1990 census, the mean family income was <$13,000. The unemployment level for adults 16 years or older was 15.6%, as opposed to 6.2% for the city and surrounding area (Michigan State University, 1999).
The Teacher

Roberta has taught middle school science for >20 years and had much experience with the diverse range of students who were enrolled in her class. Observations of Roberta’s teaching, and conversations with her after class regarding the topic of sound and earlier topics, indicated that she had a very good idea of the interest level of the students in this class, their potential for learning, and their attention spans. Among her peers, Roberta was acknowledged as a dedicated and competent teacher who was nominated for a national award for her work and who was always ready to offer supporting ideas to her colleagues to improve their practice, writing an article on this for *Science Scope* (Jacobowitz, 1997).

Conversations with, as well as classroom observations of, Roberta indicated that she was well organized in her background reading and daily classroom preparation and was diligent about grading students’ assignments and promptly handing back their work. For Roberta, this was necessary because she believed that students learn best from returned work when it was received as part of the next class session. However, this willingness to be responsive to students’ learning needs through daily preparation and assessment brought many challenges:

> It makes life difficult. Heaven forbid if I am called out of town on an emergency or something. I would have to make lessons that would not just carry from one day to the next.

These personal qualities enabled her to be flexible about her lesson preparation and assessment schedules; these qualities need to be taken into consideration when examining the results of the study reported here.

In an interview at the beginning of this study, Roberta revealed that prior to being involved in the Professional Development Schools project, she never used pretests, did not give serious attention to students’ misconceptions, and did not try to challenge students’ notions. Moreover, formerly she was more worried about “getting through the book” instead of considering students’ ideas and reasoning as a focus of instruction. Now, her current teaching and assessment approach encompassed all these issues and enabled her to include more emphasis on applications of science and use oral presentations from students’ among many other approaches. She also is more attentive to helping students reconcile their personal ideas and reasoning about natural phenomena with accepted scientific understanding.

The Topic of Study—“The World of Sounds”

The study took place over 3 weeks as Roberta taught a unit entitled, “The World of Sounds” that covered three textbook chapters on “What is sound?” “How does sound move?” and “Listening closely,” which included the structure and function of the human ear. More specifically, her unit encompassed the following concepts:

- sound travels in waves
- vibrations cause waves
- sound travels at different speeds though different media
- echoes—how they occur and how they are used
- human hearing—anatomy and effects of environment
These concepts were broken down to smaller concepts including making sounds, vibrations, speed of sound, frequency, pitch, sonograms, compression and rarefaction (called expansion in the textbook used by students), echoes, measuring sound, white noise, and noise. Essentially, the unit was aligned with the scientific literacy statements from the Michigan Essential Goals and Objectives for Science Education (Michigan State Board of Education, 1991, p. 101).

The class textbook—the Blue version of Science Plus: Technology and Society (McFadden & Yager, 1993)—is an engaging text and was selected by the local school district after an initial pilot study by the science department for this grade level because the subject matter, interest level, and reading level were considered compatible with the students in the school. According to the philosophy of the course stated in the textbook, Science Plus develops scientific process skills as an essential goal. As the curriculum progresses, the students will gradually master incredibly complex tasks. For example, students will move from directed inquiry to open-ended inquiry, and from reading and completing tables and graphs to constructing them from experimental data they have collected on their own. (McFadden & Yager, 1993, p. T15)

The textbook is produced in an attractive multicolor format with many activities and supplementary material. In Roberta’s classroom, students did not have their own books, rather class sets were available for use only while students were attending the class. Prior to commencement of the topic, a notice (Unit 5, Home Connection, McFadden & Yager, 1993, p. 163) was sent home to parents to inform them of the big ideas of the unit, presented as questions as follows: What are some of the characteristics of sound? What causes sound? How is sound transported from a sound source to a sound receiver? and Why can some animals hear sounds that people can’t hear? In addition, the packet of information sent home included a suggested activity for child and parent that involved experiencing the doppler effect.

The Research Approach

In this study, an interpretive research methodology (Erickson, 1986; Gallagher, 1991) was employed such that there was minimal interference in teaching during the actual lessons (Guba & Lincoln, 1989). At this point in the Professional Development Schools project, Roberta was familiar with the approaches for embedding assessment as part of teaching and was very comfortable with the researchers being in her classroom. During the 3-week period of the study, a researcher was present as a participant observer in all lessons that were videotaped and subsequently analyzed in terms of the teacher’s use of assessment during teaching. Following the lessons, Roberta was interviewed to clarify her use and methods of planning for embedded assessment activities. Several students were interviewed about their reactions to the lessons and particularly how the assessment strategies were used in the lessons and how they contributed to or detracted from learning the science concepts. Each interview was tape-recorded and transcribed verbatim (Merriam, 1988).

Once the data corpus had been collected, the researchers looked for particular incidences of embedded assessment. This analysis enabled the development of five assertions (Erickson, 1986) that are used to frame and interpret the data. These assertions focussed on embedded assessment tasks:

1. used during the wide variety of activities in this topic
2. used as pretests
RESULTS AND INTERPRETATIONS

Assertion 1: The Teacher Provided a Wide Variety of Activities, Most of Which had an Assessment Component Integrated Within Them

Roberta planned and implemented a wide variety of activities that included reading from a variety of sources, viewing laser disk and video clips, using simple equipment to explore various phenomena, collecting data from experiments, and explaining phenomena orally, in writing, and with diagrams or pictures. Each activity package included at least one integrated assessment component. For example, on the fourth day, students explored ways of changing the pitch of two “instruments,” tuning forks and a strip of paper with a paper clip attached to one end that they blew over. Not only did students use the instruments, they also wrote descriptions of what they had to do to change the pitch; later, the whole class discussed what they had found. These activities revealed students’ progress to the teacher at the same time giving students opportunities to clarify and compare their ideas.

A summarized description of the activities that Roberta used during the unit on sound is presented Table 1, where the last column identifies the assessment component in each activity. Because each activity has an assessment component, she was continuously able to guide and redirect students’ ideas. This embedded assessment also made students’ ideas the focus of the class.

Assertion 2: The Teacher Used Pretests to Guide Her Teaching and Instructional Decisions

Roberta began the unit by providing a pretest consisting of six open-ended questions reflecting the relevant main ideas from the *Michigan Essential Goals and Objectives for Science Education* (Michigan Department of Education, 1991) supplemented by the main ideas developed in the textbook which the district had adopted (McFadden & Yager, 1993).

The pretest, which was designed to identify students’ personal conceptions, alternative frameworks, and problems about sound and its properties, contained the following questions:

1. What makes different materials make sounds? What do they all have to do?
2. How does sound travel from one place to another?
3. Explain how your ear helps you hear. (A drawing of the ear was provided.)
4. What is an echo? How can you make an echo?
5. Can sound travel through anything else besides air? Give two examples. Which does it travel through the fastest?
6. Name an instrument that makes sound. Describe what has to happen for it to make a sound.

Fundamental issues of distinguishing sounds, differentiating pitch and loudness, high and low sounds, and how sounds are made are part of the curriculum in elementary grades, but are frequently omitted from the elementary school curriculum by teachers who often have limited scientific backgrounds and motivation to teach science.
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<th>Day/Topic</th>
<th>Activity</th>
<th>Lesson Format</th>
<th>Assessment</th>
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<td>1. Pretest</td>
<td>Introductions</td>
<td>Individual, then class discussion</td>
<td>Writing (Individual)</td>
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<td>2. The sound of silence</td>
<td>ET—Background noise is referred to as white noise, because . . . ?</td>
<td>Individual, then class discussion</td>
<td>Oral questioning</td>
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<td></td>
<td>ET—White noise is referred to as . . . ?</td>
<td>Individual, then class discussion</td>
<td>Oral questioning</td>
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<td></td>
<td>Letter to parents about key questions for unit</td>
<td>Individual, then class discussion</td>
<td>Oral questioning</td>
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<td></td>
<td>Classifying sounds/read aloud from text (pp. 264–265)</td>
<td>Individual, then class discussion</td>
<td>Oral questioning</td>
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<td></td>
<td>Five min. of silence—record and categorize sounds</td>
<td>Individual</td>
<td>Written explanation</td>
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<td></td>
<td>Read pp. 266–267, worksheet</td>
<td>Individual</td>
<td>Written explanation</td>
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<td>Use stethoscope to listen to heart, pulse, and lungs</td>
<td>Small groups</td>
<td>Questions</td>
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<td></td>
<td>Make different pitches with zoom sticks</td>
<td>Demonstration</td>
<td>Questions</td>
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<td>ET—Noise is caused when something . . . ?</td>
<td>Individual, then class discussion</td>
<td>Writing (Individual)</td>
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<td>3. What causes noise?</td>
<td>Science in the news</td>
<td>Individual, then class discussion</td>
<td>Writing (Individual)</td>
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<td></td>
<td>Sound sleuth, watch witnesses describe a distraction problem at school</td>
<td>Individual, then class discussion</td>
<td>Writing (Individual)</td>
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<td></td>
<td>ET—If a tree falls in the woods when no one is there to hear it, does it make a noise?</td>
<td>Individual, then class discussion</td>
<td>Writing (Individual)</td>
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<td>4. Making sounds</td>
<td>Worksheets from previous two days—common problems</td>
<td>Small group</td>
<td>Writing (Individual)</td>
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<td></td>
<td>Make sounds by blowing on a piece of paper with a paper clip and with a tuning fork and sounding board (p. 268)</td>
<td>Individual experiments</td>
<td>Writing (Individual)</td>
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<td></td>
<td>Write answers to Q’s—wrap-up discussion</td>
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<td>Section</td>
<td>Activities</td>
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<tr>
<td>5. Making sounds</td>
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<tr>
<td>· Discussion of activities from previous day</td>
<td>Class discussion</td>
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<td>· Tuning fork makes flame waiver</td>
<td>Demo and class discussion</td>
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<tr>
<td>· Make sound with rubber band on sounding board</td>
<td>Small group experiments</td>
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<tr>
<td>· Experiment—Which will make a lower sound?</td>
<td>Demonstration, laser disk</td>
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<tr>
<td>· Blowing on bottles with different amounts of water, rubbing finger on wine glasses with different amounts of water, shattering glass with sound (pp. 268–269 and worksheet)</td>
<td>Individual experiment</td>
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<td>6. Sound is caused by vibrating objects</td>
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<tr>
<td>· Making sounds with vibrating stick (Explanation 1, pp. 270–271)</td>
<td>Small group experiments</td>
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<td>· Video—How does sound travel? How are we able to hear it?</td>
<td>Individual</td>
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<td>· Frequency, wavelength, velocity—using slinky spring</td>
<td>Group experiment</td>
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<td>7. Sound creation and transfer</td>
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<td>· ET—Do animals make sounds in different ways? People use a voice-box or ...?</td>
<td>Individual</td>
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<tr>
<td>· Interpreting graphs (p. 273)</td>
<td>Individual</td>
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<tr>
<td>· Discussion about pitch</td>
<td>Questions</td>
<td></td>
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<tr>
<td>· Transmitting sound waves—ball-bearing, cradle, slinky spring, syringe (p. 280, Explanation 4)</td>
<td>Group experiments</td>
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<tr>
<td>· Construct own theory from experiment</td>
<td>Writing (Individual)</td>
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<tr>
<th>Day/Topic Activity</th>
<th>Lesson Format</th>
<th>Assessment</th>
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<tbody>
<tr>
<td>8. Measurement of sound</td>
<td>Individual, then class discussion</td>
<td>Writing (Individual)</td>
</tr>
<tr>
<td>• ET—Sound levels are often measured in . . . ?</td>
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<tr>
<td>• Sound that is loud enough to hurt your ear is . . . decibels</td>
<td>Lecture</td>
<td>Discussion</td>
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<tr>
<td>• Introduction to resources around room (charts, posters, news stories, etc.)</td>
<td>Group work</td>
<td>Writing (Group)</td>
</tr>
<tr>
<td>• How can you demonstrate that sound needs a medium to travel? (pp. 280–284)</td>
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<tr>
<td>• Laser disc illustration of sound waves in air and how the ear works</td>
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<tr>
<td>9. Travel of sound in different media</td>
<td>Individual, then class discussion</td>
<td>Writing (Individual)</td>
</tr>
<tr>
<td>• ET—Which of these sonograms has higher pitch or lower frequency?</td>
<td>Individual work</td>
<td>Questions</td>
</tr>
<tr>
<td>• Predicting speed of sound in different media (p. 287)</td>
<td>Group experiment</td>
<td>Class Discussion</td>
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<tr>
<td>• Echoes, representation of sound waves (p. 289) p. 290 Video of resonance, Tacoma bridge resonance with two tuning folks</td>
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<tr>
<td>10. Travel of sound in different media</td>
<td>Individual, then class discussion</td>
<td>Writing (Individual)</td>
</tr>
<tr>
<td>• ET—Circle the substance that sound travels through fastest and underline the one that sound travels slowest—glass, air, paper, plates, forks</td>
<td>Individual work</td>
<td>Questions</td>
</tr>
<tr>
<td>• Summarizing</td>
<td>Group experiment</td>
<td>Writing (Individual)</td>
</tr>
<tr>
<td>11. Production of booklets</td>
<td>Individual, then class discussion</td>
<td>Writing, reading</td>
</tr>
<tr>
<td>• ET—Why would a dentist’s drill sound louder to you than to the dentist?</td>
<td>Individual work</td>
<td>Writing (Individual)</td>
</tr>
<tr>
<td>• Begin to plan booklet on sound for 5th grade class</td>
<td>Group work</td>
<td>Writing (Individual)</td>
</tr>
</tbody>
</table>
12. Production of booklets
  - ET: Why does a yodel in the mountains sound for so long after the singer stops?

13. Production of booklets
  - ET: Why can't you use a sonar to find the distance to the moon? You hear thunder 5 sec after you see lightning. How far away is the lightning if you hear thunder 5 sec later?

15. What did the booklets tell about sound and its properties?
  - ET: Read and discuss booklets on sound for 5th-grade class.

16. A new sound making instrument
  - ET: Read and discuss booklets on sound for 5th-grade class.

Using Assessment as A Guide in Teaching
The written responses to the pretest were read within 24–48 h and it was evident from students’ responses that they used their daily experiences to answer the questions. Many responses contained ideas that are scientifically correct (e.g., “They will have to vibrate to make sounds”); however, the extension of the response (e.g., “Some materials that make the sound is (sic) brass and wood”) often indicated that exactly what was causing the sound was not clearly understood by students. Ten of 17 pretest responses (6 of the 23 students were absent when the test was administered) to Question 1 included vibration in the answer. Many of the other responses referred to sound bouncing off material or were related to weight. A similar range of responses was obtained from the other questions. It was evident that these students had some ideas about sound and its properties, but their ideas did not appear to be well articulated and students’ explanations of phenomena did not indicate a scientific understanding. For example, in response to Question 4 (What is an echo?), one student wrote “An echo is when you hear a sound that repeats itself” and that to make an echo, you “yell really loud.” While this response is an accurate portrayal of experience, it belies conceptual understanding.

Roberts did not design her teaching program specifically from students’ responses on the pretest, however, information from it was used to address known weaknesses in students’ knowledge. The pretest responses were used to see which ideas should be emphasized or were in need of reteaching in order to build more in-depth understanding. It is important to note that the students took the pretest seriously. As Roberta explained:

> The students’ written responses allow me to see how they are using words and information that they know to connect with bigger ideas related to the outcomes desired. I do inform the students before the pretest that it will be used to show me what they know and therefore it will determine what we have to learn in class. Most of the students have responded well by taking the pretest under these conditions, though I do receive answers ranging from one-word responses to several sentences.

**Assertion 3: A Wide Range of In-Class Writing Tasks Were Integrated into Each Lesson and Used as Summative Assessment of Students’ Understanding**

In addition to the pretest, embedded assessment provided another continuing source of information to guide instructional decisions. At the beginning of each lesson in the unit on sound, students were presented with a question that was to be answered individually before the planned lesson began. A similar activity used at the beginning of lessons is reported by Rillero, Zambo, Cleland, and Ryan (1996). The questions in Roberta’s class, called Eskimo Thoughts or ETs (named after Eskimos, the emblem of the school), were written on the chalkboard at the start of each lesson. Upon entering the class, students picked up their science folders that were kept in the classroom, went to their respective seats at work tables in the class, and wrote answers to the ETs individually. Roberta acknowledged that

> the information I get from the kids often is helpful in my planning and decisions. For example, sometimes I find that students completely missed an idea that I believed I had taught, and it is necessary for them to look the information up in the book and then make sense of it in their own way.

In an interview, she explained further:

> The opening use of an ET question may also show misconceptions when I ask for oral student responses. In those cases I can immediately reteach the concept, have more ex-
An all-encompassing feature of Roberta’s approach to incorporating embedded assessment in her teaching repertoire was her philosophy that every student in her class should have the opportunity to learn. To accomplish this outcome, she ensured that some simple rules of behavior were well established and that a wide range of learning opportunities was provided (see Assertion 1). By carefully arranging activities in each lesson so that students were able to develop a routine in her classes, she acknowledged that students did have many, varied opportunities to learn in her class.

Roberta also used many other written tasks. Throughout each lesson, questions were asked of the students to engage them and deepen their understanding and reasoning about science principles. Frequently, students were asked to write out their explanations for observed phenomena in the sound topic. The manner in which this was accomplished was aligned with the recommendations from the literature described earlier. In keeping with the wide variety of teaching approaches recommended by the National Research Council (1996) and by authors supporting embedded assessment practices, Roberta used group writing and individual writing to enable her to continually assess students’ progress.

**Group Writing.** After two weeks of “The World of Sound,” students were required to write an essay describing how sound travels from one place to another and to describe a series of experiments that would enable the explanation to be verified or challenged or would illustrate how it works. Students individually drafted answers, then in pairs combined their writing into a single essay which they submitted and got credit for both their own and their combined work. Students took to this task very diligently and produced remarkably good explanations and series of experiments to show how their explanation worked. In this instance, students worked cooperatively, supporting each other, questioning when differences of opinion and understanding occurred.

**Individual Writing.** One of the types of individual writing tasks that Roberta frequently used was description and/or explanations of demonstrations and experiments. The following is an example of this kind of writing task introduced by the researchers toward the end of the unit, believing that it would provide evidence to Roberta and her students about their ability to apply their understanding of how sounds are made in a new situation. The researchers introduced a didjeridoo and told the class,

> Aboriginal people in Australia use a musical instrument in tribal ceremonies and now also for the interested public. Perhaps you have seen or heard one being played. The sounds represent those sounds made by animals and birds in the environment where the Aboriginal people live. As fully as possible, explain how sound is made by the didjeridoo, and how it is possible to have such different sounds created.

Student responses to the first question generally referred to the sound being the result of vibrating lips of the blower rather than the vibrating air column so created by the blower. Even so, the responses recognized that the blower had to do different things with his or her lips or mouth to reproduce the different sounds. Looking at the textbook, the relationship between vibrating bodies and moving columns of air was often omitted,
so this would seem to be an acceptable response at this level. Students’ written responses were as follows:

Sounds are created by blowing really low or really high. You have to let your lips vibrate to get a steady sound. (Will)

I think when you blow into the didjeridoo, it’s the way your lips vibrate against the wood which makes the noise. (Alice)

The air particles vibrate, your lips vibrate, and the didjeridoo vibrates to make the noise that it does. To make noises higher, you blow faster and harder. When you want a low sound you blow low and soft. (Tom)

You blow allowing your lips to vibrate, to create different pitches you tighten or loosen your lips. (Mindy)

Certainly, the introduction of this unusual instrument that had not been seen before by any member of the class helped maintain students’ interest until the end of the topic. The written responses also showed that many students were able to apply their understanding of sound from familiar musical instruments to a new, unfamiliar instrument.

Individual writing also was used as a comprehensive assessment to permit students to demonstrate what they had learned about sound. An assignment requiring each student to produce an 8-page booklet about sound for a Grade 5 class (as an authentic audience) sparked the students’ imagination and most went about the task of compiling a booklet with great enthusiasm. In the four days available for its development to complete the booklet, students were required to answer five questions:

What is sound and how is it produced?
How does sound travel?
How do we hear?
What is an echo and how does it work?
When can echoes be useful?

Following this required part of the booklet, ten questions were posed from which they could choose a few in making their own booklet. These optional questions were:

How can sound travel through different media?
How can you describe different sounds?
How is sound measured and when must you protect yourself from noise?
Why don’t we hear sounds from space—like the big explosions of the sun?
How do you control pitch in instruments like a clarinet, guitar, or drum? How can we mufflle noise?
How fast does sound travel?
How do different animals make noise?
How does a microphone, telephone, and tape recorder work?

As is evident from the range of questions, students were able to respond to their own interests from the topic as well as address the main aspects of the sound topic. Some examples from these booklets are presented below in answer to the question “What is
sound and how is it produced?” The first answer is from a student who consistently did well in the class. The second two responses are from average students, while the last response is from a lower achieving student.

Sound is what you hear. Sound can be music or just plain noise. Sound is also a form of energy as well as it needs energy. Sound is the vibration of the air molecules (tiny particles). You hear sound through your ears as the sound waves enter (see page 9 of this booklet). Sometimes you can’t hear the sound even if the air is vibrating. This is because sometimes the object doesn’t vibrate enough. Or sometimes it vibrates too much like in a dog whistle. That’s why dogs can hear the whistle and we can’t. They have more sensitive ears than humans do. (Carol)

Sound is vibrating airwaves. When something vibrates it creates a sound. When objects hit each other, it causes them to vibrate and the vibrations will make a sound if you’ve hit them together hard enough. Take a tuning fork for instance. Hit the tuning fork on a book. You can see it vibrating and as it vibrates it makes a sound. (Liz)

Sound is anything that we hear, like tapping your pencil, playing an instrument—all these things are sound. Sound is produced when something vibrates, like for instance when you talk, your vocal cords vibrate making it [possible] for you to talk. (Chris)

Sound is the vibration of an object that causes a sound wave. (Richard)

The examples below are responses to “What causes echoes?” It was evident from students’ writing that the essential aspects of sound production, a reflecting body and sound receiver, were well understood.

An echo is the sound of our voices bouncing off of an object and coming back to our ears. To hear an echo, you should be far away from an object so that it takes time to get back to you. If you hear more than one echo, it is because sound waves from your voice can bounce off things more than once. They can bounce off a lot of different things many times. (Tracy)

When a person screams in a room with walls around you, your scream will bounce off walls. But your scream is a reflect (sic) from an echo. (Wanda)

An echo is the sound of our voices that bounces off of an object and come to our ears. (Carrie)

Students’ written work in this booklet illustrated their respective understanding of the main concepts on the various parts of the topic and enabled the teacher to assess which students were in need of further assistance prior to completing the unit at the end of the semester. The quality of the written reports provided the teacher with ample evidence of students’ reconciliation of their personal ideas and the accepted scientific concepts, as well as the continued existence of students’ initial conceptions about sound and its properties.

The production of the booklets gave the students precise guidance that caused them to think about the applications and connections about sound. As students worked to prepare booklets, Roberta oversaw their writing and gave feedback prior to completing the booklet. This approach allowed for correction of errors as they occurred. Later, Roberta graded the booklets using a scoring rubric that she designed.

The following examples document students’ thinking as they put ideas and experiences
together. One student described that “an echo is a reflection of sound; like you have a reflection of yourself in a mirror” (Ken). In explaining the working of a phone, another stated that “a phone works by pressing a button that vibrates the carbon granules through all the wires at the speed of light to one person to another” (Robert). A third student stated, “It is called white noise because white is like all the colors mixed together” (Carol). Such attempts at making connections enabled Roberta to work with these students and helped them clarify their understanding.

From the comments that some of the students made to Roberta, the value of this writing assignment was apparent to them. She observed that “some of the kids are really excited about sending these [booklets] to their grade school teachers.” The value of this work was also apparent in interviews conducted in the concluding lesson. Many students stated that they believed that the best way to show Roberta how much they had learned was in writing the booklet for Grade 5: “I think it’s fun” (Melinda) and “It gives us something to do and then it helps us learn” (Sue). Moreover, the importance of preparation of these booklets for use by fifth grade students in elementary schools in which most of the students had been enrolled a few years earlier is a great motivation for them to do quality work. Most wanted to put forth a product in which they could take pride.

Assertion 4: The Teacher Used Oral Questioning as an On-The-Spot Assessment Tool to Guide the Development of Students’ Understanding

Almost all of Roberta’s lessons included class discussions in which she engaged students in questioning that involved accepting varied responses and acknowledging students’ ideas instead of looking for scientifically acceptable responses. Much of what occurred in the class during these questioning periods is reminiscent of the descriptions of those successful teachers described by Sanford (1987) who provided students with a variety of safety nets as they answered questions in class. Certainly, all answers given by students were expressly accepted and debated. These answers were not a cause for fear or ridicule.

Roberta’s method of asking questions was of two types. In most instances, she asked questions to no particular student and most students felt free to provide answers. “Sometimes she asks questions and anyone can answer and it doesn’t matter what you say... you might not know it but you do not get into trouble for saying the wrong answer” (Chip). One of the more perceptive and hardworking students in the class had a clear idea about these different types of questions:

At other times she’ll call on different people, like people that she knows probably wouldn’t know the answers, because she wants them to learn and to see if they can at least try to understand it. (Sue)

She expanded on this questioning style:

It helps for people that (sic) don’t know it that well. It helps them learn it, and then for the people that (sic) already know it, it helps them like memorize it more. (Sue)

This approach to questioning was appreciated by the students and they reacted very positively to answers from their peers that resulted in lively discussion between class members and Roberta. However, one of the problems with the open questioning was the tendency for several students, and one in particular (Will), to give answers to questions without doing much thinking before speaking. Nevertheless, in the climate of the classroom, this male student’s responses were not disruptive and the teacher’s friendly reaction
to his sometimes unusual comments was not perceived as being a reason to not try to answer the question again—which he often did.

In conversations with Roberta after her classes, she repeatedly asserted the importance for her to keep up a steady supply of questions for students to answer on the topic, as well as encouraging students to ask her questions—the more difficult the better. In this way, she was able to assess students’ progress on understanding the key concepts of the lessons and make critical decisions about what she would do next. For example, students were interested in whether or not sound would travel faster underwater compared to air. In response, Roberta asked them to design an experiment that would enable this question to be answered. Students’ responses and ideas allowed Roberta to increase her knowledge of students’ understanding. Students suggested measuring the sounds that animals, such as whales, make, but initially had little idea about how to measure this. A suggestion from Roberta that came from the textbook—to use stethoscopes in water—generated much discussion about how this would work.

Assertion 5: Individual Students Responded to and Benefited from the Different Techniques in Different Ways

Because Roberta provided a wide variety of opportunities to learn, individual students were able to find some tasks that were highly suited to their individual learning styles. This idea came up in a number of student interviews. When asked if they preferred to answer questions orally or in writing, two female students had different views, one preferring to write out her responses, the other preferring to answer oral questions. Both these students were among the more academically able in the class, diligent, and also greatly interested in science.

During class discussion and group work on developing a theory of sound and how it travels, one student (Robert) did not say much at all, but when the opportunity came to do some individual writing, he wrote more than the other group members combined. When asked about this, he stated that he did not speak much in science because his grades were not so good. This method of assessment by writing enabled him, and others like him, to clarify and demonstrate personal understanding in an effective, nonthreatening, and timely manner. However, this facility for individual writing did not emerge spontaneously, having been nurtured by Roberta and previous science teachers in Grades 6 and 7 through the 7 years working with the Professional Development Schools project.

When asked, “In what ways do you believe you were best able to show her how much you had learned? How would you prefer your knowledge of sound to be assessed?” the students gave a variety of answers. Many students considered the booklet for fifth grade to be their best demonstration of learning about sounds (e.g., “She had us make and write a book on sound and when she reads it she will know how much I learned in this class”). Other students believed they could demonstrate their understanding by experiments and group discussions (e.g., “I think the best way I showed her what I learned was by experiments and group discussions”), by writing in different formats (e.g., “By writing a journal and poem about sounds” “I could show her what I learned by writing a report”), by participating in class (e.g., “The best way is to answer all the questions that she asked you. By listening to something or someone everyday and write about it”), or a combination of these (e.g., “Through the booklet we had made for fifth grade. I like doing experiments and hands-on things that makes this class more interesting;” “My making my sound booklet. I could also do an experiment to show what I learned”).

Another way in which the variety of assessment opportunities benefited students was that they could find opportunities that were personally motivating, meaningful, or reward-
ing. This is most poignantly illustrated by Chip’s statement to Roberta about his excitement at sending his booklet to his fifth grade teacher, “I want to send this to Ms. X., because she told me I would never amount to anything.”

Some students recognized the learning value of the variety of activities that they were given, as is reflected in an interview with Robert:

Interviewer: What about the way Roberta gives you grades? Like the assessment, all the different things you’ve to do—do you think that’s a good idea?

Robert: I do.

Interviewer: What’s good about it?

Robert: It makes you learn more things about the subject. She makes us do the book work, and that’s part of the grade; and she’ll talk to us about it and that’s another part of the grade. And so you have to like really do all your work and know what you are doing to get really good grades.

DISCUSSION AND CONCLUSIONS

This research described effective teaching that incorporated embedded assessment in one teacher’s class. Students developed their knowledge and understanding of the concepts within the topic of sound as a result of opportunities to become engaged in a large variety of activities, each of which incorporated assessment procedures. Roberta’s teaching approach enabled students to be involved in fruitful discussions with her, as well as with their student peers, to write both long and short descriptions about what they had learned, to engage in laboratory activities, and to view video material that enriched both their understanding of concepts and investigative procedures. A key feature of the activities of the students in this class was responding to questions from, and prepared by, the teacher in a variety of formats which encouraged them to learn and be perceptive about what they had learned from one class to the next. The culture of the class was that of assessment as opposed to testing.

In addition to supporting students’ learning, the teacher’s work affected the culture of the class in a number of ways. First, the teacher’s interest in students’ ideas and reasoning was perceived by students as a level of caring that was important to, and not always received by, these adolescent students. Second, the classroom became a place where ideas could be explored, discussed, reflected upon, debated, and reflected upon further, as students were guided in developing understanding of scientific ideas and in reconciling personal experiences and ideas. This was achieved in an atmosphere where all ideas, even ill-formed ones, were accepted without ridicule. However, all students were encouraged to be analytical about ideas and to find evidence that supported or refuted them. Third, in this classroom, all students found a niche for their contributions to the group, allowing some students to be active in one or more modes of interaction and to be passive in others.

The classroom culture that supported all students’ learning for understanding and application of science represents one of the major aims of the current reform movement in science education. In both the National Science Education Standards and in Project 2061, understanding and application of science for all students is a major emphasis (National Research Council, 1996; Rutherford & Ahlgren, 1990). The work of this teacher has illustrated how assessment is an important factor in achieving this significant, yet demanding aim of contemporary reform. These national goals are manifested in the school district in concerns for grades on report cards and scores on external tests. The previously low levels of achievement by students in this school district on the Michigan Educational
Assessment Program Grade 8 science test meant that grading was an important outcome. In this regard, Roberta’s grading was consistent with her teaching and assessment philosophy, in which grading and ongoing assessment need not compete. However, evidence from our staff development work shows that this point of view is not held by all teachers.

Roberta assigned grades based on students’ learning outcomes on the variety of activities dealt with in class that included a combination of data from continuous assessment of classroom activities and products prepared by students. These grades were given following written responses to discussions, experiments, or other minds-on activities (Hassard, 1992). Interviewed at the end of the semester about how she worked out her final grades for each of the students, Roberta explained,

I assign grades based on the responses to the variety of activities we have in class, usually in written form after discussions, experiments, or other minds-on activities. Often, I will have students write responses to one or two questions twice per week. This allows me to mark them quickly for rapid feedback to students and to adjust my plans if misconceptions are evident.

Assessment also included questions which were not directly related to sound, but were related to interesting aspects of science in the news, such as the space shuttle and archaeological finds. In this manner, she attempted to help students develop a better understanding of science as a whole, not just the topic under formal study. When assignments turned out to be more difficult than expected, she took the top grade and made that the maximum number possible and scaled the other grades accordingly. In this way, students gained confidence by having a high mark and this was given to them usually on a weekly basis.

Roberta used assessment as an integral part of her teaching program and has developed a well-organized style of teaching that is not prescribed in detail day-by-day. In this manner, she is able to change the daily tasks depending upon the outcomes of daily and weekly assessments. As described earlier, previous to being involved in this Professional Development Schools project, Roberta did not teach in this manner. The support of peers and university-based researchers over a long duration has been an important feature of the changes in Roberta’s use of assessment in her classroom. An advantage of being involved in the project has been the opportunity to talk with school and university colleagues about embedding assessment in teaching and being able to justify how and why this is done.

The implications from this middle school study are that it is possible to develop an assessment culture in schools, as opposed to a testing culture, and that the information so obtained from a variety of assessment strategies can be used to guide both the design and delivery of instruction. Further, the outcomes of this study showed that a wide range of ways for students to demonstrate their understanding on an ongoing basis can be provided by means of written responses and oral presentations. When students are given the opportunity to express their understanding and reconcile their personal ideas with scientifically accepted ideas, learning as shown by the student-produced booklets is written in a meaningful manner. Using the teaching approach where assessment was embedded in instruction, grades for the final course were made as a combination of continuous assessment and student products.

This case study has illustrated that the development of students’ scientific understanding is enhanced when a teacher uses information from students’ ideas and reasoning as a basis for instructional decisions. Roberta’s use of in-class writing activities and oral questioning (as reported in Assertions 3 and 4) as her predominant means of embedding assessment in her teaching repertoire can be adopted by other science teachers. In many traditional classrooms, writing tasks (often in the form of worksheets) and oral questions require...
students to respond with only one word or a phrase. Such approaches are not conducive to encouraging students to think deeply about the concepts being introduced. Helping teachers to reformulate the types of questions they ask of students in both written and oral form can be a logical starting point for professional development of teachers who wish to consider using assessment as a tool for improving science teaching. As illustrated in Assertion 2, through experience and reading Roberta was aware of the common student conceptions that are not consistent with scientific concepts. The research reported in this paper supports the findings of others that knowledge of common student conceptions can be a useful part of professional development related to assessment.

REFERENCES


Michigan State University. (1999). Background data on Otto Middle School. East Lansing, MI: Michigan State University Department of Teacher Education.


