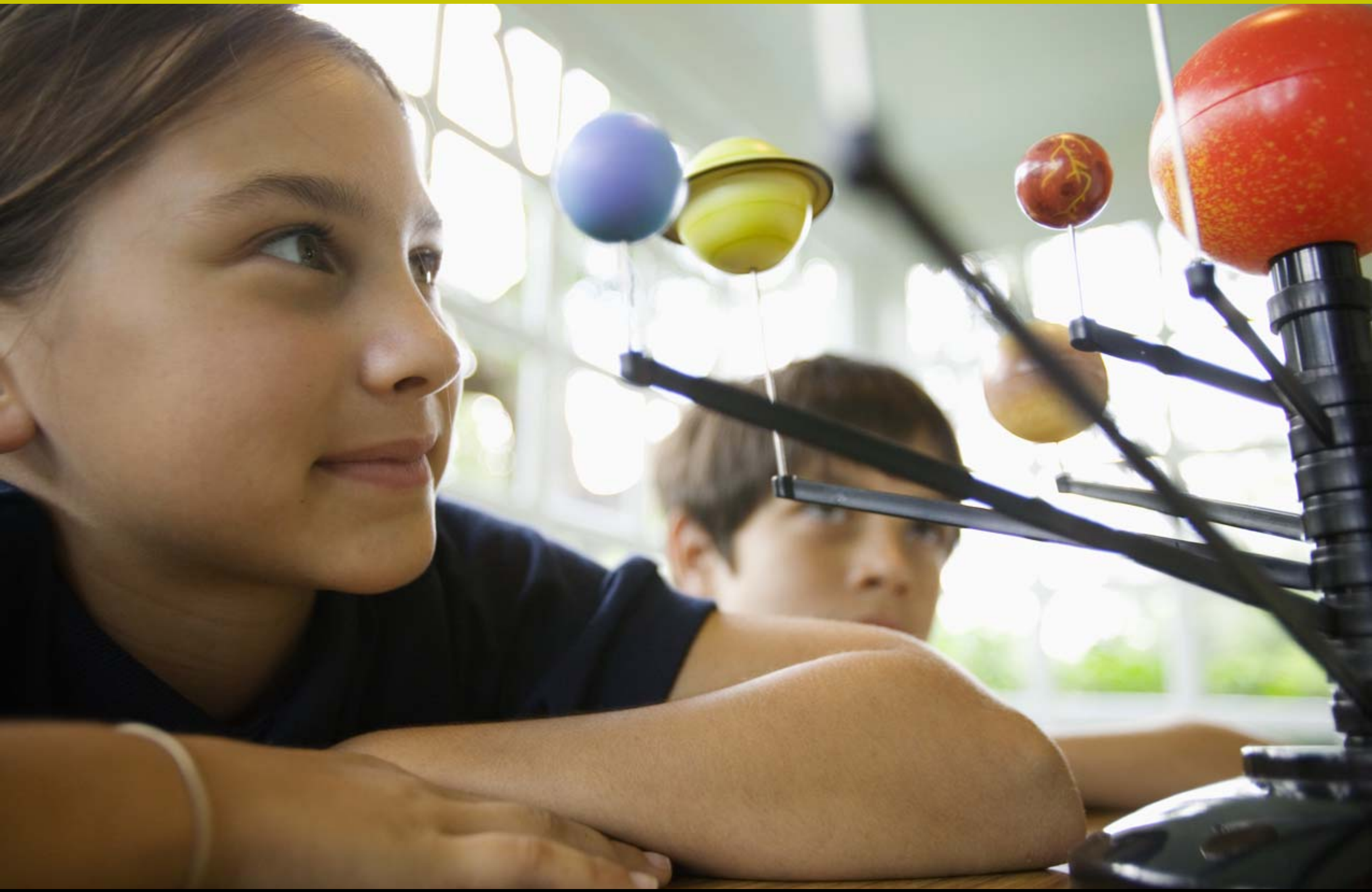
EFFECTIVE SCIENCE INSTRUCTION: WHAT DOES RESEARCH TELL US?



CENTER ON INSTRUCTION

EFFECTIVE SCIENCE INSTRUCTION: WHAT DOES RESEARCH TELL US?

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CENTER ON INSTRUCTION

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INTRODUCTION

Science education has received renewed attention in the United States in the last several decades, with calls for a scientifically literate citizenry in this increasingly technological society. *Science for All Americans* (American Association for the Advancement of Science, 1989) laid out a vision describing the knowledge a scientifically literate person would have. This vision was further elucidated in *Benchmarks for Science Literacy* (American Association for the Advancement of Science, 1993) and *National Science Education Standards* (National Research Council, 1996). These documents reflect a fairly broad consensus within the science education community of what scientific knowledge students should be expected to learn as they progress through grades K–12.

For example, *Benchmarks for Science Literacy* describes a progression of ideas that will help students understand DNA and principles of inheritance:

- Offspring are very much, but not exactly like, their parents and [they are] like one another. (Grades K–2 Benchmark)
- Some likenesses between children and parents, such as eye color in human beings, or fruit or flower colors in plants, are inherited. Other likenesses, such as people's table manners or carpentry skills, are learned. (Grades 3–5 Benchmark)
- In some kinds of organisms, all the genes come from a single parent, whereas in organisms that have sexes, typically half of the genes come from each parent. (Grades 6–8 Benchmark)
- The information passed from parents to offspring is coded in DNA molecules. (Grades 9–12 Benchmark)

National Science Education Standards describes a similar progression:

- Plants and animals closely resemble their parents. Many characteristics of an organism are inherited from the parents of the organism, but other characteristics result from an individual's interactions with the environment. Inherited characteristics include the color of flowers and the number of limbs of an animal. Other features, such as the ability to ride a bicycle, are learned through interactions with the environment and cannot be passed on to the next generation. (Grades K–4 Standard)

- In many species, including humans, females produce eggs and males produce sperm. Plants also reproduce sexually—the egg and the sperm are produced in the flowers of flowering plants. An egg and sperm unite to begin development of a new individual…That new individual received genetic information from its mother (via the egg) and its father (via the sperm). (Grades 5–8 Standard)
- In all organisms, the instructions for specifying the characteristics of the organism are carried in DNA, a large polymer formed from subunits of four kinds (A, G, C, and T)…(Grades 9–12 Standard)

These documents also emphasize that students should understand the nature of scientific knowledge—how it is generated, modified, and, in some cases ultimately rejected. According to the *National Science Education Standards (NSES):*

- Scientific literacy means that a person can ask, find, or determine answers to questions derived from curiosity about everyday experiences. It means that a person has the ability to describe, explain, and predict natural phenomena. Scientific literacy entails being able to read with understanding articles about science in the popular press and to engage in social conversation about the validity of conclusions. Scientific literacy implies that a person can identify scientific issues underlying national and local decisions and express positions that are scientifically and technologically informed. A literate citizen should be able to evaluate the quality of scientific information on the basis of its source and the methods used to generate it. Scientific literacy also implies the capacity to pose and evaluate arguments based on evidence and to apply conclusions from such arguments appropriately. (National Research Council, 1996, p. 22)

In addition to delineating the important knowledge, the national standards paint a picture of what effective science instruction might look like to accomplish the goal of producing a scientifically literate citizenry. Moreover, since the standards were published, research in the cognitive sciences has provided much new knowledge about the mechanisms by which people learn. This research and its implications for science education have been summarized in the National Research Council's *How People Learn* (National Research Council, 2003) and *How Students Learn: Science in the Classroom* (National Research Council, 2005).

This brief endeavors to distill the research on science learning to inform a common vision of science instruction and to describe the extent to which K–12 science education currently reflects this vision. A final section on implications for policy makers and science education practitioners describes actions that could integrate the findings from research into science education.

CHARACTERISTICS OF EFFECTIVE SCIENCE INSTRUCTION

A debate continues over what constitutes effective science instruction. The opposing views are often labeled, somewhat simplistically, as "reform" versus "traditional" science instruction. Reform instruction is often characterized as students working in small groups and participating in hands-on activities with students, in some cases, selecting the topics. Traditional instruction is often characterized as teachers delivering information to students in lectures and readings, and students working independently on practice problems and worksheets. Often, traditional instruction includes a weekly laboratory activity in which students work to reinforce what has been taught in a prior lecture.

Debating the mode of instruction misses the point, however, as current learning theory focuses on students' conceptual change, and does not imply that one pedagogy is necessarily better than another. For example, students may be intellectually engaged with important content in a dynamic, teacher-directed lecture, or they may simply sit passively through a didactic lecture unrelated to their personal experience. Similarly, a hands-on lesson may provide students with opportunities to confront their preconceptions about scientific phenomena, or it may simply be an activity for activity's sake, stimulating students' interest but not relating to important learning goals. Lessons that engage students in scientific inquiry can be effective whether they are structured by the teacher or instructional materials, or very "open," with students pursuing answers to their own questions. Whatever the mode of instruction, the research suggests that students are most likely to learn if teachers encourage them to think about ideas aligned to concrete learning goals and relate those ideas to real-life phenomena.

The Research Base on Elements of Effective Instruction

The science instruction model presented in this brief derives largely from the learning theory described in the National Research Council's volumes *How People Learn: Brain, Mind, Experience, and School* (2003) and *How Students Learn: Science in the Classroom* (2005). This framework views students as active processors of information. It places heavy emphasis on the ideas and understandings that students bring to the classroom. Their initial concepts and skills affect how they process content and how they view the nature of science. For students to learn science content, learning theory posits that they must be motivated to learn and intellectually engaged in activities and/or discussions focusing on what they already know. Further, learning theory suggests that students will best understand science content and the scientific process if teachers encourage them to use evidence to support their claims and help them make sense of new, developmentally appropriate ideas in the context of their prior thinking and their understanding of related concepts.[1]

Of course, effective instruction requires skilled and knowledgeable teachers, and research supports the idea that teacher understanding of content is important. Teachers with stronger content knowledge are more likely to teach in ways that help students construct knowledge, posing appropriate questions, suggest alternative explanations, and propose additional inquiries (Alonzo, 2002; Brickhouse, 1990; Cunningham, 1998; Gess-Newsome & Lederman, 1995; Lederman, 1999; Roehrig & Luft, 2004; Sanders, Borko, & Lockard, 1993). Also, studies have shown a relationship between teacher content knowledge and student learning (Magnusson, Borko, Krajcik, & Layman, 1992).

The next part of this brief expands upon each element of effective instruction and provides classroom-based examples of them.

Motivation

However well-designed the instruction, students are unlikely to learn if they are not motivated to learn. Lessons should "hook" students by addressing something they have wondered about, or can be induced to wonder about, possibly, but not necessarily, in a real-world context. In their analysis of middle school science programs, Kesidou and Roseman (2002) cited research support for the idea that "if students are to derive the intended learning benefits from engaging in an activity, their interest in or recognition of the value of the activity needs to be motivated" (p. 530).

Students' motivation may be either extrinsic or intrinsic. Extrinsic motivators include deadlines for research projects, classroom competitions, and tests and quizzes affecting students' grades. Intrinsic motivation, in contrast, usually stems from intellectual curiosity and a desire to learn. There is some evidence

[1] A number of instructional models incorporate many, if not all, of the elements described above, such as the 5E (Bybee, 1997) and 7E (Eisenkraft, 2003) learning cycles. This brief does not promote one pedagogical approach over another. Rather, it highlights the critical elements of teaching and learning described in the cognitive research. In addition, some research-based instructional strategies cut across these elements including formative assessment and other techniques for monitoring student learning. These strategies can help ensure that students are engaged intellectually with important ideas and make sense of them.

that extrinsic motivation may actually be detrimental, impeding students' intrinsic desire to learn. For example, students doing a research project might focus primarily on completing the task rather than learning the concepts (Moje et al., 2001; Nuthall, 1999, 2001). Similarly, a laboratory activity performed only to confirm a previously presented idea is unlikely to deepen students' understanding of that idea; students will likely focus more on finding the "right" answer than on understanding the underlying concepts.

The reality is that there are, and will always be, extrinsic motivators (e.g., deadlines, tests, college entrance requirements). Based on research, efforts should be made to balance intrinsic and extrinsic motivators, especially for students not achieving well even with extrinsic motivators.

There are many ways for a teacher to foster intrinsic motivation. For example, students can be highly motivated by a discrepant event that contradicts their view of the world (Friedl, 1995; Suchman, 1966). When students make predictions before starting an investigation, their interest may be raised. If students' observations do not match their original predictions, they may be motivated to find out why (Lunetta et al., 2007). Students may also be stimulated to learn when they investigate a question that has meaning to them, or if they are learning about science in a context that relates to their personal experience. As the following example[2] illustrates, students are often motivated to learn if they believe the knowledge applies to their lives.

> *The goal of a lesson near the beginning of a unit on the structure and properties of matter in a tenth grade physical science class was for students to begin to understand the kinetic molecular theory, specifically the relative speed of and distance between molecules in different phases of matter (i.e., solid, liquid, and gas). The teacher began the lesson by asking students to respond to the following question in their science journals: "Why does the inside of the windshield of a car fog up in the winter?" The students recorded their thoughts individually, and then discussed the scenario in small groups. The small group discussion was quite lively, as many of the students were preparing to get their first driver's license. The teacher then informed the students that their studies over the next several lessons would help them answer this question, as well as how cars are designed to overcome this problem.*

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[2] The examples shown in this section of the brief are composites of classrooms the authors have observed over the years. They are intended to illustrate how the element being described could play out during instruction.

Eliciting Students' Prior Knowledge

Research has shown convincingly that students do not come to school as empty vessels. They come with ideas and beliefs gleaned from books, television, movies, and real-life experiences. These ideas can either facilitate or impede their learning (National Research Council, 2003). In many cases, students have ideas that get in the way of learning new ones. For example, the commonly held belief that objects in motion contain a force that keeps them moving, or the idea that plants take in food from the soil, make it difficult for students to accept that both ideas are wrong. Considerable evidence from research suggests that instruction is most effective when it elicits students' initial ideas, provides them with opportunities to confront those ideas, helps them formulate new ideas based on evidence, and encourages students to reflect upon how their ideas have evolved. Without these opportunities, students "may fail to grasp the new concepts and information that are taught, or they may learn them for purposes of a test but revert to their preconceptions outside the classroom" (National Research Council, 2003, p. 14). Thus, learning theory suggests that instruction is more effective when it takes students' initial ideas into account.

Eliciting students' knowledge has value even when their ideas are consistent with scientists' views. The more students connect new knowledge with pre-existing knowledge, the better they will understand that new knowledge. Instruction that ties new and existing ideas together increases the likelihood of learning, adroitness with the knowledge, and retention over time.

There are different ways to elicit student ideas. One common method is a KWL chart, in which students brainstorm *what they know* about a certain concept (K), *what they want to know* (W), and finally *what they have learned* (L) by the end of a lesson or unit. The charts work best when students have time to reflect on the differences between the K and the L. Students may also demonstrate their initial ideas with drawings, concept maps, or cartoons. The impact of visual methods increases if students explain the thinking behind their illustrations (Edens and Potter, 2003). Open-ended teacher questions can also elicit students' ideas, especially if teachers probe for deeper explanations (Harlen, 1998). Finally, when teachers encourage students to raise questions of their own, they can access students' existing ideas, especially if students are asked to suggest answers or explanations (Iwasyk, 1997; Watts et al., 1997; Gibson, 1998).

The following example illustrates how a teacher elicited the ideas that very young students had about the weather, and used their ideas as a launching point for a lesson on water.

A weather lesson: second grade

A second grade lesson on weather began with the teacher passing out 8½ x 11 sheets of paper on which students were instructed to write everything they knew about weather. Students could use words or draw pictures, as long as the pictures were labeled. The teacher then asked each student to pick one idea and share it with the class. Each student read his or her idea aloud. The teacher listened to all ideas, sometimes asking for a repeat or clarification. Other students were also encouraged to ask questions. Based on the students' contributions, the teacher summarized their ideas and then focused on the ideas that centered around water. She pointed to a few drawings of rain, and asked students, "What is rain?" "Where does it come from?" After students offered their ideas about why there was water in the sky, the teacher stated, "today we are going to focus on water to help us begin to understand weather."

Intellectual Engagement

Research on learning suggests that effective lessons include meaningful experiences that engage students intellectually with important science content. The mode of learning may vary, as long as students have opportunities to investigate meaningful questions, engage with appropriate phenomena, and explicitly consider new experiences and knowledge in light of their prior conceptions. The important consideration is that lessons engage students in doing the intellectual work. It is not enough simply to provide students with an interesting hands-on experience that does not connect to learning goals, such as building and flying paper airplanes with no discussion of the forces involved in flight. Although such an activity may be successful at piquing students' interest in science, it is unlikely to teach important ideas if it does not focus on a meaningful question. Classroom activities must be explicitly linked to learning goals so that students understand the purpose of the instruction and feel motivated to engage with the ideas, not just the materials (White and Gunstone, 1992).

Students do not need to participate in hands-on activities to engage with phenomena; an interactive lecture that encourages students to think about their ideas may be just as effective. For example, in the following lesson the teacher used students' experiences to engage them with the structure and function of the skeletal system.

An anatomy lesson: fifth grade

As part of a lesson on the skeletal system started, a life size skeleton, named Mr. Bones, was introduced to the fifth grade class. The teacher talked about specific bones of the body, frequently capturing students' attention by telling stories and personal experiences to which students could relate: her husband's broken collar bone, actor Christopher Reeves' spinal cord injury, and her father's arthritis. Students shared their stories as well. For example, they talked about the mailman with carpal tunnel syndrome and a mom with temporomandibular joint disorder (TMJ). The teacher integrated numerous questions that drew out relevant student knowledge and others that required students to use the new ideas they were learning to explain past experiences.

Use of Evidence to Critique Claims

Being scientifically literate requires understanding both scientific ideas and the nature of the scientific enterprise (National Research Council, 1996). Students should be encouraged to see science as a process by which knowledge is constructed, not as the memorization of facts. Scientists collect and interpret data, using them to make new claims. Scientists may also use data to critique claims—to see if they are supported by the evidence. Students should experience this process in their education and learn how we come to know what we know about the world.

Science lessons may provide multiple opportunities for students to back up their claims with evidence, and to use evidence to critique claims made by other students. Venues for the use of evidence may be as formal as classroom debates and open-ended essay questions, or as informal as class discussions and journal entries. Students may use either their own observations, experiences, or data collected during classroom experiments; or they may use data collected by others that they have read or heard about.

The following classroom example illustrates how one teacher encouraged students to back up their claims during a class discussion about an experiment, and created a culture in which students used data to critique each other's claims.

An electricity lesson: fourth grade

In a fourth grade lesson on electric circuits, students worked in pairs to test whether any of a given set of items (including a paper clip, a rubber band, a wooden stick, and sandpaper) would conduct electricity. The tests were performed by placing each object in the middle of an electric circuit they had built the day before using a battery, a battery holder, and two wires. Students recorded their observations in their notebooks. After they had finished this task, they were encouraged to try out different objects in the room to see which ones conducted electricity. The teacher then brought the class together in a large-group discussion, during which students reported what items did and did not conduct electricity. The teacher listed the items on the board as they were suggested. Students commented on each others' findings; for example, one student reported that a rubber band conducted electricity, but another raised his hand and said that it had not. The teacher asked why the results may have differed, and a student suggested that the first student may have accidentally touched the wire to one of the clips on the battery holder, thus inadvertently completing the circuit. The teacher encouraged this student to try the experiment in front of the class, taking care to touch only the rubber band, and she found that the rubber was not in fact a conductor. After the discussion, students were instructed to copy the list of conductors and nonconductors in their notebooks, and use this list to generate a hypothesis about what types of materials conduct electricity.

Sense-Making

An effective science lesson requires opportunities for students to make sense of the ideas with which they have been engaged (National Research Council, 2003). Because it is unlikely that students will be able to draw the appropriate conclusions on their own, regardless of how engaging the activities, it falls to the teacher to ensure that students make sense of their science experience through skillful questioning, facilitation of class discussion, and/or explanations. For example, students may be encouraged to make connections between what they did in the lesson and what they were intended to learn, so that they see a purpose to their activities. In addition, students may be asked to reflect on their initial ideas, becoming aware of how their thinking may have changed over the course of the lesson or unit. The teacher may also help them connect the ideas to what they have learned previously, thereby placing the lesson's learning goals in a larger scientific framework and helping them organize their knowledge (National Research Council, 2003; Gallagher, 2000). Finally, students may be given opportunities to apply the concepts to new contexts, which helps both reinforce their understanding of the ideas and build their reasoning skills.

As with other elements of effective instruction, sense-making may be accomplished with a variety of pedagogies. For example, in a lecture, the teacher may place facts within a broader framework and provide analogies that connect the ideas to students' previous experience. In a hands-on activity, the teacher may provide explanations at appropriate junctures, and facilitate a discussion at the end to help the students understand the data they collected in light of current scientific theories. The teacher's role is crucial in either case, as students would be unlikely on their own to be able to determine what the main ideas are in a lecture, or to understand the science ideas underlying a laboratory investigation. The teacher's effectiveness in asking questions, providing explanations, and otherwise helping to push student thinking forward as the lesson unfolds often determines students' opportunity to learn. The following example illustrates how one teacher effectively used a familiar analogy to help students in a middle school physical science class make sense of a fairly abstract concept.

A lesson on light using analogy

In a unit on light and waves, students were learning about the properties of light. In this lesson, students were trying to qualitatively understand the relationship between the intensity of light and its distance from the light source. Students conducted an experiment where they varied the distance between a flashlight and a screen (in this case, a large piece of white paper), and made observations about the image of the light on the screen. They noticed that as they increased the distance between the flashlight and the screen, the image grew larger and fainter. Although the students were drawing the correct conclusion from the experiment, they were struggling to understand what caused this result. To help the students understand what was going on, the teacher asked them to think about a balloon as it was being inflated. The students agreed that the balloon had a constant amount of material, and that as it was inflated, that material was spread out more and more, becoming thinner and thinner. The teacher explained that light behaved similarly; as it spread out, there was less and less light at any one point, but the total amount of light (on the surface of the sphere) stayed the same.

PREVALENCE OF THESE CHARACTERISTICS IN SCIENCE INSTRUCTION IN THE UNITED STATES

How common are these features of effective instruction in science classrooms across the United States? A number of nationally-representative surveys of science education—e.g., The National Survey of Science and Mathematics Education (Weiss et al., 2001); National Assessment of Educational Progress (NAEP) (Grigg et al., 2006); Trends in Mathematics and Science Study (TIMSS)[3] (Martin et al., 2004)—provide nationally representative information on instructional practices used in science classes, though the studies used different measures to characterize instruction (e.g., some looked at how instructional time was spent, others looked at teachers' use of various instructional strategies).

The teacher survey administered as part of the 2005 fourth grade NAEP found that about one-third of science lessons included students reading from a science textbook and about one-quarter included students doing hands-on activities. The NAEP data also indicate that students work on group activities in about one out of every five lessons.

The 2003 TIMSS teacher survey found that 30 percent of instructional time in eighth grade science lessons was devoted to students listening to lecture-style presentations, either initial presentations on new content or re-teaching/clarification of content and procedures. The survey also found that 34 percent of instructional time was spent on students working problems, either with the teacher's guidance or on their own. The survey did not ask for the percent of time spent on hands-on or laboratory activities.

Similarly, the National Survey in 2000 found that about one-third of instructional time in grades K–12 was spent on whole class lecture/discussion, and that about one-sixth of instructional time was spent on students reading textbooks and/or completing worksheets. This survey also found that science teachers were devoting a substantial portion of instructional time to hands-on/laboratory activities: 30 percent of time in grades K–4, 24 percent in grades 5–8, and 22 percent in grades 9–12.

It is important to note, however, that these studies were limited to describing the types and frequency of instructional practices, as the field has

[3] Although the main purpose of TIMMS is to provide data for international comparisons, it provides a great deal of information about science education in the U.S.

not yet figured out how to measure quality of instruction (e.g., the extent to which students are intellectually engaged with important science content in a lesson) with a survey. The field's understanding of the quality of science education as it relates to the vision of effective instruction has been enhanced by two large scale observation studies that were conducted in recent years. One was the 1999 TIMSS Video Study (Roth et al., 2006) which examined eighth grade science instruction in several nations, including 88 lessons in the U.S. Another was the 2001 Inside the Classroom study (Weiss, Pasley, Smith, Banilower, & Heck, 2003)[4] which included classroom observations of 180 science lessons across grades K–12 from a nationally representative sample of classes (from which all of the vignettes in this section of the brief were drawn).[5] However, though quite a few of the tenets of the learning theory described earlier were embedded in the frameworks used by these researchers, neither of these studies was designed or reported using the exact framework, making it difficult to accurately gauge the frequency with which all of these characteristics occur. Still, elements from these studies provide information that can be used to make some rough estimates.

Motivation

The extent to which science lessons include a motivational element is particularly difficult to pin down. The 1999 TIMSS Video Study found that 63 percent of U.S. eighth grade science lessons contained at least one motivating activity, and that across all lessons, 23 percent of instructional time was devoted to motivating students. However, the researchers did not report the extent to which lessons relied on extrinsic vs. intrinsic motivation.

Data from the Inside the Classroom study, in which researchers observed and rated a nationally representative sample of 180 K–12 science lessons, found that only about 40 percent of science lessons included a motivational element. Many lessons "just started":

[4] The methodology of each of these studies is described in the appendix.

[5] It is important to note that these vignettes are examples from real lessons that were observed and are not intended to be exemplars of best practice.

More sense-making lessons

For example, a teacher began a third grade lesson simply 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."

"Just starting" is not restricted to review lessons. For example, a high school teacher announced that, "Today we're going to talk about Roman Numeral III.H.," referring to a lengthy outline he had given the students previously. (Weiss et al., 2003, p. 41-42)

Of the lessons that did attempt to motivate students, more than one in three relied on extrinsic motivation (e.g., preparation for an assessment), rather than attempting to foster student interest in science.

In contrast, some lessons attempted to build intrinsic motivation by piquing student curiosity and interest with vivid hands-on experiences. For example:

A lesson on animal needs: fourth grade

In a fourth 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.

A lesson on electricity: high school

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.

Other lessons used real-world examples to bring a concept to life and foster student interest in the topic:

> The teacher began the study of the water cycle in a high school earth science class by noting that their state held the dubious honor of being the second driest state in the union.

> The teacher asked students in a sixth grade science class to name different kinds of rocks, based on size, and then explained that the Earth's crust is made up of many different-sized rocks. She asked: "Who's been to [a nearby city park]? What's at the bottom of the stream? Have you ever felt squishy stuff between your toes? That's sediment." Students then raised their hands and described their family vacations to different locations with interesting rock formations, and described how the bottom of various lakes felt to them.

Eliciting Students' Prior Knowledge

It is hard to set a standard for an absolute frequency with which teachers need to elicit students' prior knowledge. Unlike other aspects of the learning theory, such as intellectual engagement, that one would hope to see in every science lesson, one could reasonably expect elicitation of students' prior knowledge to occur at the beginning of instruction on a new topic rather than in every lesson. Unfortunately, the available evidence for this element used lessons, rather than topics, as the unit of analysis. Thus, the following data may underestimate the prevalence of this practice in instruction at the unit level.

The 2000 National Survey of Science and Mathematics Education (Weiss, Banilower, McMahon, & Smith, 2001) surveyed a nationally representative sample of over 2,500 science teachers. Among other topics, teachers were asked how often they conduct a pre-assessment to determine what students already know. Responses indicated that only about one in six lessons included such a pre-assessment (though teachers may have interpreted the item to mean a formal assessment, which may further underestimate the prevalence of this practice). Based on data from this survey, the practice appears to be less common in grades 9–12 than in grades K–8.

The Inside the Classroom study indicates that 35 percent of lessons contained some form of elicitation. However, in some cases the prompt was not well-aligned with the learning goal stated by the teacher and was therefore unlikely to bring out relevant student ideas. For example, in a second grade lesson on how mammals survive in the ocean, the teacher asked students to first brainstorm a list of animals that live in the ocean. The students suggested several animals, including fish, turtles, and lobsters (none of which are mammals). The teacher then described the characteristics of mammals (e.g., fur, warm blooded, babies born alive). The remainder of the lesson consisted of the teacher showing students pictures of different aquatic mammals, and asking them to indicate if the mammal used fur or fat to keep warm. At no point were the animals originally listed by the students dealt with (e.g., by applying the characteristics of mammals that the teacher described to determine whether the students' suggestions were mammals, or by comparing/contrasting the animals listed by the students to the mammals shown by the teacher), making the list of student animals irrelevant to the lesson.

Even when relevant student ideas were elicited, they may not have been put to any use in the instruction. Researchers found that only 25 percent of science lessons built on students' prior ideas and only eight percent included instructional activities to confront incorrect student ideas.

The following lesson was representative:

A lesson on plants: fourth grade

Toward the end of a fourth grade unit on plants, the teacher told students they would be observing and identifying the parts of a seed. This lesson started with the teacher asking the class to get out their science books and get with their partner that they used last time. He then asked the entire class, "Who can tell me something about seeds?" Students raised their hands and volunteered different responses, including:

"They have food for the newborn plant."

"They're inside the fruit."

"It's an ovary."

"If you graft you get a better fruit."

In this lesson, the teacher did not discuss any of the features of plants mentioned by the students, even when they related to the goal of the lesson.

Intellectual Engagement

The main data source for the extent to which lessons intellectually engage students is the Inside the Classroom study, which found that only 35 percent of science lessons were successful in engaging students with the relevant science ideas. In many lessons, students were completely passive. For example:

A lesson on evolution: ninth grade

In a ninth grade biology lesson on evolution, students were first asked to individually complete a worksheet in which they had to decide whether statements were true or false. Once they had finished working individually, students were instructed to check their work in the book, working in small groups to come to a consensus on the answers, and to document on what page and paragraph they found the answer. When they had finished the worksheet, the students copied from the board a timeline of evolution that focused on bacteria.

The teacher then gave a lecture based on the chapter students had just read. He began by asking students to look at the inside of the textbook's back cover, which showed a chart of the evolution of all life and when each life form was found. He told students that this chart summarized the material they were about to cover. The rest of the lecture consisted of a series of names of organisms and time frames of their existence. The focus was on lists of facts taken from the book; at several points, the teacher read straight out of the textbook or asked students to do so. He introduced new topics by saying, "Next they start talking about continental drift" or "Then it starts talking about sharks." Students followed along in the book. The teacher instructed them to take notes in a two-column format in which one column was titled "Main Themes" and the other was "Detail." Only a few students followed this format, and the teacher never followed through or helped to identify the "Main Themes."

In other lessons, students were physically engaged with activities, but were not helped to make the connections between the activities and the important science ideas. The 1999 TIMSS Video Study found that 27 percent of U.S. eighth grade science lessons involved students with hands-on activities, but made no connections made between the activities and the science content. The following example from the Inside the Classroom study illustrates a lesson where students "did" things, but with little expectation that they would draw connections between their activities and science content.

A bridge building activity: sixth grade

In a sixth grade lesson, students participated in a bridge building activity. The teacher explained that each group would receive 35 straws, 10 rubber bands, one foot of masking tape, and 10 paper clips to build their bridges. The teacher stated that the groups that worked diligently together would receive extra materials. The students built different components of the bridge by cutting or inserting straws or assembling pre-made structures into the bridge. Once the groups were finished, the teacher put the bridge across a span of one foot and asked students to gather around. The students placed objects with different weights on the bridges to test their strength, but no standard was used for all of the groups. The lesson ended after these trials with no discussion of why different bridges supported different amounts of weight.

Use of Evidence to Critique Claims

Science, as a dynamic body of knowledge, evolves as new data emerge. However, teachers often present science as a static body of knowledge, with a focus on vocabulary, which students are expected to simply accept as true. Researchers in the Inside the Classroom study (Weiss et al., 2003) found that few lessons engaged students with concepts in a way that allowed them to understand the nature of science, specifically how scientific knowledge is generated, enriched, and changed. Fewer than 1 in 10 science lessons required students to use data or examples as evidence in supporting or critiquing conclusions.

Even when students were involved in data collection, in some cases they were not asked to use the data to generate conclusions or evaluate their feasibility. In other lessons, the activities had students changing multiple variables at once, making it impossible for them to draw appropriate conclusions about what factors affected the outcome. Typical lessons included:

A lesson on plant growth: sixth grade

Late in a unit on plant growth, a sixth grade class focused on the parts and functions of angiosperms. The lesson began with students finishing a two-week long lab activity from their text, in which they grew different types of seeds in a beaker with wet paper towels. Over the course of two weeks they had made daily observations about the plants' growth and development. As this was the final day, students took their plants from the beakers and made final measurements of the root system, stem, and leaves. The students recorded their observations on a lab worksheet/journal, and then the teacher led the large group through answering the questions that came along with the worksheet. Questions included, "Do all seeds planted at the same time germinate at the same time?" and "Compare the growth rate of different seedlings." Although students could have used the data they had collected to respond to these prompts, the teacher answered the questions for the students, short-circuiting their opportunity to draw conclusions from their data.

A physics lesson: eight grade

An eighth grade lesson during a unit on motion, forces, and energy focused primarily on reviewing measurement, and secondarily on projectile motion. Students conducted a lab in which they used spoons to catapult marshmallows, launching at various angles and measuring how far they went. Students worked in groups of three in an outdoor area just outside the classroom. During the activity, students were making many errors in measuring both distances and angles that went unnoticed by the teacher (e.g., when they launched a marshmallow that went over a two foot wall, they draped the measuring tape over the wall instead of just measuring the horizontal distance; the students were not using the protractor correctly as they did not understand that you had to line up the base of their catapult with the crosshairs at the base of the protractor). The students were also failing to control for other variables such as how far back they bent the spoons on their catapults. Also, there was no consideration of the effect of the wind, which was strong and gusty.

Sense-Making

As is the case with intellectual engagement, sense-making can be fostered in a number of ways. However, as with intellectual engagement, there are no specific classroom practices that guarantee sense-making. Only a quarter of science lessons observed as part of the Inside the Classroom study were judged to include adequate sense-making (Weiss et al., 2003). The following examples illustrate lessons that seemed to help students make sense of the important ideas.

An anatomy lesson: high school

The teacher in a high school human anatomy and physiology class began a lecture by drawing a diagram of a nerve receptor, connected by a nerve fiber to (eventually) the brain. He explained the concept of a threshold for a receptor, noting that stimuli could be either sub-threshold, threshold, or super-threshold, stressing that only after the threshold is reached does the receptor respond to the stimulus and send a signal to the brain. He spent most of the remainder of the lesson explaining that receptors vary in threshold and, "Your brain recognizes the highest threshold receptor stimulated."

Using the hand as the point of reference, the teacher differentiated among different stimuli—touch, pressure, poke, punch, hammer, excruciating pain. He gave the example of an instance where if "punch" receptors were stimulated, the brain would not register "touch," only "punch." A student asked, "Does it work that way with taste, hearing, and sight?" The teacher responded that it does, and the student asked, "How does it work with sight?" The teacher gave the example of caution signs being made of certain colors because the receptors for those stimuli have the lowest threshold, and of an artist using certain colors to create light and draw a person to a particular part of a painting.

The teacher summarized this portion of the lecture, reiterating the all-or-nothing principle and the differentiation of nerve receptors by threshold. He spent the last few minutes of the class moving on to the next portion of his outline, in which he drew and labeled the parts of a synapse. Said the observer, "this lecture was extremely engaging, accessible, and focused on worthwhile content. The teacher emphasized sense-making throughout the lesson, using examples familiar to the students and connecting the content to their lives. The students appeared to be very engaged."

A chemistry lesson: high school

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 important science ideas, they concluded that, "Teachers seem to assume that the students will be able on their own to distinguish the big ideas from the supporting details in their lectures, and to understand the mathematics/science ideas underlying their computations, problem-solving, and laboratory investigations" (Weiss et al., 2003, p. 71). The following lesson provides examples of inadequate sense-making.

Inadequate sense-making

The teacher guided a third 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.

The observer noted that "each of the physical science topics demonstrated in this lesson was appropriate to the ninth 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."

An observer reported that the purpose of the lesson in a high school biology class was for the students to learn about adaptation and natural selection, but that it was unlikely the purpose was being achieved. The observer stated, "I have serious doubts, however, as to whether the students learned anything at all about the intended content. The students were not engaged in ideas; they were engaged in getting the handout done. Since the lab activity described on the handout was not accompanied by a meaningful discussion of the students' ideas, findings and questions, the activity reduced science to facts and vocabulary. There was no sense-making whatsoever in this lesson. A few of the questions on the handout might have required the students to summarize their learning, but they just got the answers for those questions from the teacher."

SAMPLE LESSONS

As illustrated in the previous sections, the key elements of science instruction are sometimes designed and implemented effectively and sometimes ineffectively, whether the instruction is "reform-oriented" or "traditional" in nature. The section further develops the vision of effective science instruction by illustrating that the elements of effective instruction can be combined into a coherent whole, and that it is possible to do so in both styles of teaching. Two hypothetical classroom scenarios are described that embody the characteristics of effective teaching described in the research. Each scenario portrays a well-designed and well-implemented lesson for a typical class of middle school students in terms of both family background and schooling experiences; the primary difference between the two scenarios is that one uses traditional and the other reform teaching practices.

The sample lessons come near the beginning of a unit on forces and their effects on motion. Prior to this lesson, students have spent time examining and describing different types of motion: no motion (objects at rest), constant speed, changing speed, and changing direction. Students have also learned that when a net force acts on a moving object in the direction of motion its speed increases, and that a net force in the direction opposite to motion causes its speed to decrease. The purpose of each lesson is to begin to develop students' understanding of the idea that when no forces act on an object, there is no change in its motion.

Lesson 1: Reform-Oriented Instruction

Lesson 1 begins with the teacher asking students to respond to the daily "warm-up" question in their notebooks. Today's question is, "If an object is already moving, what will happen to its motion if there are no forces acting on it, and why?" Students spend a few minutes working in small groups to come up with an answer, which they also record in their notebooks. Next, the teacher asks students to share their responses to the question, recording their ideas on the chalkboard. A wide range of student ideas emerges, including:

> *Student 1: "The object will stop moving because there are no forces to keep it going."*

Student 2: "It will keep moving at a constant speed for a while, but eventually it will slow down and stop. Everything slows down and stops eventually."
Student 3: "Friction will cause the object to slow down and stop."

The teacher continues to ask students for their ideas, without commenting on their correctness, until no new ideas are mentioned. Next, the teacher tells the class that today they will be doing an experiment that will help them answer the question. The experiment consists of students launching a wooden block across their lab tables using a rubber band launcher, but varying the surface of the table with different coarsenesses of sandpaper. The teacher tells the class that the purpose of the investigation is to figure out how the type of surface affects the motion of the block.

After showing the students the materials they will use, but before setting them to work, the teacher leads a brief discussion on the variables in the experiment and the need to hold them constant. The students then conduct the investigation, recording their observations. After the students have collected their data, the teacher gathers the students and asks what they observed. All of the students agree that the rougher the sandpaper, the shorter the distance traveled by the block. The teacher then asks what happens to the speed of the block in the different trials. After some discussion, the students agree that the block started at about the same speed in each trial, and that its speed decreased more quickly the rougher the surface was.

The teacher next asks the students what they think would happen to the speed of the block if the surface was made smoother and smoother. The class agrees that the block will go farther the smoother the surface is because the smoother the surface is, the less its speed decreases. The teacher then asks the groups to develop a response to the following question: "What would happen to the speed of the object if the surface were perfectly smooth?"

The students work in their groups discussing the question and formulating an answer. After several minutes, the teacher asks groups to report out their answers. Some of the groups indicate that they think the object's speed wouldn't change. Other groups think that the object's speed wouldn't change very much, but would slow down some because of air resistance. The teacher asks, "What is air resistance? We haven't discussed that term yet." One student answers that it is like wind pushing on a sail. After some discussion, the class agrees that air resistance is a force. The class ends with the teacher asking students to reconsider the day's warm-up question, to look at their initial answer to the question, and to write a new answer based on what they experienced that day.

Lesson 2: Traditional Instruction

Lesson 2 begins with the teacher telling the class that they are going to continue their unit on forces and motion, and that they should have out paper and pencil for taking notes. She asks the class, "Have you ever seen or been to an ice hockey game? Do you know how they come out in between periods and smooth the ice with the Zamboni? Why do you think they do that?" (The teacher knew that hockey was a favorite sport for students in the school and that most of the students would be familiar with it.) Students eagerly raise their hands to answer, and the following discussion ensues:

> *Student 1: So the hockey players don't trip on the holes in the ice.*
> *Student 2: So the puck will slide better.*
> *Teacher: What do you mean by "slide better"? Why would smoother ice make it better?*

The students and teacher spend most of the class period discussing the motion of the puck on ice. The teacher continues to use questions to draw out relevant experiences students have had about the motion of objects, what they know about forces and motion from previous lessons, and to help them clarify their thoughts (e.g., "Have you ever played with a toy car on the carpet? How is it different than playing with the car on a wood or vinyl floor?" "We've already learned that applying a force can cause an object's speed to increase or decrease, depending on the direction of the force. What might the force be like on an object when its speed isn't changing?").

The entire class is involved in this discussion; the teacher's classroom management requires all students to participate (students must raise their hands and be called upon to answer so that all students have a chance to think about her questions). Through the question-and-answer discussion, she skillfully guides them to the conclusion that an object will move at a constant speed if there are no forces acting on it. In addition, the teacher helped students see how the examples they talked about related to this idea.

At the end of the discussion, the teacher summarizes the main ideas of the discussion on the board, and students copy the key ideas down in their notebooks, including some important related ideas that the class had previously studied:

- A force is a push or pull.
- A net force on a moving object in the same direction it is moving will cause its speed to increase.
- A continuously acting net force in the direction of motion will cause a moving object's speed to keep increasing.
- A net force on a moving object in the direction opposite to its motion will cause its speed to decrease.
- Friction is a force that acts against motion (a backward force).
- The reason many things lose speed and stop moving is because of friction.
- If no net force acts on an object, its speed will not change.

After completing the list, the teacher tells the students that their homework, which is to be started in class, is to come up with an example for each of these points that would help someone who hadn't been taught the idea to understand it.

Lesson Analysis

Although these two sample lessons are quite different, they both reflect many of the characteristics of effective instruction described in the research, and in both cases the successful implementation requires the teacher to have strong disciplinary knowledge, pedagogical content knowledge, and classroom management skills. Each lesson incorporates elements that foster students' intrinsic motivation to learn science. The first lesson involves students in a hands-on activity to answer a question; the second lesson helps students tie what they're learning in science to experiences in their everyday life.

Both lessons elicit students' initial ideas about the topic, though in very different ways. The first lesson uses a question directly related to the learning goal for the lesson, asking the students to explain what will happen in the scenario based on their current understanding of the world. In contrast, the teacher in the second lesson uses a series of questions to probe and draw out students' ideas.

Students in both lessons are intellectually engaged with the target idea and are asked to consider phenomena from which the idea stems. In the reform-oriented lesson, students engage with the phenomena via the hands-on activity. In the traditional lesson, students are engaged with phenomena through the examples they and their teacher consider. In both lessons, students are asked to do substantive intellectual work. Both lessons also require students to draw and support conclusions with evidence; in the first lesson they do so with data from their hands-on experiment, in the second lesson with examples from their everyday life.

Finally, both lessons provide opportunities for students to make sense of the targeted idea. The first lesson asks students to reflect on their initial ideas in light of what they experienced in the lesson. The second lesson summarizes the big ideas students have been learning and asks them to revisit the evidence for each idea. In both of these lessons, students are involved in the process of scientific inquiry, attempting to come up with a description of how the world works that fits their data or examples.

IMPLICATIONS FOR POLICY MAKERS AND PRACTITIONERS

This document has focused on a vision for science instruction that is based on research on how people learn. The research indicates that to be effective, instruction needs to engage students in ways that take into account what they already know (or believe) about a topic. Students need to be intellectually engaged in the learning process, whether or not the instruction involves engaging them with hands-on activities. Instruction also needs to emphasize students evaluating evidence and making claims based on evidence, so they develop an understanding of the nature of science as a discipline. Finally, students need opportunities to reflect on and make sense of what they have learned, and consider how their current understanding compares to what they thought prior to instruction.

What are the implications of this vision of effective instruction for policy and practice?

- **States need to reduce the number of science standards to enable effective instruction.**
  State standards are a major driver of instruction through the specification of learning goals and often, preferred pedagogical approaches. However, it is one thing to suggest that "less is more," advocating for in-depth learning of a smaller number of important ideas, and quite another to actually designate a small enough set of learning goals so that in-depth learning is possible. The large number of national and state science standards makes it difficult to design a science program that enables students to learn all of them in the course of their K–12 program.
- **States and districts need to support efforts to implement effective instruction by making sure that teachers receive consistent messages.**
  Lack of policy alignment within the system puts teachers in a difficult spot. What should they emphasize when state standards call for conceptual understanding but state assessments measure knowledge of vocabulary? (Teachers typically indicate they opt to teach what is assessed.) Or what should teachers do when district guidelines describe

particular learning expectations but there is only partial overlap between those and the available instructional materials? (Teachers often use the textbook as the primary organizer of instruction.) Analyzing the extent of alignment of state/district standards, assessments, instructional materials, professional development programs, teacher evaluation systems, and teacher induction systems can highlight areas of need so corrective action can be taken.

- **Textbook publishers should be encouraged to develop student instructional materials to facilitate effective instruction.**
  In addition to knowledgeable teachers, effective instruction requires well-designed instructional materials. Textbooks and other instructional materials should pose questions to students that elicit their ideas, and include tasks that engage students with the phenomena that will enable them to confront and refine their prior ideas. In addition, student instructional materials can be educative for teachers (Davis and Krajcik, 2005), providing summaries of key concepts, describing how concepts are intended to be developed in a unit, and highlighting how each activity in the unit is expected to build on previous experiences in helping students understand key ideas.
- **"Textbook adoption" states (those that develop lists of approved materials for district use), and large districts should use their influence with textbook publishers to improve the design of student instructional materials in light of what is known about effective instruction.**
  Publishers are in business to sell books, and they will respond to guidelines provided by states and districts that they believe are likely to affect their sales. Textbook adoption guidelines might request, for example, that each lesson or set of lessons includes opportunities for students to make their initial ideas explicit. Similarly, textbook adoption guidelines could set expectations that lessons will incorporate the phenomena that are most amenable to understanding the targeted learning goal, and that they will provide opportunities for reflection. States and districts might also define what they mean by educative instructional materials and require publishers to provide those kinds of supports with their textbooks to be considered for purchase.

- **Prospective teachers need opportunities to learn important science concepts and to develop a vision of science instruction that is based on what is known about how people learn.**
  If teachers have experienced effective science instruction, and if that instruction has focused on powerful science ideas, then they will have an understanding of key disciplinary content, which is essential if they are to be able to guide their students' learning. In addition, the more opportunities teachers have to learn science well, perhaps including examples of effective instruction that are traditional in nature as well as examples that are reform-oriented, and to consider how that instruction was designed and implemented to facilitate their learning, the more likely they are to develop a vision of effective instruction.
- **Science teachers need on-going professional development to deepen their content/pedagogical content knowledge and assist them in applying what they are learning to their classroom instruction.**
  Like all professionals, science teachers need opportunities for continuing education—in disciplinary content and in content-specific pedagogy. The latter area, often referred to as pedagogical content knowledge, is receiving increasing attention of late, with the recognition that teachers need an understanding that goes beyond knowledge of science content to include knowing how students typically think about concepts, the questions teachers can ask to figure out what their particular students do and do not understand about a specific topic, and the experiences they can provide to help move student understanding forward. The emerging knowledge base on effective professional development can provide guidance in designing and implementing opportunities that enable teachers to both deepen their understanding and apply what they are learning to improve their instruction.

APPENDIX

The methodologies of the large scale national studies referenced in this brief are summarized in this appendix.

Surveys

2005 National Assessment of Educational Progress

The National Assessment of Educational Progress (NAEP) periodically assesses the science knowledge and skills of students in grades 4, 8 and 12 in a nationally representative sample; the most recent science assessment was in 2005. In addition to the student assessment, a background questionnaire is given to teachers whose students took the science assessment at grades 4 and 8. These questionnaires collected data on teacher background and training, and at grade 4, instructional practices, and results are reported as percent of students whose teachers reported a particular practice. The questionnaires were developed by the NAEP staff and were reviewed by external advisory groups and piloted prior to their use with the national assessment.

2003 Trends in Mathematics and Science Study

The Trends in International Mathematics and Science Study (TIMSS) assessed a nationally representative sample of students in 4th and 8th grade in science and also surveyed the science teachers of these students. The teacher questionnaires were designed to collect information about the teachers' preparation, professional development, pedagogical activities, and implemented curriculum.

TIMSS used a two stage system where schools are chosen in the first stage and classrooms are selected in the second stage. For the first stage of sampling, a systematic probability-proportional-to-size (PPS) technique was used. There was stratification by poverty level, school type (public, private), region, urbanization, and minority status. During the second sampling stage, one classroom per school was sampled again using the PPS technique at each school. Sampling weights were calculated for each teacher that participated, based on the selection probabilities for schools and classrooms. For the United States, there was a school participation rate of 78 percent for grade 8, and a school participation rate of 70 percent for grade 4. In total, the study assessed 480 schools in the U.S.

The development of the teacher questionnaires started with reviewing the questionnaires used in the past TIMSS iterations. The teacher questionnaires were field tested, reviewed in light of field test results, and a final version was created.

2000 National Survey of Science and Mathematics Education

The 2000 National Survey of Science and Mathematics Education was designed to provide up-to-date information and to identify trends in the areas of teacher background and experience, curriculum and instruction, and the availability and use of instructional resources in grades K–12 in the 50 states and the District of Columbia.

The sample design for the National Survey was a national probability sample of schools and teachers, with one randomly selected science class. The response rate was 73 percent at the school level and 74 percent at the teacher level (from participating schools), yielding questionnaire responses from 2,795 science teachers.

The design of the questionnaires started by reviewing the questionnaires that had been used in the earlier national surveys in 1977, 1985–86, and 1993. Preliminary drafts of the new questionnaires were reviewed by professional organizations. The survey instruments then went through several iterations of field testing and revision to help ensure that individual items were clear and unambiguous and that the survey as a whole would provide the necessary information with the least possible burden on participants.

Observation Studies

1999 TIMSS Video Study

The Trends in International Mathematics and Science Study (TIMSS) 1999 Video Study investigated and described teaching practices in eighth grade classrooms in several countries including the United States. The study involved determining a sample of classrooms to videotape, collecting videos of an entire lesson from these selected classes, and developing and applying codes to the videos in order to describe patterns of science teaching practices.

The TIMSS Video Study used a systematic probability-proportional-to-size technique to select the participating schools. Each of the selected schools submitted a list of the science classes that were taught for eighth grade students. From this list, one class was randomly selected to videotape from each school. The selected classes were videotaped once, from start to finish. No substitutions of teachers or class periods were allowed, although classes were not allowed to be videotaped on days when a test was planned to take the entire class period. The lessons were evenly distributed over the entire school year. The percentage of eligible schools that participated in the study in the U.S. was 81 percent, giving a total of 88 American schools who participated.

A Science Code Development Team consisting of science specialists, researchers and representatives from each of the countries involved in the study, developed the codes, trained the coders, and monitored their reliability. They also collaborated with two advisory groups of national research coordinators and a steering committee of North American science education researchers. The Science Content Coding team coded the videos in terms of the science content that was covered, and the International Video Coding Team coded lessons for all other aspects of the lessons that did not require science content knowledge. Inter-rater reliability was established through percentage agreement for the International Video Coding Team, and the Science Content Coding Team used consensus coding of all the team members.

Inside the Classroom

For the Inside the Classroom study, researchers conducted observations and interviews during the period November 2000–April 2002. A subset of 40 middle schools was selected from the nationally representative sample of 430 middle schools participating in the 2000 National Survey of Science and Mathematics Education. For each of the middle schools that agreed to participate, the elementary schools and high schools in the same feeder pattern were identified, and one of each was randomly sampled along with the middle school. A simple random sample was drawn from among the science teachers in each sampled school, and one class from each of two science teachers was observed. Due to time and resource constraints, HRI visited 31 sites that were representative of districts and schools in the nation. The observed teachers and classrooms were compared to the National Survey data, and were found to be representative of those in the nation in terms of teacher backgrounds, instructional objectives, and instructional activities.

The classroom observation instrument originally developed and validated as part of the core evaluation of the National Science Foundation's Local Systemic

Change initiative was adapted for use in this study. To ensure that all observers had a complete understanding of the purposes and procedures of the study, each researcher participated in a two-day intensive training session. The data collection instruments were introduced, and researchers watched a series of videotaped science lessons, completed protocols, and discussed their ratings. By the end of the training, there was substantial agreement on ratings and on how to use the protocol to communicate the results of their observations and interviews.

Once data collection began, the core research team read the observers' descriptions of the lessons observed to determine factors that distinguished designs, implementations, science content, classroom culture, and entire lessons judged to be effective from those judged to be ineffective. Data from the classroom observations were weighted in order to yield unbiased estimates of all science lessons in the nation, as well as by school urbanicity and grade range.

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