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Looking Inside the Classroom: Science Teaching in the United States

Findings from the *Inside the Classroom Study* suggest that the key is not the particular instructional strategies that are used, but rather engaging students in ways that lead to their conceptual understanding.

For the past few decades, the nation's attention has focused with varying intensity on the quality of science education. Out of concern that an overemphasis on science vocabulary had led to a misrepresentation of the nature of science, the National Science Education Standards argued for more attention to inquiry as the hallmark of good science instruction (National Research Council, 1996). However, there continue to be differences of opinion about the extent to which student inquiry should be directed by the teacher and/or instructional materials, with some accepting guided discovery as appropriate inquiry, and others defining inquiry as students devising their own approaches to answering their own questions. One line of reasoning is that given the time required, if the curriculum includes a great deal of open inquiry, students will not have an opportunity to learn many important science concepts. In some cases, use of hands-on activities has been equated with inquiry; others note that hands-on without minds-on is hardly scientific; while still others point out that computer simulations and even thought experiments may also count as inquiry. Although there is not always agreement about the best instructional strategies, there does appear to be consensus that the goal of science instruction is teaching for understanding, not only understanding of science disciplinary content, but also understanding the centrality of inquiry in science.

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Understanding is defined generally in the literature, as "a matter of being able to do a variety of thought-demanding things with a topic—like explaining, finding evidence and examples, generalizing, applying, analogizing, and representing the topic in a new way" (Perkins and Blythe, 1994). It is also "the capacity to use current knowledge, concepts, and skills to illuminate new problems" (Gardner and Boix-Mansilla, 1994). These definitions are usually not the focus of debate. Divergence in the science education community centers on the process of how students attain these understandings.

The most prominent theories on how students develop understanding are based on the idea that learning, in children as well as in adults, is active (Bransford et al., 2003). Piaget suggested that learning involves the acquisition of organized knowledge structures … "[and] the gradual acquisition of strategies for remembering, understanding, and solving problems" (Bransford et al., 2003). Vygotsky stressed, among other things, the importance of social interaction for learning (Greeno, 1997). Ausubel (1967a) suggested that regardless of whether one experiences "reception learning" (the acquisition of information through lecture, print, image, etc.) or "discovery learning" (through which the principal content must be discovered by the learner), the learner must be able to relate new information to existing cognitive structures in order for learning to be meaningful.

These theories have vast implications for instructional practice. Since students clearly enter the classroom with knowledge and ideas about the world (Bransford et al., 2003), teachers must identify and evaluate student preconceptions and incorporate this understanding into instructional decision-making (Ausubel 1967a, 1967b; Bransford et al., 2003; Carey

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and Smith, 1993; Tytler, 2002). Under the right conditions, students integrate these ideas with new concepts and information and arrive at a deeper level of understanding, what Ausubel (1967a) termed, meaningful learning. Science teachers are challenged on a daily basis with understanding student preconceptions and creating the "right conditions" for meaningful learning of science concepts to occur.

Science instruction needs to be contextualized for students. Factual information is important as a means, rather than as an end in itself, for students to construct deep understanding. Facts are essential, but without a broader framework, they lose their power. Similarly, when teachers facilitate students' inquiries or investigations into a topic, it is important that those experiences be meaningful, relevant, and situated in a broader conceptual framework (Ausubel, 1967a, 1967b; Bransford et al., 2003; National Research Council, 1996; Wong et al., 2001). Teaching for understanding places demands on teachers and learners that exceed those associated with either direct instruction or open inquiry. It "requires teachers to have comprehensive and in-depth knowledge of subject matter, competence in representation and manipulation of this knowledge in instructional activities, and skill in managing classroom processes in a way that enables active student learning" (Cohen et al., 1993).

Until recently, there was very little known about the extent to which teaching for understanding occurs in our nation's schools. Much of the large-scale information that exists on classroom practice comes from survey data. Although surveys have the benefit of providing information on the extent to which various strategies are being used, survey data are much weaker in describing the quality of instruction (Burstein et al., 1995; Mayer, 1999; Porter et al., 1993; Spillane and Zeuli, 1999).

A major national observation study, the Case Studies in Science Education (Stake and Easley, 1978), involving a cross-section of 11 U.S. school districts, described the conditions and needs of science, mathematics, and social studies education. The authors noted that the quality of science instruction students experienced was quite varied; while some of the observed science classes stressed important science ideas and were described as interesting to students, most "overemphasized facts and memorization" and were not seen as relevant to the students. Science education observation studies since that time have generally either been quite small, or have been conducted in the context of the evaluation of a reform initiative, in both cases limiting the generalizability of the results.

The *Inside the Classroom Study* provides new insight into the extent to which teaching for understanding is occurring in our nation's schools. The study included observations of 180 science lessons, selected to be representative of lessons nationally, and interviews with the teachers of those lesson. Lessons were documented and analyzed in a number of different areas, including the quality of the science content and the extent to which the classroom culture facilitated learning. The lessons were ultimately assessed on the extent to which they were likely to impact student understanding in science and develop their capacity to successfully "do" science. Findings about the national status of quality science instruction and the components of lessons that seem likely to promote student understanding have important implications for science educators.

Methodology

The study design for *Inside the Classroom* drew upon the nationally representative sample of schools that had been selected for the 2000 National Survey of Science and Mathematics Education (Weiss, et al., 2001). A subset of middle schools from the schools that participated in the 2000 National Survey were selected. To ensure that these sites would be as representative of the nation as possible, systematic sampling with implicit stratification was used. When

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Regardless of the pedagogy (e.g., investigations, teacher presentations, reading, discussions with each other or the teacher), high quality lessons provided opportunities for students to interact purposefully with science content and were focused on the overall learning goals of the concept.

a middle school agreed to participate, the elementary schools and high school(s) in the same feeder pattern were identified and one of each was randomly selected. Two science teachers were randomly selected from each school for classroom observations.

Researchers were asked to take detailed field notes during the observations, including describing what the teacher and students were doing throughout the lesson, and recording the time spent on various activities. Following the observation, the researcher interviewed the teacher about the lesson, focusing on why the particular content and instructional strategies had been selected. Researchers completed an analytic protocol using the data collected during the observation and interview, and data from the analytic protocols were weighted in order to yield unbiased estimates for all science lessons in the nation. The weighted estimates of the frequency of classroom practices based on *Inside the Classroom* data are generally equivalent to those based on the 2000 National Survey sample, suggesting that estimates of lesson quality based on the observation data are an accurate depiction of what happens in the nation's science classes.

The Quality of Science Lessons Nationally

Inside the Classroom researchers rated the observed lessons on individual indicators in a number of areas, e.g., the quality of teacher questioning. Following the rating of individual components of the lesson, researchers were asked to provide an overall rating of the lesson. The scale observers used is divided into the following levels:

Level 1: Ineffective instruction
- a. passive "learning"
- b. "activity for activity's sake"

Level 2: Elements of effective instruction

Level 3: Beginning stages of effective instruction (low, solid, high)

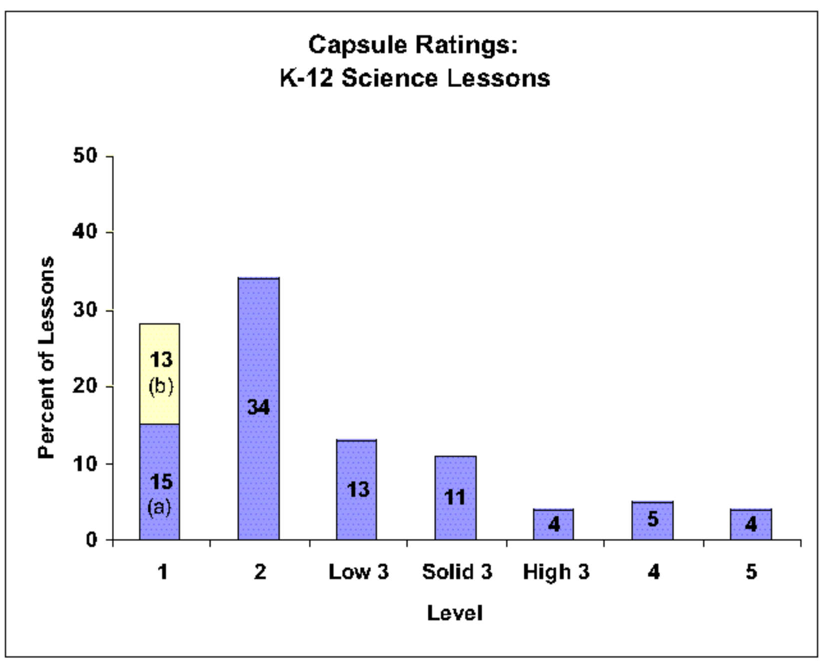
Level 4: Accomplished, effective instruction

Level 5: Exemplary instruction

Lessons judged to be low in quality (those rated 1a, 1b, and 2) are unlikely to enhance students' understanding of important science content or their capacity to do science successfully. While low quality lessons fell down in numerous areas, their overarching downfall tended to be the students' lack of engagement with important science. Examples of low quality lessons include:

- A primary grade lesson in which students drew their favorite animal, but never focused on science concepts;
- A lesson that attempted to teach a 3rd grade class about buoyancy, clearly not developmentally

Figure 1



appropriate for these students; and

- A class where students followed the steps through laboratory procedures, but did not seem to understand why they were doing what they were doing.

At the other end of the scale, high quality lessons (those rated high 3, 4, and 5) were designed and implemented to engage students with important science concepts; they were very likely to enhance their understanding of these concepts and to develop their ability to engage successfully in the processes of science. Regardless of the pedagogy (e.g., investigations, teacher presentations, reading, discussions with each other or the teacher), high quality lessons provided opportunities for students to interact purposefully with science content and were focused on the overall learning goals of the concept. Examples of high quality lessons include:

- A lively discussion in a science class focused on interpreting and identifying trends in data collected in lab the previous day;
- A lecture where high school students were engaged in learning about how nerve receptors are differentiated to distinguish levels of pain; and
- Students working individually on research reports related to environmental problems in their community.

In the middle, were lessons that were purposeful and included some elements of effective practice, but also had substantial weaknesses that limited the potential impact on students. The specific areas where "middle quality" lessons fell down varied. Examples include:

> **Effective lessons include meaningful experiences that engage students intellectually with science content.**

- A small group exploration that was short-circuited by the teacher, who told the students what they should find;
- A lesson in which the needs of a subgroup of students were not addressed;
- A lesson where students were ridiculed for asking questions, which interfered with the implementation of a well-designed learning activity; and
- A discussion that involved high-quality ideas, but was too fast-paced for many of the students.

Data from the *Inside the Classroom* study indicate that most science lessons in the United States are low in quality and that there is a general lack of teaching for understanding. As can be seen in Figure 1, based on observers' judgments, only 13 percent of K-12 science lessons in the United States would be considered high in quality, 24 percent medium in quality, and 62 percent low in quality. In the high quality lessons, students were fully and purposefully engaged in deepening their understanding of important science content. Some of these lessons were "traditional" in nature, including lectures and worksheets; others were "reform" in nature, involving students in more open inquiries. In contrast, in the low quality lessons, which included both traditional and reform-oriented lessons, learning science would have been difficult, if not impossible.

More detailed analyses were conducted in order to learn more about the characteristics that distinguished lessons that seemed to promote student understanding from those that did not. A number of factors emerged, including the extent to which the lesson was able to:

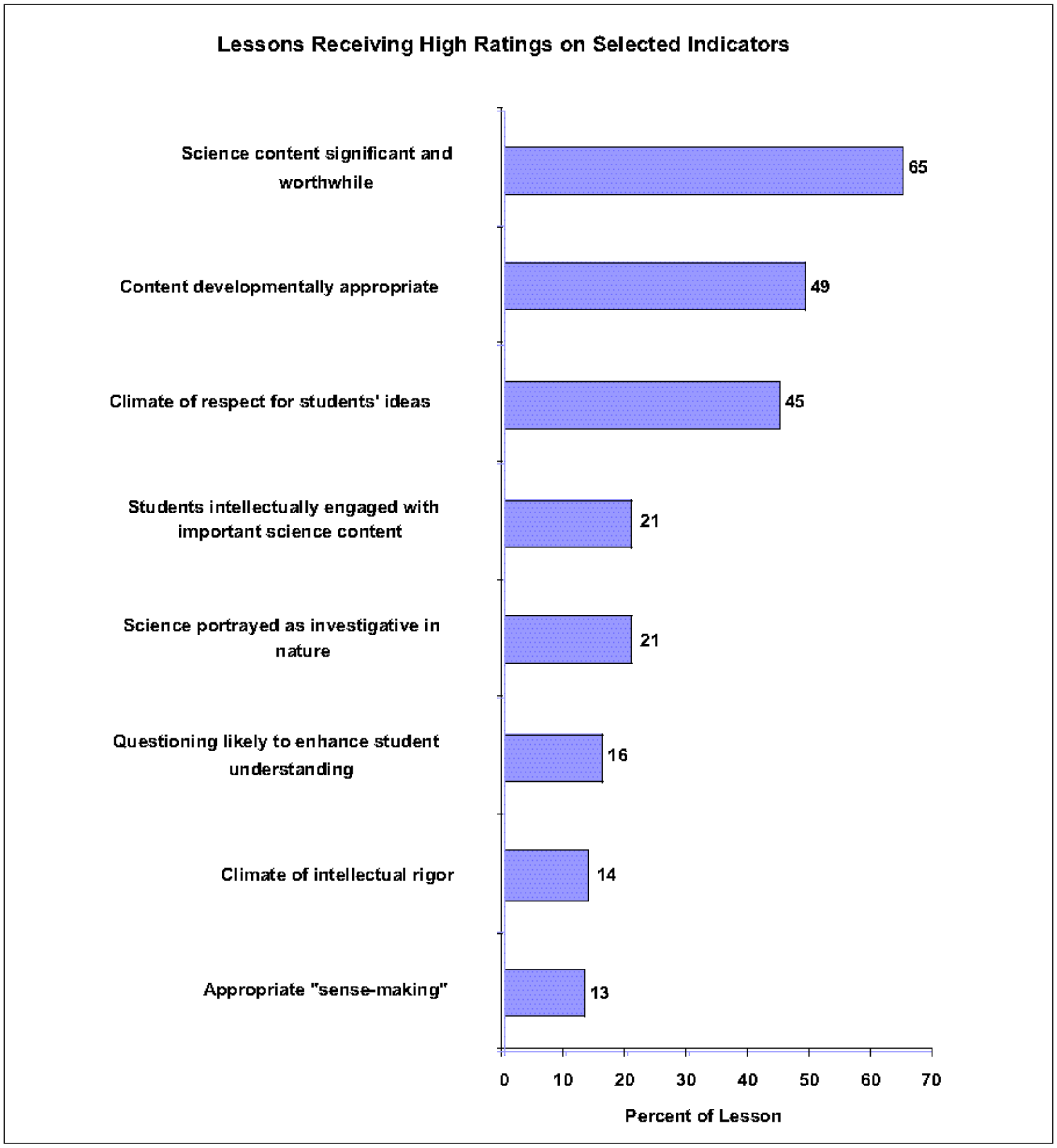
- Engage students with the science content;
- Create an environment conducive to learning;
- Ensure access for all students;
- Use questioning to monitor and promote understanding; and
- Help students make sense of the science content.

Effective Lessons Provide Students with Opportunities to Grapple with Important Science Content in Meaningful Ways

Certainly one of the most important aspects of effective science lessons is that they address content that is both significant and worthwhile. Lessons using a multitude of innovative instructional strategies would not be productive unless they were implemented in the service of teaching students important content. Based on the lessons observed in this study, science lessons in the United States are relatively strong in this area, with 65 percent of lessons judged to include significant and worthwhile content. (See Figure 2.)

It is important to note that while the majority of science lessons in the United States included important content, most lessons were nevertheless rated low. Clearly, while the inclusion of important content is necessary for high quality science instruction, it is not sufficient.

Figure 2



Effective lessons include meaningful experiences that engage students intellectually with science content. These lessons make use of various strategies to interest and engage students and to build on their previous knowledge. Effective lessons often provide multiple pathways that are likely to facilitate learning and include opportunities for sense-making. Unfortunately, K-12 students are not often intellectually engaged with important science content, with only 21 percent of lessons rated highly in this area.

Lessons should "invite" students to purposefully engage with content

It is clear that teachers need a thorough understanding of the purpose of the lesson in order to guide student learning. It has also been argued that *students* need to see a purpose to the instruction, not necessarily the disciplinary learning goals the teacher has in mind, but some purpose that will motivate their engagement (Kesidou and Roseman, 2002). In the ideal, lessons will "hook" students by addressing something they have wondered about, or can be induced

How science is portrayed is key to student understanding of the discipline.

to wonder about, possibly but not necessarily in a real-world context. Many observed lessons failed to incorporate strategies to gain student interest and motivation; in many cases, lessons "just started." For example, a teacher began a 3^{rd} grade lesson by having the students open their textbooks to the designated chapter, while she handed them a review worksheet. Similarly, a high school lesson began with the teacher distributing a packet of questions and saying, "All right now, these pages should be very easy if you've been paying attention in class. We talked about all of this stuff."

Teachers who succeeded at engaging students intellectually with science content had various strategies for doing so. Some lessons that "invited the learners in" did so by engaging students in first-hand experiences with the concepts or phenomena. Others invited the students in by using real-world examples to vividly illustrate the concept. Still others used stories, fictional contexts, or games to engage students with the content of the lessons. The following are examples of lessons that were particularly successful at motivating student interest and engagement:

> In a 1^{st} grade science lesson, the teacher read a story about a girl who discovers an arrowhead in her backyard. The class then engaged in an excavation activity in pairs, where one child was the "archeologist" who found the "hidden treasures" in their "midden [refuse heap]" and the other was a "curator" who put their "hidden treasures" in a "museum."
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> In a 4^{th} grade science lesson about the basic needs of animals and how different body parts help animals meet these needs, the teacher handed out a tail feather and a magnifying glass to each pair of students, and asked them to examine the feather, pull the barbs apart, and look for the hooks. They then pulled the feather between their fingers, making the barbs stick back together. The teacher then handed out a down feather and they repeated their investigations.
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> A high school physics teacher had the students explore static electricity using a Van de Graaf generator, Tesla coil, and fluorescent light tube. The teacher explained how each worked, and used students to demonstrate what happens when electrons are pulled from one source to another.

Lessons should foster students' understanding of science as an investigative process

How science is portrayed is key to student understanding of the discipline. Lessons can engage students with concepts so they come away with the understanding that science is a dynamic body of knowledge, generated and enriched by investigation. Alternatively, lessons can portray science as a body of facts and procedures to be memorized. Based on *Inside the Classroom* observations, only 21 percent of science lessons nationally provide experiences for students that clearly depict science as investigative in nature (rated 4 or 5 on a five-point scale). The following lesson is illustrative of those that highlighted the investigative nature of science:

> The focus of this 3^{rd} grade science lesson was on the idea that Earth is a "water planet." The teacher provided the background and motivation needed to launch the students into the investigation through whole group discussion. Students were asked to work in groups, first to make predictions, and then to toss a "beach ball model" of the Earth and observe if their finger landed on land or water. After each group had made ten tosses, the class shared their data and compared their observations to their predictions. The lesson ended by having each group of students try to explain the data, while the recorder wrote down the group's reasoning. The lesson was to be followed up the next day by representing the different oceans on Earth with squares on graph paper and using that to visualize how much of the Earth is made up of water, and to picture the relationships between bodies of water and land. The observer noted that the lesson was well designed, with "a focused experience using a model that should help students understand not only why the Earth is called 'the water planet,' but how scientists figure out the relative quantities of a substance on Earth by using scale models."

In contrast, many lessons presented science as a static body of knowledge, focusing on compilations of factual information. The following examples are typical:

> Students in a 4^{th} grade science class were given a worksheet consisting of statements from the textbook with multiple-choice response options. The students were instructed to find the right answer and to note the page in the textbook where the answer was found. The teacher circulated among the students and helped them find the answers if they were having difficulty. The observer indicated that the questions on the worksheet were factual and low level, requiring vocabulary recognition rather than application of knowledge. A question on air pressure read: "What does a barometer measure?" The answers from which the students were asked to select included: (a) humidity, (b) temperature, (c) air pressure, (d) wind. When the groups had finished the assignment, the teacher asked them to regroup with a new partner and compare their answers and reference pages. When this assignment was completed, the teacher read the correct answers and page references from her master copy and the students corrected their worksheets. The observer noted

that the content was limited principally to definitions and terms; "although the vocabulary was important, the lesson did not encourage students to use the vocabulary as a way to communicate information and give meaning to observations."

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An 8th grade science lesson was designed to give the students a great deal of factual information on Newton's Third Law of Motion. The students copied notes from the blackboard for half of the lesson, and the next half of the lesson was spent with the teacher asking them to recall information from the notes. The observer wrote: "The lesson was designed in a way that allowed the students to be very passive, interacting little with each other or the content. The students spent a great deal of time hurriedly copying the notes; only those students who were called on by the teacher during the review time were required to think about the content, and even that was at the basic level of recalling facts they had just written down."

Lessons should take students from where they are and move them forward

Although it is unlikely students are learning if they are not engaged, engagement is not enough; to develop student understanding of science, lessons need to be at the appropriate level, taking into account what students already know and can do, and challenging them to learn more. Approximately half of all science lessons were rated high for the extent to which the content was appropriate for the developmental level of the students in the class. The estimated 20 percent of lessons nationally that were judged to be at the low end of the scale on developmental appropriateness were only occasionally too difficult for the students. Sometimes students lacked the prerequisite knowledge/skills, and the content seemed inaccessible to them; at other times, the vocabulary was at far too high a level for the students. More often lessons were pitched at too low a level for some or all of the students. The following examples are typical:

Students in a 6th grade science lesson demonstrated in the introductory whole-class discussion that they already had a good grasp of what owls eat, so the subsequent activity of dissecting owl pellets to determine an owl's diet would not advance their understanding.

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Prior to the observed lesson the students had drawn the parts of the digestive system on the figure of a man, described the function of each part, and traced the path of a piece of food through the system. When they were then asked to write a story describing a cheeseburger's journey through the digestive system, many of the students were bored with the assignment. Said the observer, "they stated this fact on numerous occasions; they passed notes; they did their hair. They were not intellectually engaged. The assignment was too obviously busy-work—they had already done essentially the same thing the previous day."

Some lessons used multiple representations of concepts to facilitate learning, providing greater access to students with varying experiences and prior knowledge, and to help reinforce emerging understanding. One such lesson was observed in a 7th grade science class:

Beginning with a review of the main facts about fossilization that students had been studying, the teacher provided information about how fossils can be dated and went on to explain radiocarbon dating techniques. She then led the class in constructing standard radiocarbon dating curves, which the students used to date their own "fossils" (plastic bags of pennies). The "heads" represented C-14 atoms, which the students then replaced by paper clips, representing N-14 atoms. By counting the number of C-14 atoms in their "fossil," students were able to determine its age. Students who finished this task were then asked to create an N-14 standard curve. The observer noted that the lecture was effective, and that the use of the small group, hands-on activity "helped make this rather abstract concept more concrete and interesting."

Effective Lessons Create an Environment Conducive to Learning

Based on the observations in this study, a classroom culture conducive to learning is one that is both rigorous and respectful. Nearly half of science lessons nationally received high ratings for having a climate of respect for students' ideas, questions and contributions. Ratings for rigor were much lower, with only 14 percent of science lessons nationally judged to have a climate of intellectual rigor, including constructive criticism and

Table 1
Cross Tabulation of Climate of Respect and Intellectual Rigor

		Percent of Lessons: Intellectual Rigor, Constructive Criticism, and Challenging of Ideas Are Evident		
		Low	Medium	High
Climate of Respect for Students' Ideas, Questions, and Contributions	Low	26	0	0
	Medium	26	1	1
	High	16	17	12

the challenging of ideas. Table 1 shows a cross tabulation of the two variables; note that only 12 percent of science lessons nationally are strong in both respect and rigor, and 26 percent are low in both areas.

Sixteen percent of science lessons were categorized as respectful but lacking in rigor. *Inside the Classroom* observers used phrases like "pleasant, but not challenging" to describe such lessons. The following examples are typical.

> In a 6^{th} grade science lesson, "the teacher appeared to want all students engaged in the lesson, and distributed her questions to various students … [However,] intellectual rigor did not seem to be a priority, as long as students could give the verbatim responses for each cell part. Discussion of differences between plant and animal cells noted the different cell components (chloroplast, cell wall) but did not ask students to pose conjectures as to why the differences should exist, or what the effect would be, for example, if animal cells had a cell wall. The tone was friendly and supportive, but that was as far as it went."
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> The observer reported that "emotionally, the culture of this 9^{th} grade science class was good. The teacher had a warm relationship with the students, and it seemed clear that there was great deal of mutual respect. Intellectually, however, the culture in this classroom was very weak. Science was presented as facts and formulas to memorize, with no requirement that things make sense or even be internally consistent. Students were asked to respond to the teacher's questions but did not interact with each other, or propose new ideas for the class to discuss."

Effective Lessons Help Students Make Sense of the Science Content

Focusing on important science content; engaging students; and having an appropriate, accessible learning environment set the stage for learning, but they do not guarantee it. It is up to the teacher to help students develop understanding of the science they are studying.

The important consideration is that lessons engage students in doing the intellectual work, with the teacher helping to ensure that they are in fact making sense of the key science concepts being addressed.

The teacher's effectiveness in asking questions, providing explanations, and otherwise helping to push student thinking forward as the lesson unfolds often appeared to determine students' opportunity to learn.

Researchers observed some extremely skillful questioning, where the teacher was able to use questions to assess where students were in their understanding, and to get them to think more deeply about the science content. There were many more instances where the teacher asked a series of low level questions in rapid-fire sequence, with the focus primarily on the correct answer, rather than on understanding. Questioning was among the weakest elements of science instruction, with only 16 percent of lessons nationally incorporating questioning that seemed likely to move student understanding forward. Lessons that were otherwise well-designed and well-implemented often fell down in this area.

Researchers saw teacher questioning used effectively both to find out what students already knew and to provoke deeper thinking in helping them make sense of science ideas. For example:

> As the students in a 10^{th} grade science class were examining the results of their experiment, the teacher asked questions that pushed them to examine their results further and to provide evidence for their conclusions. Examples of questions asked by the teacher are: "How could we test if there is still sugar in the reservoir?" "Why didn't it [the iodine indicator] reach equilibrium?" and "How do you know?"

More often observers noted that the teachers moved quickly through the lessons, without checking to make sure that the students were "getting it." As soon as the few most verbal students indicated some level of understanding, the teacher went on, leaving other students' understanding uncertain.

By far, the most prevalent questioning pattern in science lessons was one of low-level "fill-in-the-blank" questions, asked in rapid-fire, staccato fashion, with an emphasis on getting the right answer and moving on, rather than helping the students make sense of the science concepts. The following example illustrates this pattern as it played out in one 6^{th} grade science lesson on weather and the atmosphere:

Teacher: "The first layer is the what?"
Students: "Troposphere"
Teacher: "How many layers are there?"
Students: "Four"
Teacher: "What happens in the troposphere?"
Student: "It rains"
Teacher: "What happens in that layer?"
[Students unsure]
Teacher: "w, w, w…"
Student: "Water?"
Teacher: "What have we been studying?"
Student: "Weather."

Teacher: "What are four forms of precipitation?"
Students: "Rain, snow, sleet, hail"

Interestingly, observers reported that some teachers asked good questions, but were so intent on getting the right answer that they supplied the answers themselves, in effect short-circuiting student thinking. Said one observer, "The teacher discouraged any comments or ideas that were not exactly what she asked for, answering her own question if the first response was not what she desired."

Teacher questioning is one way, but not the only way to help students understand the science at hand. The important consideration is that lessons engage students in doing the intellectual work, with the teacher helping to ensure that they are in fact making sense of the key science concepts being addressed. The following examples illustrate lessons that included appropriate "sense-making."

> The purpose of a 5th grade science lesson was for students to know what a seed was and to understand methods of seed dispersal. The teacher started the lesson by having the students name things that seeds require in order to grow and then the whole class covered the definition of a seed. Next, the teacher elicited from students ways that seeds are carried from place to place and then the class discussed the definition of seed dispersal. The teacher then gave the class directions for the group activity. Students in groups selected an "action card" which contained a description of a method of seed dispersal. Groups then used items already available at their tables to create a model of that method of seed dispersal. The observer remarked that "the designing of models of seed dispersal provided a way for students to process their new information and to express their understanding of it in a creative and unique way." When all groups were finished creating their models, each group stood up and shared their action card and model with the entire class. The lesson concluded with students writing in their science journals about what they had accomplished in this lesson and then each student sharing some of what they had written with the class. The observer noted, "this sharing allowed students to listen to each others' ideas which reinforced their understanding while also allowing the teacher to check for student comprehension."

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> Students in a high school chemistry class had been working on properties of compounds and elements. The observed lesson built upon that knowledge, focusing on compound formation. There were three main components to the lesson: (1) a quick review of the previous lesson's concepts; (2) a lecture/discussion on the new material; and (3) a question/answer review of the new material. The lesson included time for sense-making during the lecture portion of the class (the teacher asked questions throughout to ensure comprehension), and a wrap up question/answer segment at the end. The lecture itself moved through content sequentially, building from the specific to broader conclusions. Said the observer, "this was a well-designed lesson with clear objectives that were all met."

Although researchers observed some lessons where students were helped to make sense of the science content as the lesson progressed and/or at its conclusion, most lessons lacked adequate "sense-making;" only 13 percent of lessons received high ratings in this area. Many teachers seemed to assume that the students would be able on their own to distinguish the big ideas from the supporting details in their lectures, and to understand the science ideas underlying their laboratory investigations. The following lesson descriptions illustrate inadequate sense-making in science lessons.

> The teacher guided a 3rd grade class through the completion of a science worksheet by referring the students to a particular question, telling them to turn to a specific page in their textbook and look for the answer, asking one student volunteer to read the answer from the book, then writing the answer on an overhead transparency copy of their worksheet. The observer reported the following conversation as an example:

Teacher: "Let's look at lesson two. Turn to page E16. Fill in the blank. Look on the page. Matter is made of … what?"
Student 1: "Atoms."
Teacher: "Adding heat changes a solid to a what?"
Student 2: "Liquid."
Teacher: "Good. Now read number three."

> At the completion of the worksheet, the teacher then went over the questions and answers to summarize the content in the lesson. The students were instructed to keep their worksheets for the next lesson.

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> The observer noted that "each of the physical science topics demonstrated in this lesson was appropriate to the 9th grade curriculum (mechanical waves, sound and light waves, mixing colors), and could be grasped by these students at some level. Moreover, each of the demonstrations was in itself interesting and motivational for the students, and for the most part kept their attention. However, the teacher presented all of these demonstrations in rapid succession, without providing appropriate ties to the material studied in class. As a result, the overall effect was more show than substance. No attempt was made to anchor the demonstrations into any conceptual framework."

In summary, while the aim of instruction in all cases needs to be understanding, based on the *Inside the Classroom* observations, there appear to be multiple approaches for achieving this goal. Observers saw lessons that were well-designed and well-implemented using lectures, hands-on activities, or paper and pencil tasks to help develop student understanding of important science concepts. Observers saw other lessons using each of these strategies that seemed unlikely to lead to student conceptual understanding.

Factors that seem more instrumental than choice of instructional strategies in promoting student opportunity for learning include the extent to which lessons engage students with important science concepts; create an environment that is both respectful and rigorous; use questioning effectively; and help students make sense of the science concepts being addressed.

Discussion and Recommendations

Although people can still be heard to say "It's okay if teachers don't know the science, they can learn along with their students," there appears to be a general consensus among science educators that teaching science for understanding requires teachers who themselves understand the science concepts being addressed, and who have the knowledge and skills needed to help students develop their understanding of important science concepts. Rather than focusing so much attention on which instructional strategies teachers use, student understanding would more likely be enhanced by ensuring that whatever strategies are used, instruction is purposeful, accessible, and engaging to students, with a clear and consistent focus on student learning of important science concepts.

It seems clear that teachers' understanding of science as a discipline, and command of science disciplinary content knowledge, need to be established before they enter the K-12 science classroom. Although this is clearly a daunting task, especially when preparing elementary teachers who need in-depth background in multiple disciplines, there is simply not enough time, nor enough resources, for in-service education to compensate for major deficits in teachers' science

Even if their initial preparation is excellent, teachers, like all professionals, need on-going opportunities for continuing education.

content background. To the extent that teachers teach as they were taught, they need to be taught for understanding if they are to teach for understanding. While some have called for the use of hands-on methodologies, cooperative learning, and other "reform-oriented" strategies in undergraduate science courses, findings from the *Inside the Classroom* study suggest that the key is not the particular strategies that are used, but rather engaging prospective teachers in ways that lead to their conceptual understanding.

It is clear that any instructional strategy can be implemented well, or implemented poorly. Open inquiries that never lead to understanding are no more helpful to learners than are uninteresting, inaccessible lectures. And lectures do not necessarily need to be boring recitations of factual information; they can be engaging explanations of phenomena. In theory, at least, a good lecture can be an inquiry experience, describing how we came to know what we know—what questions were asked; how they were investigated; which turned out to be useful pathways, and which dead ends—as well as what we don't yet know. Enabling prospective teachers to experience a variety of well-implemented instructional strategies in their pursuit of science content understanding, with explicit attention in their science education courses to what constitutes high quality use of each, seems most likely to prepare them to implement high quality instruction in the classrooms.

Even if their initial preparation is excellent, teachers, like all professionals, need on-going opportunities for continuing education. Professional development providers can help teachers refine their vision of effective instruction and use it to guide their lesson design and implementation. Lesson study is one potentially effective route to helping teachers understand this overall vision and improve their practice. With assistance from skilled, knowledgeable facilitators, teachers can start with group discussions of videos of other teachers' practice, and move towards examining their own practice. In addition, with the advantage of knowing which science concepts are addressed at a particular grade level, and often which student instructional materials are being used, in-service education can be designed to provide very targeted assistance for teachers—clearly identifying the key learning goals for specific activities; sharing the research on student thinking in the specific content area; suggesting questions that teachers can use to monitor student understanding; and outlining the key points to be emphasized in helping students make sense of the science concepts. At the same time, workshops and other teacher professional development activities need to themselves reflect the elements of high quality instruction with clear, explicit learning goals; a supportive but challenging learning environment; and means to ensure that teachers are developing understanding.

In our experience, professional development often focuses on, and advocates, a particular instructional strategy, such as the use of hands-on instruction. In the lessons observed in this study, however, instructional strategy did not determine lesson quality. Consequently, we believe that professional development should focus on aspects of effective instruction that cut across instructional strategies: learning goals that are both important and developmentally appropriate; activities focused on these learning goals that capture students' interest and attention; an intellectual climate that both nurtures and challenges students; and, critically important, the need for questioning and other techniques that explicitly help students make sense of the content at hand.

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