CHAPTER FIVE
Strengths and Weaknesses of Mathematics and Science Lessons

Introduction

As noted in the previous chapter, the quality of the lessons teachers design and enact to help students learn mathematics/science content varies considerably. Researchers saw some terrific lessons—classrooms where the students were fully and purposefully engaged in deepening their understanding of important mathematics and science concepts. Some of these lessons were "traditional" in nature, including lectures and worksheets; others were "reform" in nature, involving students in more open inquiries. Observers saw other lessons, some traditional and some reform-oriented, that were far lower in quality, where learning mathematics/science would have been difficult, if not impossible. In an effort to determine which characteristics were most important in determining quality, the authors did an in-depth analysis of lesson descriptions for lessons judged very effective and decidedly ineffective. The factors that seem to distinguish effective lessons from ineffective ones are their ability to:

- Engage students with the mathematics/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 mathematics/science content.

These results are presented in the following sections, using excerpts from lesson descriptions to illustrate the findings. All quantitative data provided are weighted to represent all mathematics and science lessons in the United States, grades K–12.

Engaging Students with Mathematics/Science Content

➢ **To be judged effective, lessons need to provide students with opportunities to grapple with important mathematics/science content in meaningful ways.**

Certainly one of the most important aspects of effective mathematics and science lessons, if not the most important, 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, mathematics and science lessons in the United States are relatively strong in this area, with the majority of lessons including significant and worthwhile content. (See Figure 11.)

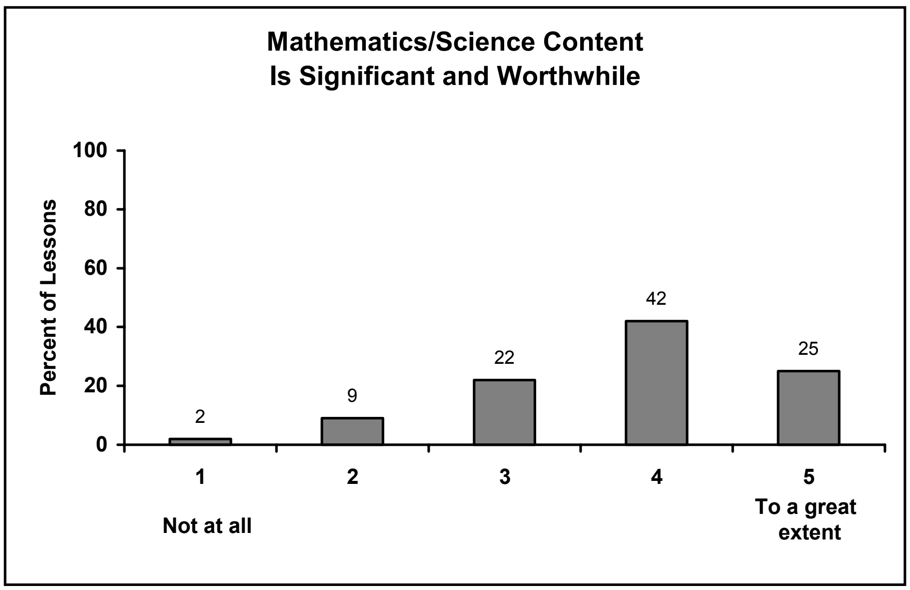

Figure 11

Although lessons generally include important content, most lessons are nevertheless low in overall quality. Clearly, while the inclusion of important content is necessary for high quality science/mathematics lessons, it is not sufficient.

"Inviting" the Learners into Purposeful Interaction with the Mathematics/ Science Content

The hallmark of lessons judged to be effective is that they include meaningful experiences that engage students intellectually with mathematics and 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. As can be seen in Figure 12, few lessons in the nation engage students intellectually with important mathematics/science content.

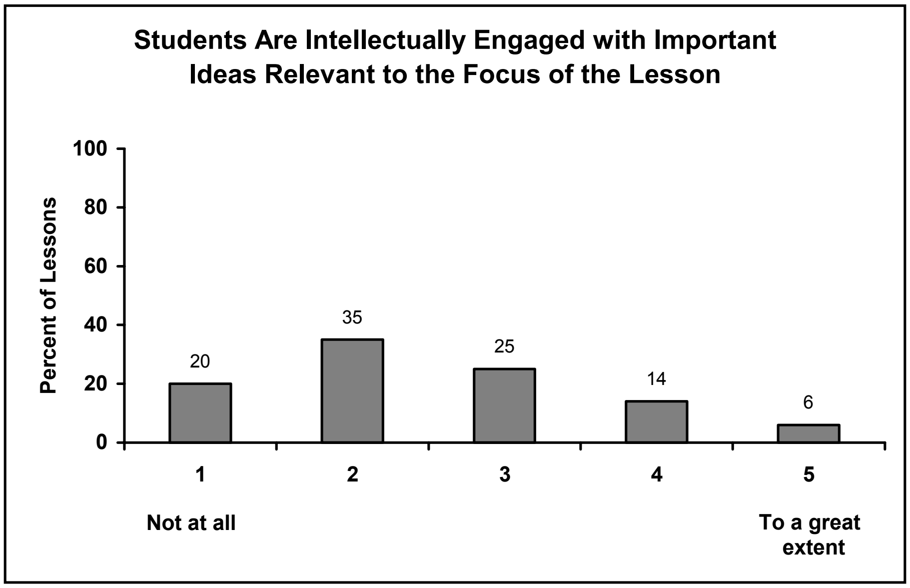

Figure 12

Earlier we noted the importance of lessons being "purposeful" in relation to important learning goals, with teachers having a clear understanding of the purpose of each lesson in terms of those goals. We would argue, further, that *students* also 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; lessons need to "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.[6] The observation protocol used in this study did not specifically ask researchers about the strategies that teachers used to engage students in the lesson, but observers often commented on the presence or absence of this feature in their lesson descriptions. The following sections describe how lessons address, or fail to address, the need to engage students with the mathematics/science content.

- ***Many lessons do not include an element of motivation.***
  Observers noted that many lessons "just started." For example, a teacher began a 3rd 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."

[6] A similar argument was made by Kesidou and Roseman (2002) in their analysis of middle school science programs, citing 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)

"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. In some cases students did not engage in lessons such as these; in other cases they were attentive, typically with an upcoming test rather than interest in the problem being posed as the apparent motivation.

- ***Some lessons motivate interest by engaging students with phenomena.***
  Lessons that "invite" the learners in sometimes do so by engaging students in first-hand experiences with the concepts or phenomena. For example:

> In a 4th 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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> In a lesson on fractions and as an introduction to percents, the teacher in a 7th grade mathematics class asked three students to come to the front of the class for a demonstration. One student measured the height and arm spread of a second student, while the third student wrote the numbers on the board. The students used these numbers to express the relationships both as a ratio and as a percent.
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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.

- ***Other lessons use real-world examples to generate interest.***
  Some teachers, instead of providing students with first-hand experience, invite the students in by using real-world examples to vividly illustrate the concept. The following lesson descriptions illustrate lessons where real-world examples played a large role in student engagement:

> As a lesson on the skeletal system started, a life size skeleton, named Mr. Bones, was introduced to the 5th grade class. The teacher talked about specific bones of the body, frequently capturing students' attention by telling stories and personal experiences: her husband's broken collar bone, actor Christopher Reeves' spinal cord injury, and her father's arthritis; students shared similar stories about the mailman with carpal tunnel syndrome and a mom with TMJ.
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> The teacher asked students in a 6th grade science class to name different kinds of rocks, based on size, 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.
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> A 7th grade mathematics lesson used examples from architecture, carpentry, and dressmaking to help

students understand the concept of symmetry; students were invited to provide their own examples as well.

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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.

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The teacher in an honors pre-calculus class led a brief discussion of the Doppler effect as an application of trigonometric functions; she also used a Slinky to model the wave pattern of sine and cosine functions.

- ***Some lessons use "contrived" contexts to engage students.***
  Teachers sometimes use stories and other fictional contexts to engage students with the content of the lessons. For example:

In a 1st 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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A teacher of a 3rd grade mathematics class worked to develop an understanding of how parentheses may be used to direct order of operations in number sentences by involving students in writing number models for different ways a basketball team might score 15 points.

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In a high school Algebra I lesson, the teacher presented three line graphs showing data about two fictitious companies regarding productivity (intersecting lines), production cost (parallel lines), and sales (equivalent lines). She discussed each graph with the class and then asked the class to vote for the company they would hire based on the graphs.

- ***Other lessons use "games" to engage students with the content.***
  Some lessons use games to engage students with the mathematics/science content of the lesson. It is important to note that while the games provide a context that generates student interest, in lessons judged to be effective these games are designed to keep the focus on the learning goals. The following lessons illustrate this point:

After reviewing states of matter, the teacher of a 2nd grade class introduced a scavenger hunt for solids, liquids and gases in the classroom, which was "seeded" with some objects specifically for this lesson. The students took the items back to their tables and classified them as solid, liquid, or gas. The teacher then asked the students to explain to the rest of the class how the group had classified their objects.

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The teacher started a mathematics lesson in a 3rd grade class by anchoring the content in the students' prior work with graphs, and then moved quickly to comparing the coordinate system to mapping and directions. To help make the comparison more real, she asked the students to close their eyes and began to talk through an example to show how following specific directions lead to an exact spot. She stated: "Go out this door. Turn right. Go through the double set of doors. Go a few feet further. Whose room is to the right?" The class in unison called out the name of the teacher who teaches in that room.

In introducing the concept of probability to a 5th grade class, the teacher used a spinner which she placed on the overhead. It had 8 sections; 5 sections had odd numbers in them and 3 had even numbers, but she did not point that out. She called two students to the front to be the players, and another to keep track of points on the board. One player got points every time the spinner landed on an odd number and the other every time it landed on a even number. The person to get 10 points first would win. The students took turns spinning and after a few spins into the game, one player, the one who had the even numbers, started to complain. The class discussed what was unfair about the spinner and what could be done to make it more fair.

The teacher began an elementary mathematics lesson with a review of the terms for solid geometric shapes. She then asked the class to find a number of shapes. For example: "I spy a shape that has six faces, eight corners, and twelve edges. What solid is it? Can you find an example in the room?" Said the observer: "The children eagerly participated in the game, and had surprisingly little trouble recognizing a rectangular prism, just from the teacher's verbal description."

As a review, the students in a high school Algebra II class played "Jeopardy"; the teacher would hold up a card and a student would call out the appropriate question. For example, for the card $(a)^m + (a)^n$, the student asked, "What is a to the (m plus n)?"

Portraying Mathematics/Science as a Dynamic Body of Knowledge

In addition to motivating students to engage with mathematics/science content, another characteristic of lessons judged to be effective is the manner in which they represent the disciplines of mathematics and science. Lessons can engage students with concepts so they come away with the understanding that each of these disciplines is a dynamic body of knowledge generated and enriched by investigation. Alternatively, lessons can portray mathematics or science as a body of facts and procedures to be memorized. Based on *Inside the Classroom* observations, only 18 percent of mathematics and science lessons nationally provide experiences for students that clearly depict mathematics/science as investigative in nature (rated 4 or 5 on a five-point scale). (See Figure 13.)

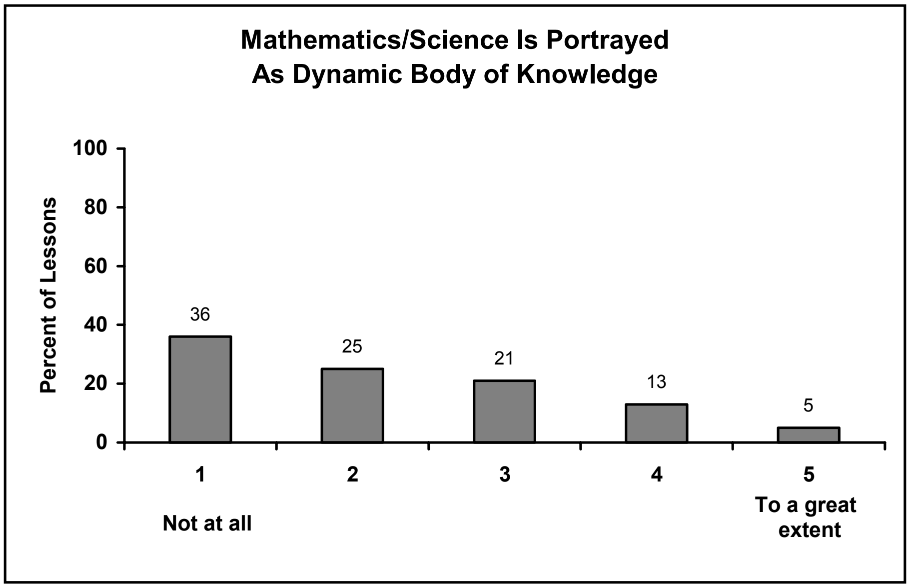

Figure 13

The following lessons are illustrative of this quality:

A 3rd grade science lesson focused 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."

A 7th grade pre-algebra lesson began with the teacher introducing a new word problem. The purpose was to help reinforce the need for careful reading of problems, justification of strategies used and solutions presented, and the concept that there are multiple ways to approach solving a single problem. The students and teacher were engaged for three-quarters of this lesson in a whole class discussion about strategies used to solve this single word problem and presenting their solutions. The teacher stressed that there was "not a right way or a wrong way" to solve a problem, but "many ways to get into an investigation." Throughout the lesson, the teacher made statements like "I think it would be a good idea to make sure you can verify your answer with others in your group." and "I need you to convince me it's the right answer."

A 6th grade science lesson consisted of a teacher-led discussion of the process of sedimentary rock formation. By drawing upon the experiences and prior knowledge of the students, the teacher helped the students devise a model of how sedimentary rock is formed. For example, the teacher asked students, if they broke a vase, what they would need to fix it. The students decided that not only would they need glue, they would also need something to push the pieces together. The teacher then asked the students, "Where might the force come from [to push sand together to make sandstone]?" The teacher probed students until they considered possible sources of the pressure. This lesson emulated the scientific process of using observable data and knowledge of basic scientific principles to create a model of an unobservable process.

In contrast, in many lessons mathematics and science are presented as static bodies of knowledge, focusing on vocabulary and algorithms. Observers of these lessons said things like "the teacher did the thinking throughout the lesson—there was no investigative spirit. The teacher had knowledge, which he attempted to transmit to students." The following examples are typical:

Students in a 4th 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."

According to the observer, "success in this 6th grade mathematics class hinged on students learning algorithms. Students were to learn rules and procedures, not the concepts behind them. Although the teacher had told them at the beginning of the lesson that moving the decimal place in both the divisor and dividend the same number of places was essentially the same as multiplying them both by the same power of 10, the message he gave students throughout the lesson was, essentially, 'Just do it.' When students pushed him for the reason they had to move the decimal, more than once the teacher responded: 'The divisor must be a whole number.'"

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."

The observer of a 9th grade lesson on atomic theory noted that: "The lesson content was presented in a way that was inaccessible and uninspiring for students in this 9th grade class. The students copied notes from the book, listened to a lecture, and completed a worksheet on the same, low-level factual information."

In a 9th grade teacher's efforts to help his students better understand how to solve equations and inequalities, he asked them to remember and repeat the procedures he had demonstrated in the beginning of the class. The teacher's presentation of the content included questions and comments such as, "There's the variable, what's the opposite?" and "Tell me the steps to do." He did very little to engage students with the content; two students slept through the teacher's entire presentation, and one read a magazine. Other students contributed very little, spending most of the time asking about the particulars of the upcoming assignment.

A high school Algebra II lesson started out with the students working individually on the problem of the day, determining whether a particular relation was a function. After going over the problem, the teacher introduced the concept of the inverse of a function and walked the class through several examples. At the end of the lesson, the students were given a worksheet from the textbook and were assigned the odd-numbered problems to do for homework. Noted the observer, “the lesson design did little to engage students with the meaning of the concepts presented. The students were purely engaged in rote working of exercises with little understanding of the meaning of the exercises they were working.”

The Influence of High Stakes Testing

High stakes accountability may help explain why some lessons tend to focus on facts and procedures rather than portraying mathematics and science in more authentic fashion. Based on *Inside the Classroom* observations, an estimated 18 percent of mathematics lessons and 5 percent of science lessons nationally include review/practice to prepare students for externally mandated tests. Although it is theoretically possible to assess student understanding, in practice it is very difficult and expensive to do so, and many tests used for accountability purposes focus at the factual level (Shepard, 2002).

On rare occasions, teachers are able to integrate test preparation fairly seamlessly into instruction that is clearly geared toward learning of mathematics/science. More often, the test preparation piece has the feel of an “add-on,” or the entire lesson is focused on having students perform well on a high stakes test without also focusing on student understanding.

The following example illustrates high quality instruction in a lesson that focuses on test preparation for an externally-mandated test.

The teacher passed out two worksheets to the students in an 8th grade pre-algebra class. The first one contained the mango problem, in which members of a family each take $^1/_3$ or $^1/_5$ of the mangoes in a basket until finally there are only three left. The task for students was to determine how many mangoes were originally in the basket. The second worksheet was for students to use to write down their solution to the problem; it included prompts such as “what I know,” “strategy,” and “steps.”

The students worked independently; the teacher moved around the room and looked over shoulders, but said little. His questions encouraged students to think about what they were doing, and challenged them to articulate their ideas with more than a one-word answer. For example:

Teacher: “What do you think about that answer?”
Student: “It’s too high.”
Teacher: “Why?”

Students felt free to ask questions of the instructor, and of their peers, even though the lesson did not specifically call for them to work together. The students and teacher were interested in the processes each used to get the answer, rather than simply finding the answer given in the book.

The teacher noted that he was trying to continue with the planned curriculum while getting students ready for an upcoming benchmarks exam. The observer indicated that the lesson in fact provided a nice combination of test-preparation and a review of problem-solving strategies.

In other lessons, the test preparation component is clearly separate from the rest of the lesson, but does not detract from the quality of the instruction. The following examples are typical.

> In a 1st grade mathematics lesson, the first ten minutes were spent to prepare students for a standardized test. The observer noted that the content of the lesson segment was out of sequence from the rest of the lesson, but that the teacher was able to use this external constraint to motivate students to assess their own proficiency. In this warm-up activity, the teacher showed addition problems on flash cards (e.g., 7 + 5 = __) and students raised their hands to answer. "They were very eager to participate and to prove to themselves that they got it right. Then students took a very rapid quiz to test their proficiency in addition, as required for the standardized tests. They were expected to finish only half of the 30 problems in the limited time available, but they wanted to do them all."
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> The first part of a 6th grade lesson was review/reinforcement of computation skills in preparation for the mandated district and state tests. When the students walked in, the teacher had the problems for a review quiz already written on the chalkboard. This quiz took 10 minutes at the beginning of the lesson, then the teacher moved on to the content that was going to be the focus for the remainder of the lesson.

In other cases, the test preparation appears to have a negative effect on the quality of the instruction, with more of a focus on being able to get the test answers correct than on engaging students in learning the mathematics and science involved.

> For 30 minutes the teacher directed the students in a 1st grade class to complete a test preparation worksheet. The class then went over the answers. The observer noted that "the pace was monotonous and seemed to lose students' attention."
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> A 4th grade science lesson began with a segment to prepare students for the 5th grade state science assessment. The teacher reviewed specific strategies for test-taking as outlined in the booklet, and then directed the students to complete a written assignment. They were instructed to describe the differences in morning and afternoon temperatures using terms from the vocabulary list in the booklet. When the students had completed the exercise, the teacher selected several students to read their writing aloud. She commented positively on their use of the listed vocabulary: "Sounds like [name of student] used a lot of the listed words they told us to use."
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> The observer indicated that the content of a middle school mathematics lesson on trigonometry ratios "was stripped down to just the knowledge needed for the state test. That ended up being the definitions of sine, cosine, and tangent and the meaning of opposite and adjacent sides. The context and the meaning were removed and, along with them, any motivation to do anything but memorize for a test. The students were not encouraged to reason about the content, and there was really nothing in the way the content was presented to reason about."
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> The teacher of an 8th grade mathematics class reminded students that, "When you take the test, they might not give a specific unit, but all the units will be cubic." The teacher then turned to the topic of inequalities. She asked: "What's the opposite of an inequality?" Students responded: "An equality." The teacher said: "Okay, we're going to refer to these as inequalities. This is important because you can use inequalities to represent everyday situations. Why should you learn them? Because they're on the test."
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> The teacher passed out a packet of sample questions from the 8th grade science state test. This review took half of the class time. The teacher then directed the students to a list of 30 terms on the board, which came from the

state science test. He told the students that they should already have the first 15 definitions done and that he had added 15 more. He reminded them that they would be tested on all 30 the next day.

The teacher told the 9th grade biology class, "I guarantee that there will be a question on the test about osmosis and diffusion. If you see passive transport on the test, you know it is diffusion." Moving to the next topic within classification, "I guarantee this next thing will be on the test."

The teacher wrote "Katie Put the Cat Out For Getting Smart" on the board. The students obviously knew this mnemonic and called out the categories as he wrote them: Kingdom, Phylum, Class, Order, Family, Genus, Species. The teacher once more repeated, "I guarantee that this will be on the test. I guarantee they will ask you this but it will be from largest to smallest."

The teacher said, "Any questions? Let's talk about the kingdom system"; and then wrote the five kingdoms on the board.

Teacher: "What is the classification system for man?"
Student: "Homo Sapiens."
Teacher: "What language is used?"
Another student: "Latin."

Teacher said, "You need to know that. I guarantee it will be on the test. I guarantee that they will ask you 'What is binomial nomenclature?'"

The observer of a high school Math Analysis class noted that, "Much emphasis during the teacher's lecture was placed on how many points a certain type of question would be on an upcoming classroom test and on different strategies to help students tackle questions on externally-mandated tests."

Taking Students From Where They Are and Moving Them Forward

Earlier sections described ways in which lessons engage, or fail to engage, students with the mathematics/science content. Although it is unlikely students are learning if they are not engaged, engagement is not enough; to enable learning, lessons need to be at the appropriate level for students, taking into account what they already know and can do, and challenging them to learn more.

- ***Gearing the lesson to the developmental level of the students***
  As can be seen in Figure 14, approximately half of all mathematics and science lessons are rated high for the extent to which the content is appropriate for the developmental level of the students in the class.

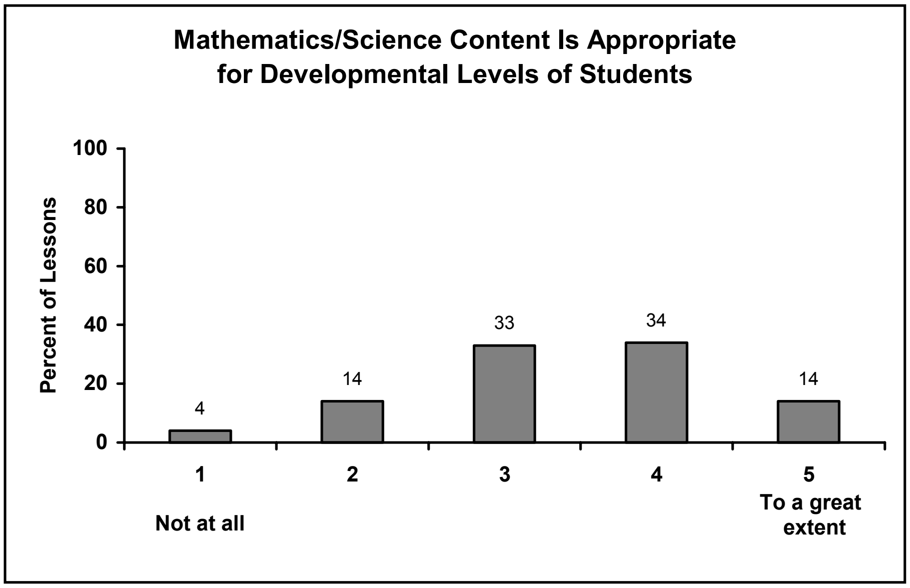

Figure 14

The following descriptions illustrate lessons that build effectively on students' existing knowledge and move them forward:

A 7th grade mathematics lesson consisted of a teacher-led discussion of three warm-up problems on volume, followed by a review of area and an introduction to surface area. A tissue box was used to model the surface area of a rectangular prism, and other examples were drawn on the board. The lesson was designed to develop both a conceptual understanding of surface area and an algorithm; both were developed through questioning students in a discovery-based style. The whole class discussed the surface area of two example problems before being given a homework assignment of 8 problems in the textbook. The observer noted that "the lesson was carefully planned, with attention given to student readiness and prerequisite knowledge by reviewing volume and area before introducing surface area."

An 8th grade science lesson was designed for students to test their skills at identifying unmarked rocks based on characteristics that they had studied and recorded in their field notes. Students were divided into groups of four with each person being given a role to carry out in the group. Groups examined samples of unknown rocks, recorded their observations, and tried to identify the rocks. The class then came together as a whole, with the various groups describing their observations and conclusions. At the end, the correct answers were revealed to the entire class. The lesson ended with students taking a few minutes to individually "beef up" their notes on rock descriptions so they would be better prepared to use them for further identifications. The observer noted that "this lesson was excellently designed to take students' prior knowledge and experiences with rocks, which they themselves had been recording in a lab journal, and apply it in an investigative, cooperative manner to a new situation and set of rock materials."

The focus of the lesson in an advanced calculus class was on problem-solving. The class began with a discussion of previous problems, of "how they did in the past," to what types of problems the past methods applied, their limitations, and how they could be extended. Then the teacher introduced the new topic: the understanding of Cavalieri's theorem and its application to non-rotational bodies. The lesson was designed to let students do most of the thinking. After a brief presentation of the topic the teacher

> assigned part of a problem and had students work in pairs. Time for small group discussion was given after the pairs had sufficient work time. During this period the teacher walked around, encouraging students to confront the limitations of their own conceptions. Then the teacher brought the whole class together to explain the solution and to answer questions. There were several cycles like this, with students' work alternating with the teacher's presentations. The observer commented that one of the strengths in the lesson was that it was built around a small number of problems, breaking down the conceptual content so that it would connect with students' experiences, and extend the boundaries of their previous knowledge.

The estimated 18 percent of lessons nationally that are not developmentally appropriate are only occasionally too difficult for the students. Sometimes students lack the prerequisite knowledge/skills, and the content seems inaccessible to them. At other times, the vocabulary is at far too high a level for the students. The observer of the following 1st grade mathematics lesson noted that the students "did not understand what they were doing or why they were doing it."

> The teacher distributed crayons and worksheets, and began the lesson by noting: "Today, we're going to find differences for facts of five."
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> Teacher: "When we say difference, does that mean add or subtract?"
> [Calls on a student.]
> Student: "Add?"
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> Teacher repeats what she said.
> Another student says: "Subtract?"
> Teacher: "That's right."
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> "Before we start, I want to pass out these mats and counters. Take 5 counters out of the bag. Place them on the top line of the mat. Now put three white counters on the bottom.
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> If I tell you 5 plus 3, are you going to add everything or take something away?"
> Students: "Take away."
> Finally someone says: "Add."
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> "If I say nine minus five, how many are you going to take away?"
> Students call out every number except 5.
> Teacher (getting impatient): "You're not listening."

The issue in a 1st–2nd grade science lesson was the complexity of the vocabulary.

> Teacher: "What does this bird eat?"
> Student: "Worms."
> Teacher: "Worms are animals. This is carnivorous. If you eat plants, you are herbivorous."
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> Other terms introduced in this lesson included "oviparous" and "temperate climatic regions." The observer judged the "inappropriately advanced vocabulary" to be a serious weakness of the lesson, acting as a barrier to many of the students.

More often lessons were pitched at too low a level for some or all of the students. The following examples are typical:

> Some of the students in a 2nd grade mathematics class appeared to find the lesson too easy, and were handed worksheet after worksheet to keep them busy.

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.

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."

The content of an 8th grade mathematics lesson seemed to be at too low a level for the students. "There were no instances in which the students seemed really stuck, when the process of moving to a deeper understanding of the content could occur. They were introduced to a new concept, they made sense of the definition, they applied it to different situations, but they didn't take the next step and see how this concept might be further explored."

- ***Providing multiple pathways to understanding a concept***

  Some lessons go further than simply providing content at a level that is appropriate for the students. These lessons use multiple representations of concepts to facilitate learning, both to give greater access to students with varying experiences and prior knowledge, and to help reinforce emerging understanding. Many lessons judged to be effective include a variety of experiences where students would be likely to "tap into" one or more of the pathways in developing or reinforcing a concept. Examples of such lessons follow:

A 5th grade mathematics lesson began with a teacher-led discussion of problem-solving strategies in mathematics. First, the teacher worked through an example using charting as a strategy for solving the problem. Students were then organized in small groups; each group was assigned a problem, and instructed to apply an appropriate strategy to solve it.

After the students had worked on their assigned problems, each group took a turn at the blackboard and explained their solution and strategy to the large group. The class was encouraged to ask questions and to copy the work in their own notebooks. At the end of the presentations, the teacher reviewed the various strategies used with the large group.

In the next segment of the lesson, students began working on a textbook assignment on the multiplication of decimals using calculators. After they had completed this assignment, they were instructed to work on the next section of the textbook lesson without the benefit of the calculator. The teacher indicated to the students that this would give them an opportunity to use the "guess and check" problem solving strategy.

A 6th grade mathematics lesson engaged the students in a number of different activities to help them explore the concepts of fractions, rates, and ratios. The lesson began with a review of fractions to help ground the students in what they already knew. Said the observer, "The teacher used multiple strategies (discussion, writing on the board, hands-on work with manipulatives at the overhead) to have students examine fractions, reflecting attention to students' different learning styles." The lesson then moved to explore rates and ratios, again involving different approaches (discussion, taking up questions from the overhead, reading definitions aloud, role playing a ratio). For the last quarter of the class, the teacher had students complete a worksheet to review what they had learned during the lesson.

Beginning with a review of the main facts about fossilization that students had been studying, the teacher in a 7th grade science class 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."

The teacher introduced the concept of symmetry to a 7th grade class by first demonstrating the concept with examples. The concept development unfolded by engaging students in (a) exploring the concept, (b) investigating its application to familiar cases, (c) making connections to meaningful contexts, and (d) expanding it in a more challenging activity. First, the teacher used her body to illustrate the idea of symmetrical objects and line of symmetry. For instance she explained and acted: "If I fold my body, eye will fold on eye, ear will fold on ear, hands will fold on hands, fingers will fold on fingers." Students were attentive and excited. Students worked individually on specific examples, then participated in a teacher-led discussion about their exploration. Their task was to write the alphabet in capital letters and find which letters have a line of symmetry. The teacher drew examples on the chalkboard A, B, C, D, E, to explain, demonstrate, and discuss possible lines of symmetry. Students then worked on their own for a few minutes, investigating the symmetrical properties of each letter, expressing some puzzlement about letters like N, Z, and H.

A discussion about symmetry in real world and familiar examples followed. The teacher presented examples that helped students make connections between symmetry and familiar contexts. Then she continued soliciting students' input of their own examples. The teacher welcomed their ideas and expanded the discussion around each example. In the last 15 minutes of the lesson, students worked on a hands-on activity designed to apply the concept of symmetry. Students were to draw the left side of a Christmas tree (on graph paper), add decorations of their choice, (e.g., half of a star), then exchange with their neighbor and draw the other half of their neighbor's tree.

A teacher used tiles on an overhead projector to give students in an Algebra I class a sense of what it looks like when multiplying monomials, binomials, and polynomials; she asked questions of the group while she walked through a few examples. After going through the physical models with the algebra tiles, the teacher introduced the FOIL method to the whole group, detailing each step while she worked through examples on the board.

The entire class then went to the board and simultaneously practiced problems that the teacher read aloud; she walked around while they worked, and monitored their progress. After several examples, the students sat down and began work on their homework assignment. Again, the teacher walked around and helped individuals until the class ended. The observer noted that "the use of the algebra tiles and FOIL method provided different ways of getting students to understand the concept."

Creating An Environment Conducive to Learning

➢ **To be judged effective, lessons need to be both rigorous, and respectful of students.**

Important content and well-designed tasks at an appropriate developmental level are essential in order for students to have an opportunity to learn. So too is a classroom culture conducive to learning, one which is both rigorous and respectful. As can be seen in Figure 15, 45 percent of lessons nationally receive high ratings for having a climate of respect for students' ideas, questions and contributions; 27 percent receive low ratings in this area; and the remaining 28 percent are somewhat respectful. Ratings for rigor are much lower, with only 14 percent of lessons nationally having a climate of intellectual rigor, including constructive criticism and the challenging of ideas; 69 percent of lessons receive low ratings in this area, and 18 percent are somewhat rigorous. (See Figure 16.)

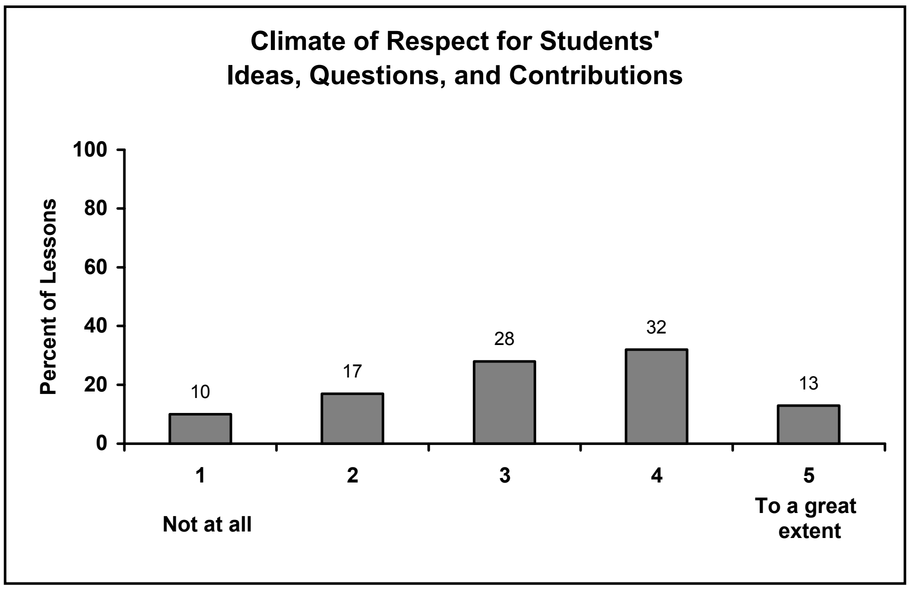


Figure 15

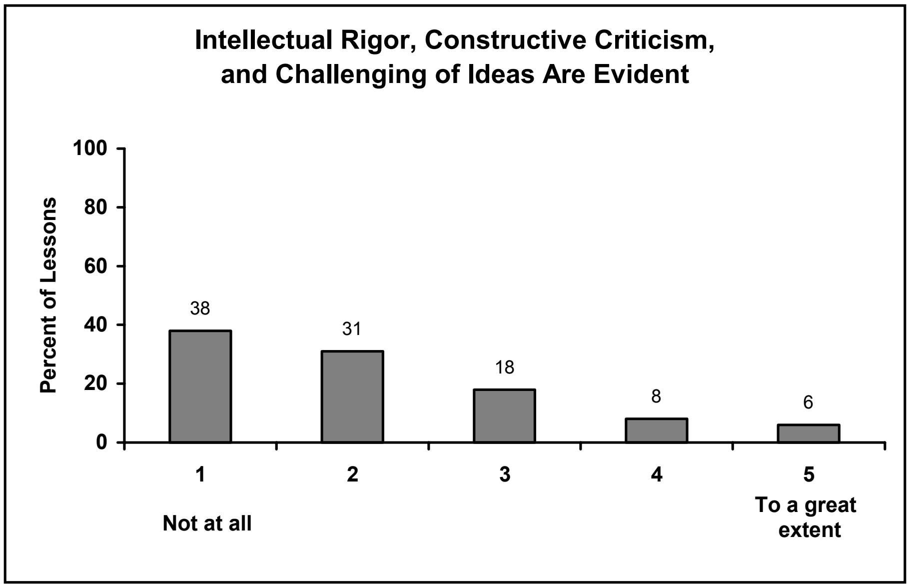


Figure 16

Table 18 shows a cross tabulation of the two variables; note that only 13 percent of lessons nationally are strong in both respect and rigor, and 26 percent are low in both areas.

Table 18
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	1	0
	Medium	24	3	1
	High	17	14	13

- ***Providing learning environments that are simultaneously respectful and rigorous***
  As noted above, only 13 percent of lessons are highly respectful and at the same time highly rigorous, encouraging the students to engage in serious learning. As the following examples illustrate, researchers observed highly respectful, highly rigorous lessons in both mathematics and science at the elementary, middle, and high school levels.

> An observer of a 1st grade science lesson described a climate of mutual respect between teacher and students, and among students. "The teacher's voice was always soft and her manner inviting. It was evident that she enjoyed being with these children, and they loved being with her…I was particularly impressed by the way the teacher was able to inject intellectual rigor into the lesson with children so young. Without putting students down, she was able to challenge them and encourage them to think. An excellent example of this came at the end of the lesson, when the children were discussing what they could infer from their findings. When one child said that finding an arrowhead meant that the Indians hunted buffalo, the teacher asked her if she had found any buffalo blood on it, and pointed out that

finding an arrowhead doesn't necessarily mean they hunted buffalo."

☙ ❧

An observer described the classroom culture in a 3rd grade mathematics class as "phenomenal," noting that "at any given point there was an extraordinary amount of excitement, and the content was new and rigorously-taught for this bunch of students." During the introductory discussion on coordinates the teacher allowed students the opportunity to challenge one another's answers by asking questions such as "Is this correct?" and "Does anyone have a different idea?" After the discussion the students worked in pairs on plotting. When they had completed the assignment, students came up and placed pictures on the overhead version of the grid and the teacher allowed other pairs to comment on the correctness of the placement. The observer noted that, "The teacher seemed to know the students well and was easily able to get nearly all students participating by calling on both volunteers and non-volunteers. Both the teacher and students were respectful of each other's thoughts. Discussions were lively and included multiple students' perspectives."

☙ ❧

Students in a 5th grade science class worked extremely well in pairs, offering constructive criticism of each other's findings. The observer described an example where one student concluded that a rubber band conducted electricity, but her team-mate pointed out that she had accidentally touched the wire to one of the clips, completing the circuit. The pair of students then tried the experiment again, taking care to touch only the rubber band, and found that the rubber band was not a conductor. "The teacher eagerly answered questions, and encouraged exploration. There was—pardon the pun—an air of electricity and excitement in the room, and the students had to be shooed away from their activities for recess. It would be hard to imagine a classroom more conducive to learning."

☙ ❧

The classroom culture in a 7th grade mathematics class "was based on a dynamic of serious work. As the lesson progressed, students who seemed somewhat indifferent at the beginning of the lesson began to fall into the rhythm of engaged learning. The teacher modeled respect for ideas and questions, and she pushed her students to monitor and assess their own learning. They talked intently with their partners about mathematics concepts and the meaning of different terms and phrases. The teacher encouraged them to use precise language in their responses to her questions. She exuded confidence in her ability to work with mathematical ideas, and the students displayed this same confidence in their own ability to learn mathematics."

☙ ❧

The researcher reported that all of the students in a high school biology class were involved throughout the lesson and it was clear that all of them were expected to contribute. "The students worked together in groups, discussing and challenging each other's ideas. The teacher also challenged students to back up their ideas with evidence from the lab (e.g., 'How do you know?' and 'What happened [when you tested it]?'). The classroom atmosphere was rigorous, but friendly; it was clear that the teacher had a good relationship with the class. The culture facilitated the learning of all students."

☙ ❧

Students in a high school geometry class were clearly comfortable participating and going to the board to work on problems. Said the observer: "The teacher called on volunteers as well as non-volunteers, and the teacher and students were respectful of each other's thoughts. One particular example that stands out was when a student offered an answer that was slightly off-base and confusing to many others in the class. The teacher responded with, 'Right idea, let's clean it up a bit.' The class remained supportive as students offered suggestions for ways to clean the answer up, building on the first student's answer rather than totally dismissing it. Although the work on the board was to be individually completed, the culture was such that students assisted, and benefited, from their neighbors. The rigor of this lesson was very high, and most of the teacher's questions caused students to really think about the mathematics. The teacher seemed able to relate to the students, and overall the classroom seemed to be a good environment in which to learn."

- ***Classroom climates that are respectful, but lacking in rigor***

  Seventeen percent of lessons nationally could be 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.

An observer described a 4th grade mathematics lesson where "the teacher was very enthusiastic, and encouraged her students to be the same. She gave lots of verbal encouragement to students as they worked…The culture suffered from a lack of focus on the intellectual content, however. The teacher appeared more intent on the students having a positive experience with mathematics through completing the task than really engaging with the concepts. The classroom was a welcoming environment for students, and there was a focus on 'learning,' but the level of learning expected seemed rather low."

In a 6th 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."

Said the observer: "The tone of this 8th grade mathematics classroom was cordial, and the teacher appeared to encourage all students to participate. [However,] there was little in the way of challenging ideas, unless it was to note that a response was not the answer sought."

The observer reported that "emotionally, the culture of this 9th 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."

- ***Classroom environments that are lacking in respect for students***

  Roughly 1 in 4 lessons nationally are lacking in respect, in some cases even hostile and demeaning to students; nearly all of these are also very low in rigor.

The observer noted that: "There was little concern for learning and even less respect for the students as individuals" in this 2nd grade mathematics lesson. "Students were criticized and told they were wrong, but only occasionally helped by the teacher. Students who tried to contribute ideas ran a substantial risk of being told to stop. Most ideas from the students were met with a statement like the one given to a girl in the class, 'Please let me be the teacher.'"

The researcher reported that she had never seen a class with a poorer classroom culture than this 3rd grade class. The teacher's main classroom management strategy was to chastise the class repeatedly, "pockets on your seat, eyes up, lips zipped." She allocated "points" for each table behaving as she had requested, and recorded these table points on the board….To ensure that the students were able to follow the instructions, she called on individual students to repeat each instruction as it was given. For example, "While I am handing out the construction paper, please finish writing. When you get the construction paper, write your name on one side; that will be the back… Where do you need to write your name?" She would then call on individual students, and each one would parrot, "on the back."

Said the observer: "The classroom culture in this 7th grade mathematics classroom was horrible! The entire lesson was a screaming match between teacher and students. The teacher did not treat the students with respect, nor did the students treat the teacher with respect. When the teacher asked a question, many students totally ignored him while others screamed out answers so as to be heard above others. When the students were supposed to be writing about their findings from the 'School Supplies' activity, most students were not doing it. The teacher shouted out, 'I don't see writing. I just hear talking.' Then the teacher turned to one student who had been out of his seat most of the period and shouted, 'Don't sit down now. I want you to stand up for the rest of the class.' Then he turned to another student and said, 'Where have you been while I went over all of this? That's okay. You can just have a zero.' At one point a group of girls were giggling and screaming and the teacher just joined in with their silly prattle. When the teacher took up the calculators, he said one calculator was missing and was very ugly to the class, as a whole, saying, 'I had 30 calculators at the beginning of this class; only 29 were turned in; all of you will have to pay for it.'"

The observer noted that the culture in a high school biology classroom was one of an authoritarian teacher and uninspired students. About half the class was entirely disengaged for the entire block period, and several did not even fill out the worksheet during the time allotted. Students remained silent during work time and apologized when they gave a wrong answer. On three different white boards the teacher had written: "If anyone writes with my pens again you will pay the price."

"The teacher in this high school physical science class spent the first few minutes of instructional time reminding the students of the discipline system that she has imposed in the classroom. If students 'misbehave,' they are given 'demerits.' Students with more than two demerits have to stay after school for 15 minutes. So, 'If you don't want it [a minus sign], what do you do? Behave!'… Several times during the class, she quietly went to the side board and placed a 'minus' sign next to a student's name. The classroom climate revealed anything but mutual respect between students and teacher."

The observer of a 9th grade Pre-Algebra class reported that comments like "Stop talking," "Settle down," and "Am I disturbing you or something?" were used to interact with students throughout the lesson. "The teacher focused less on participation and more on control….There was no rigor and no opportunities for trying to talk about or make sense of any ideas. …The teacher did not seem to trust the students to do the computations in their heads—at four times during the lesson he told them to use the calculators and not to trust their own thinking."

Ensuring Access for All Students

- **To be judged effective, lessons need to ensure that all students are able to participate in learning important mathematics/science content.**

Part of the teacher's role is to ensure that students are in fact accessing the mathematics/science content, and that no students are slipping between the cracks. Accordingly, researchers were asked to rate the extent to which lessons encouraged active participation of all students. They also described cases where some students were "left out" of the lesson, and cases where the teacher was particularly successful at engaging learners with special needs. As can be seen in Figure 17, only 47 percent of lessons nationally would be rated high in terms of encouraging active participation of all students.

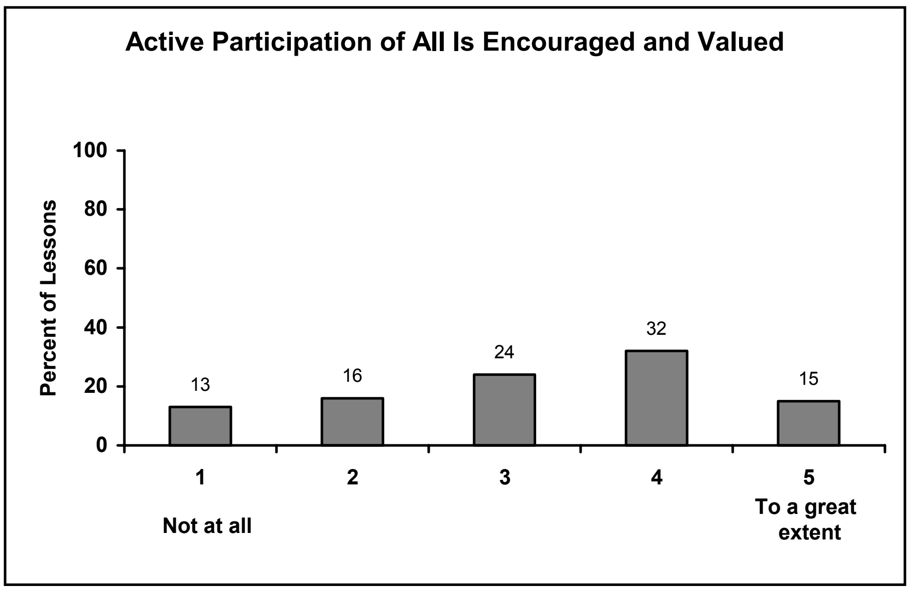


Figure 17

In most cases, low ratings on the active participation indicator reflect overall low levels of student engagement. In a few instances, observers noted differential patterns of participation by gender and/or race. For example, one observer noted that "of the 20 problems that were presented at the board [in a middle school mathematics lesson], only 3 were explained by the girls in the class. The teacher explained that she has tried different ways to get the girls to participate more, but they are often shy or embarrassed." In another lesson, the observer reported that one student was called on repeatedly and "this student happened to be the only Caucasian boy in the class."

In a very few cases, the observer described situations where the teacher clearly demonstrated unequal treatment.

> An observer reported that the teacher “had students she liked and students she didn’t like…One boy and one girl were particular favorites. The sole African American boy was treated differently and badly. Any answers he suggested were dismissed with a strong ‘No.’ even when they were much closer to the correct answer than the suggestions of white students in the class.

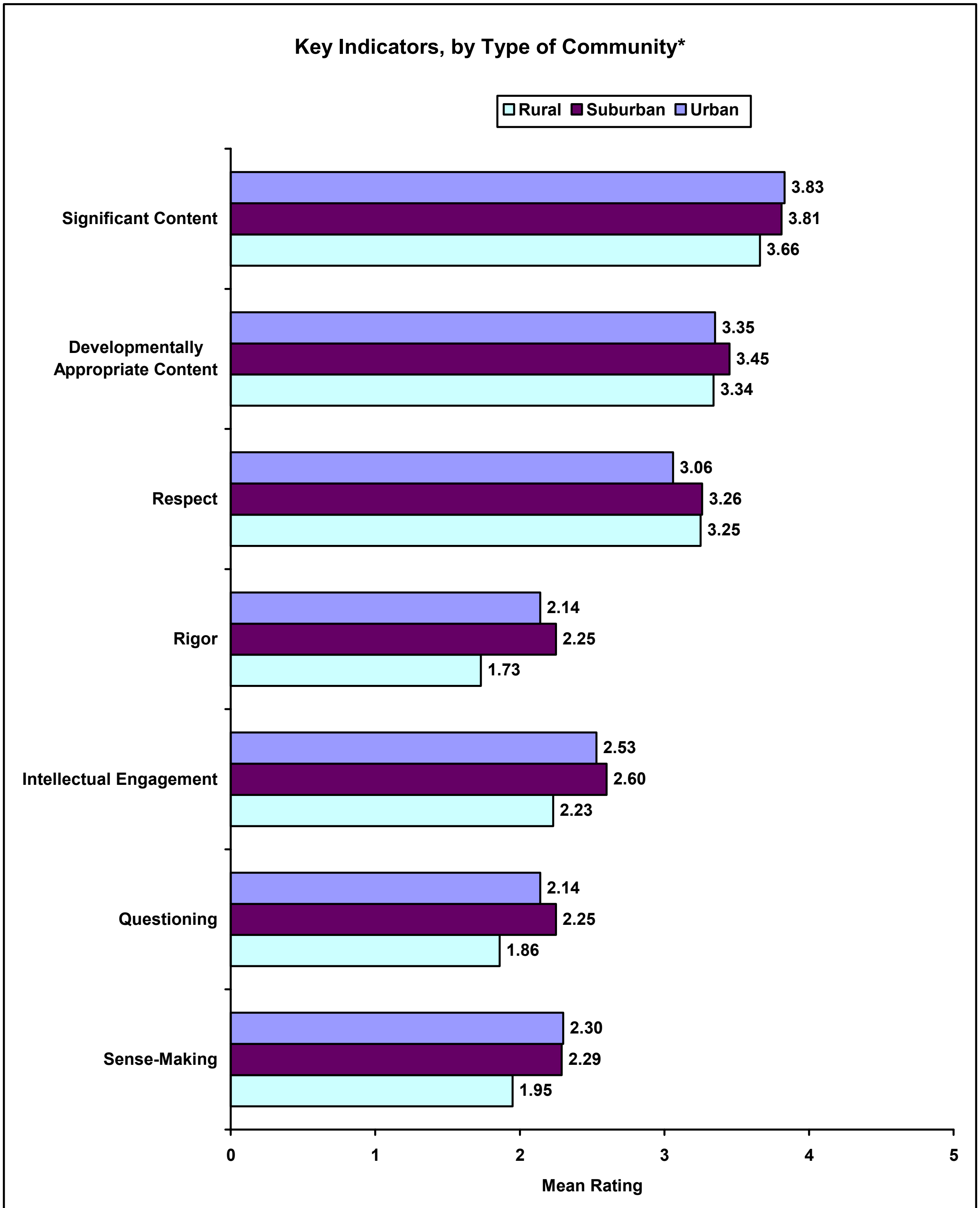
Sometimes, teachers find it difficult to engage all students in a given lesson because of the extent of heterogeneity in their classes.

> A teacher noted that the students in his 7th grade mathematics class varied widely in ability levels, with some students "who can retain information at jet speed" and other students who are “very low functioning.” The observer noted that the teacher “made no adjustments in instruction to accommodate the diverse needs of his students. This lesson was designed as a ‘one size fits all lesson’ without attention to students’ levels of mathematics development.”
>
> Another observer noted that although the teacher had identified a few students in a high school science class as special education students, “no effort could be observed during the class to engage them in any way different from the techniques used for the general group.”

Other observers described lessons where extensive efforts were made to ensure that all students had access to the lesson.

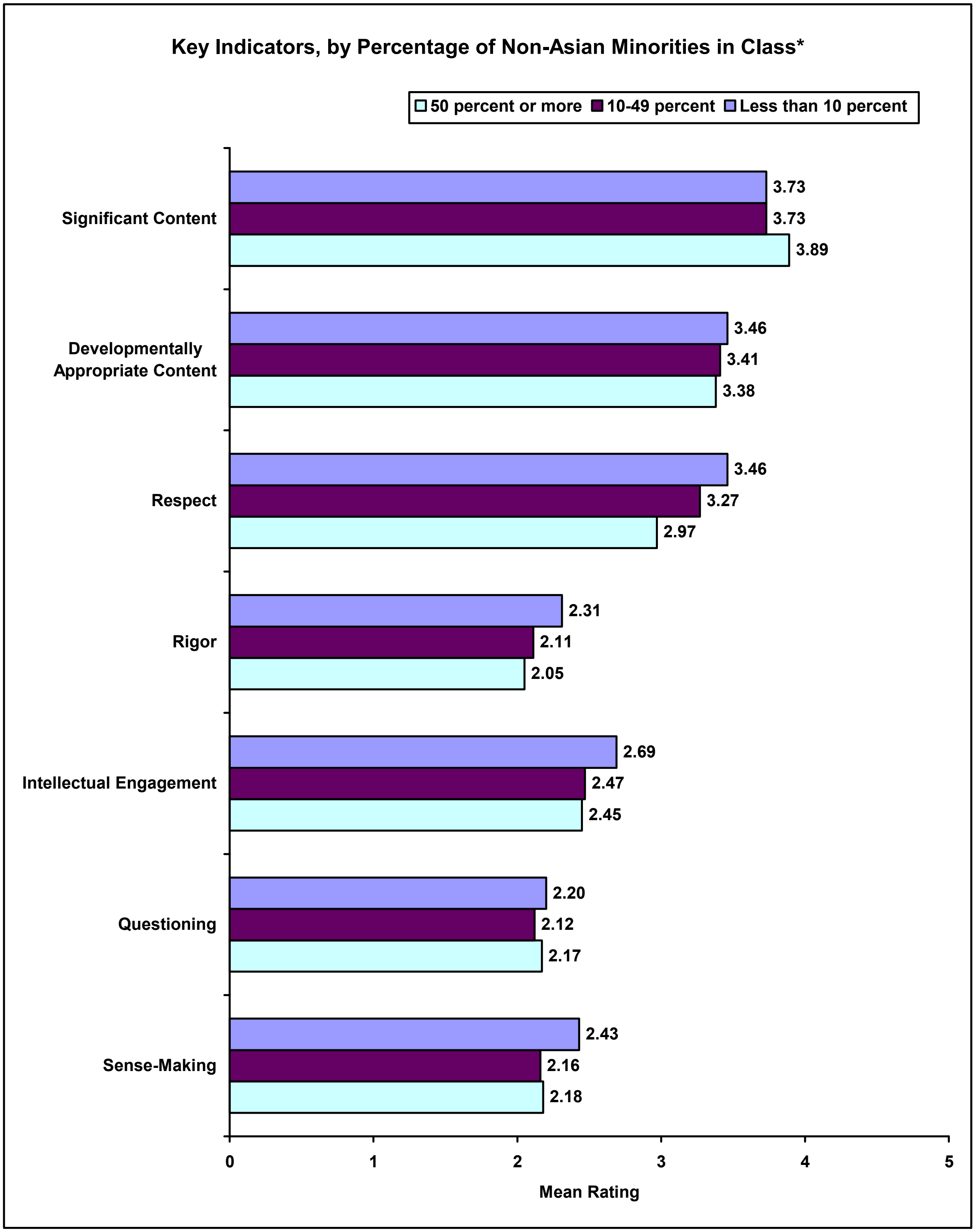
> A researcher indicated that a student in a 2nd grade class was hearing-impaired and wore a special amplification device. The teacher had a microphone/transmitter around her neck, which beamed her voice to the hearing device. Said the observer, “the student participated in the lesson to the same extent as all the others, including being asked the same level of questions by the teacher.”
>
> A 3rd grade teacher altered her lesson plan to accommodate the varying levels of her students. She required that all students depict what they had observed in the experiment that they had conducted during the class. The more able students could do this in a six part step-by-step description, with pictures, of the experiment. Other children, who had more difficulty with writing, were allowed to express their understanding through a cartoon or other drawing.
>
> An observer of a 7th grade mathematics class noted accommodations for special needs students. “There were at least two hearing-impaired students in the room. An aide used sign language, and the teacher wore a microphone to amplify her voice. It appeared as though the teacher consciously made an effort to somewhat exaggerate movement of her lips when talking, as if to facilitate lip reading. Another student [who was apparently visually impaired] moved close to the front of the room when the teacher wrote on the overhead.”
>
> Another observer reported that “two non-English speaking students were included fully [in a middle school science lesson], using specially translated notes, translation tools, and lots of contact with the teacher and other members of their group. These students contributed to the making of observations, recording of information, and identification of the rock samples.”

As part of the investigation of the extent to which lessons ensure access for all students, multivariate analysis of variance was used to determine if there were overall differences on a set of key indicators for each of a number of categorizations: type of community, class ability level, and percent minority students in the class. As can be seen in Figure 18, lessons in rural schools are significantly weaker in these key indicators than are lessons in urban and suburban schools. Lessons in classes with 50 percent or more of the students from traditionally underserved minorities are rated lower than lessons in classes with smaller proportions of minorities. (See Figure 19.) Finally, as shown in Figure 20, lessons in classes that teachers categorized as low in ability, and in those they considered "middle" in ability, are significantly weaker in these key areas than are lessons in heterogeneous and high ability classes.



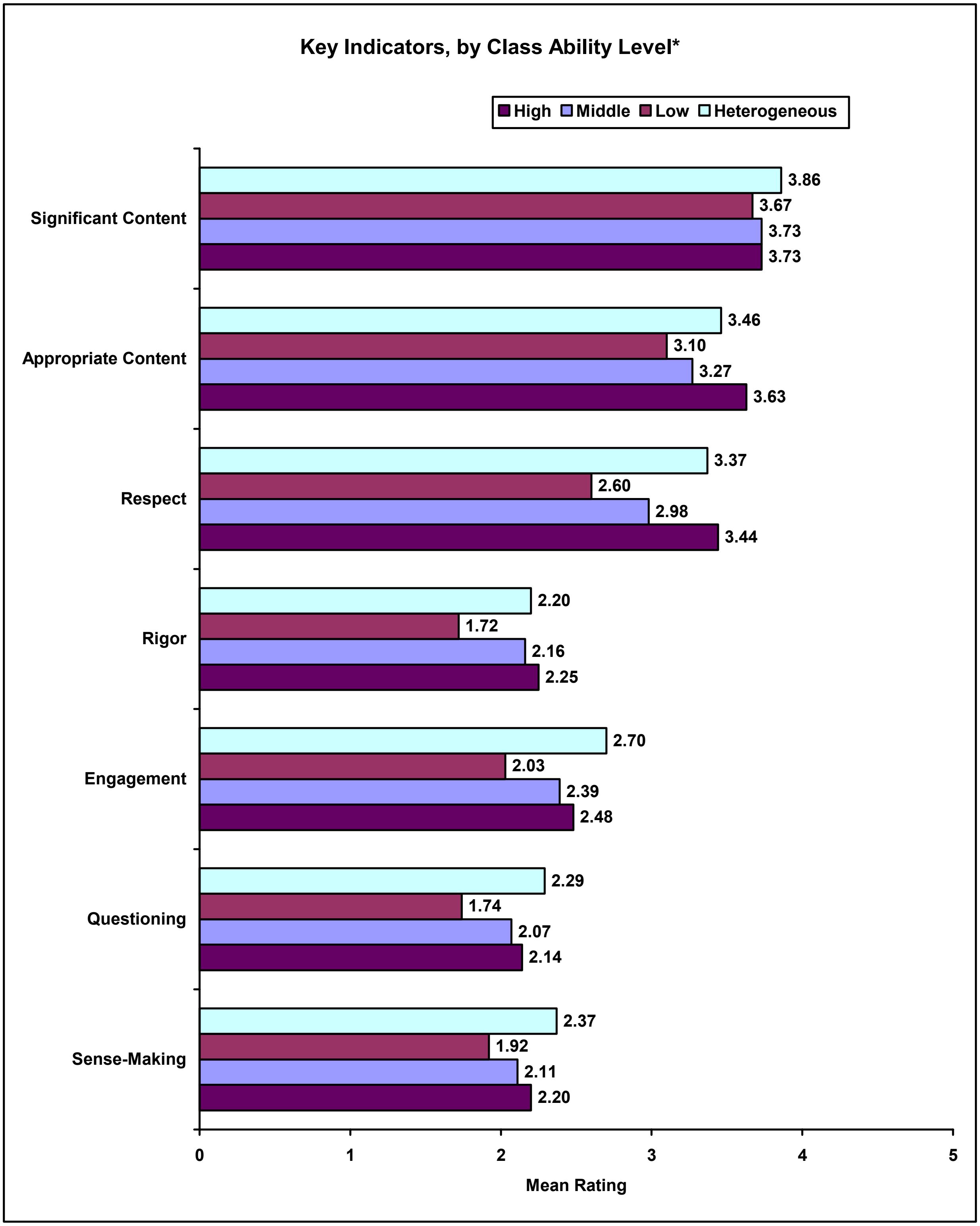
* On these indicators as a set, lessons in classes in rural communities rated significantly lower than lessons in classes in either suburban or urban communities, defined in this study as large and mid-size cities (MANOVA, $p < 0.05$).

Figure 18



* On these indicators as a set, lessons in classes with 50 percent or more students from underrepresented minorities rated significantly lower than lessons in classes with either fewer than 10 percent minorities or 10 to 49 percent minorities (MANOVA, $p < 0.05$).

Figure 19



* On these indicators as a set, lessons in classes with low or middle ability students rated significantly lower than lessons in classes comprised of either high ability students or heterogeneously grouped students (MANOVA, $p < 0.05$).

Figure 20

Helping Students Make Sense of the Mathematics/Science Content

➤ **To be judged effective, lessons need to help students connect their activities to the learning goals.**

Focusing on important mathematics and 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 mathematics and science they are studying. The teacher's effectiveness in asking questions, providing explanations, and otherwise helping to push student thinking forward as the lesson unfolds often appear to determine students' opportunity to learn.

- ***Questioning to encourage students to think more deeply***
  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 mathematics and 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 is among the weakest elements of mathematics and science instruction, with only 16 percent of lessons nationally incorporating questioning that is likely to move student understanding forward. (See Figure 21.) Lessons that are otherwise well-designed and well-implemented often fall down in this area.

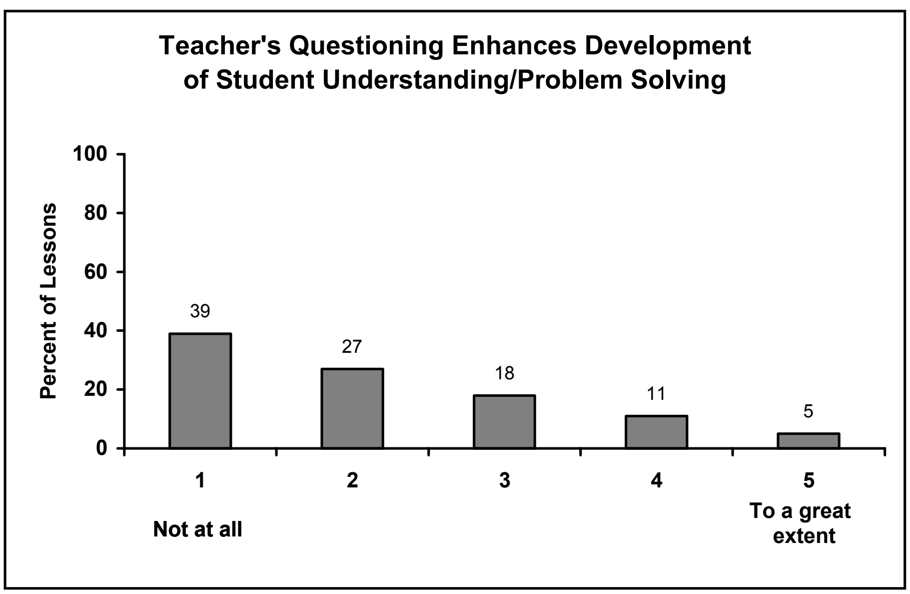


Figure 21

The following descriptions illustrate how some teachers are able to use questioning skillfully, both to find out what students already knew and to provoke deeper thinking in helping them make sense of mathematics and science ideas.

> The purpose of the lesson in a 5th grade science class was to help students understand methods of seed dispersal. The lesson began with the teacher asking the students what they had learned about plants thus far. The teacher used their responses to provoke more in-depth thinking. For example, one student volunteered, "They need sunlight." The teacher asked, "Why do they need sunlight?"
>
> After the class discussed this idea, and others prompted by the student responses, including talking about seeds, the teacher asked a question to focus the discussion on the topic for today: "How do those seeds disperse? In other words, how did they leave their parent plants, their homes and spread out to grow?" Students began volunteering answers, and the teacher asked questions of each to see if they were on target, and to make sure they were expressing their ideas clearly for the rest of the class.
>
> The observer reported that an 8th grade mathematics class was a very nice illustration of an interactive lecture, where the instructor asked for examples and justifications from the students as a means of assessing their understanding. "For example, when generating examples of tessellations around the room one student proposed the border of the bulletin board that was made of circles.
>
> Student: 'How about the border?'
> Students: 'No… that won't work.' (several students talk at once and reject this contribution)
> Teacher: 'Why won't it work? Can the circle ever work?'
>
> The discussion became focused on why the circle did not create a pattern that fit the definition of a tessellation. While the student who suggested the circle had been focusing more on patterns, the disagreement helped him redirect his analysis back to the definition of tessellations presented earlier."
>
> As the students in a 10th 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?"

- ***Using questioning to monitor student understanding of new ideas***

  When teachers ask questions, and individual students respond correctly, it is often difficult to tell if others in the class have a similar level of understanding. Some teachers were able to overcome this difficulty by asking for a show of hands (or as in the following example, "thumbs-up, thumbs down"), having established a culture where it was okay to be wrong in the process of working toward understanding. The importance of knowing not just how many, but which students are struggling and which students are "getting it," is illustrated in the following example, where the teacher used that information to assign students to small groups.

> A 7th grade mathematics lesson began with a five-minute warm-up exercise—a review of division and fractions. When the students were finished, the teacher read the correct answers and the class indicated whether their answers were correct by a "thumbs-up" or "thumbs down" signal. The teacher did a quick visual tally for each question and reported to the class, "Looks like we did well on that question. About 80% got the answer," or "That may be the kind of problem you need to look at again."

> At this point, the teacher instructed the students to complete the worksheet they worked on previously. She organized the students in pairs for this part of the lesson. Her rationale for the arrangement, as she explained it to the students, was, "I looked over your papers and tried to have you work with someone who understood the problem you had trouble with. You can help each other." The students worked together efficiently and with intensity, asking each other questions and often negotiating about the problem. The teacher circulated among the students, checking for understanding and offering suggestions.

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.

- ***Questioning that is unlikely to deepen understanding***

By far, the most prevalent pattern in mathematics and science lessons is 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 mathematics/science concepts. Said one observer, "The students who were working on the problems were concerned with finding the right numbers and which numbers to subtract from which number. Students likely were not connecting the numbers to any meaning. The teacher-provided content information was accurate but again superficial. There was no attempt at closure."

The following examples illustrate this pattern as it played out in mathematics and science lessons across the grades.

> Said the observer of a Kindergarten science lesson, "The teacher's questioning was fast-paced and primarily low level." For example,
>
> Teacher: "Do leaves all look the same? What is different about them?"
> Student: "Veins."
> Teacher: "What else?"
> Students: "Shape."
> Teacher: "What do some trees have and others don't?"
>
> After a few incorrect guesses, a student said, "Pine cones."
> Teacher: "What else?"
> Student: "Fruit."
>
> ~ ~
>
> According to the observer, the teacher's questioning strategies in a 1st grade mathematics lesson "tended to focus on facts and single word student responses. That is, the teacher asked low order questions in a rapid-fire manner, with directions to students interspersed. For example, as she, very quickly, led the class discussion for #1 on the fact family handout:
>
> 'Find Problem #1, Complete the fact family.
> Read the first problem and tell me the answer (i.e., 6 + 4 = ___).
> You should write 10 in the blank.
> Who can tell me the addition fact that is related to 6 + 4 = 10?
> You need to write 4 + 6 = 10 on your paper.

Who can tell me a related subtraction fact?'"

Said the observer, "the pace of the lesson was often too fast for many of the students in the class; frequently the teacher left the students behind as she continued on with the 'discussion.' The teacher did not attend very well to students' levels of understanding, and she did not adjust instruction based on students' understanding."

The researcher reported that the teacher's questions in a 6th grade mathematics lesson were low-level, "micro-questions." "As she worked the long division problem 4,879,000 divided by 0.39 on the board, she called on students, by name, to give her each number to write down. When the 'brought down part' was 99 and a student had told her that 39 would go into 99 two times and another student had told her that 39 times 2 is 78 (which she wrote down), she asked a third student, 'What is 9 minus 8?' The student answered, '21' (i.e., she did the complete subtraction, 99 minus 78). The teacher responded, '9 minus 8 is 21? You know that's not right!' When the student said, 'I just did the whole thing,' the teacher responded, 'you should answer the question that I ask—what is 9 minus 8?'"

The following question and answer session took place in a 6th 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"

An observer reported that a teacher in a high school biology class asked students a series of questions about cells.

Teacher: "Animal cells don't have what?"
Student 1: "Chloroplasts and cell walls."
Teacher: "Plant cells don't have what?"
Student 2: "Centrioles."
Teacher: "If you are (constructing a model of) an animal cell make sure you don't have what?"
Students: "Chloroplasts and cell walls."
Teacher: "If you are doing a plant cell make sure you don't have what?"
Students: "Centrioles."

The observer reported that questions asked of students in a 12th grade mathematics class tended to be low-level and leading. The students were given the following system of equations:

$$6x + 5y = -2$$
$$5x - 4y = 31$$

The following "discussion" occurred:

Teacher: "What do we want?"
Students: "x and y"
Teacher: "What do I need to do to get x and y?"
Students: "Get rid of the first matrix."
Teacher: "What do I need to do to get rid of it?"
Students: "Multiply by the inverse."

Said the observer, "discussions during this lesson were much more about identifying steps to do than about justifying the steps by considering conceptual underpinnings."

- ***Teachers answering their own questions***
  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." The following examples are typical of this pattern.

The researcher reported that the teacher moved too quickly for some students in this 1st–2nd grade science lesson, with her questions coming at them in rapid succession. "At times the teacher worked to get the students to think on their own, but mostly she answered her own questions if the students were not giving her what she wanted to hear. She was very leading in her questioning." For example:

Teacher: "Are birds useful?"
Student: "We eat chickens, but we don't eat blue jays."
Teacher: "What about feathers? Some pillows are made with feathers."
Student: "Oh, yeah."

The observer of a 6th grade mathematics lesson noted, "Although some of her questions had the potential of generating good discussion, they mostly fell flat when she accepted a student's answer and moved on. Questions intended to push students to process information became trivialized by students' short answers. There was little wait time and in many cases she answered her own questions. For example:

Teacher: 'There are 9 factors. Why aren't there 81 products on the board?'
Student: 'If you had 81, you need higher than 9 as factors.'
Teacher: 'Why?'
Student: 'Because some of the numbers have factors higher than 9.'
Teacher: (takes over the explanation) 'If you put the paper clip on 6 and 2, what do you get?'
Student: '12'
Teacher: 'What about 2 and 6?'
Student: '12'
Teacher: 'What about 3 & 4 and 4 & 3?'
Student: '12'
Teacher: 'So, since several numbers have more than one combination of factors we only have 36 products.'"

The observer noted that the purpose of a physical science lesson was to review the work that the class had been doing on speed and velocity. "Throughout the lesson, the teacher would ask a question such as, 'How do we calculate speed?' Either the student called upon would not know or would give a wild guess. Sometimes, a student would blurt out part of the answer. Using a series of 'hints,' with virtually no wait time, the teacher would supply the answer. 'What is the speed? We have 40 divided by 4? Visualize the fraction.' When a student answered '10,' the teacher told the class, 'Right, 10 Km/second.' She did not probe to see if they understood what the units would be; she gave it to them."

Said the observer of a high school calculus lesson, "When the teacher put a problem on the board and asked students to solve it, which they did in silence at their seats, the teacher often solved the problem on the board as they were working through the problem, or else waited about one minute and asked a student for input. On one problem the teacher asked for a student's input as to the next step toward the solution, but then disregarded the student's suggestion (which was one correct way to proceed) and went with his own strategy, saying: 'Yes, we can do that. But let's….' So the teacher solved the problem his way, even though he had asked for a student's strategy."

- ***Helping the students "make sense" of the mathematics/science***

  Teacher questioning is one way, but not the only way to help students understand the mathematics/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 mathematics and science concepts being addressed. The following examples illustrate lessons that included appropriate "sense-making."

The purpose of a 2nd grade mathematics lesson was to allow students to demonstrate understanding of place value—ones, tens, and hundreds, and to practice with thousands place. The lesson emphasized numbers containing a zero, since this was something students found difficult. The lesson began with students working in groups of four. Each student in the group had a group member number. The teacher would give a digit for all the #1s to write on their marker board, then a digit for all the #2s, #3s, and #4s. The teacher would then give a number using all the digits and the students in the group would line up with their digits in the proper order to build the number. Students would look at each group's response and indicate their agreement with thumbs up or down. The teacher encouraged students to question each other if there was an answer they didn't understand or didn't agree with. If a group did not represent the number correctly, the teacher would probe with questions to see if they could identify their error. She also asked students to respond to discrepancies that appeared among the groups' solutions. The class did several examples like this and then the students worked individually on more examples. After that the teacher had the students put their marker boards away, then wrapped up the lesson by asking, "What did we learn in math today?" Students gave responses like, "If there's a zero, you have to count it" after which the teacher asked for more explanation. She emphasized, "When we write numbers, the digits have to be in the right spot. Remember that the zeros are important, too. This will get easier as we go along."

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."

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."

- ***Inadequate attention to "sense-making"***

  Although researchers observed some lessons where students were helped to make sense of the mathematics/science content as the lesson progressed or at its conclusion, most lessons lack adequate "sense-making;" as can be seen in Figure 22, only 16 percent of lessons in the nation would receive high ratings in this area. 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.

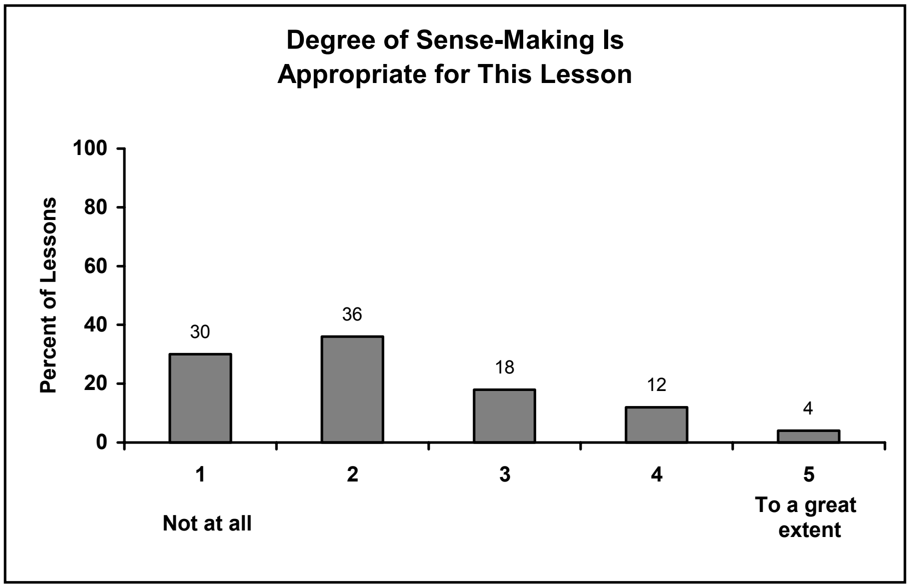


Figure 22

Many lessons consist of what one observer characterized as "working problems with no discussion of the relationship among topics or how the pieces fit into important mathematical concepts." The following lesson descriptions illustrate inadequate sense-making in elementary, middle, and high school mathematics and 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.
>
> ☙ ❧
>
> The purpose of a 4th grade mathematics lesson was to extend the students' knowledge to multiplying single-digit numbers by dollar and cents amounts, e.g., $3.42 x 7. The teacher indicated that she wanted "to get students used to using decimal points and dollar signs." As students completed problems on the board, she would answer with a simple, "Correct" or ask questions to guide them to their errors such as, "Where's your decimal" and "What's 6 times 3 plus 3?" Students would hurriedly correct their work and upon receiving the confirmation that the work was correct, erase it immediately. Very few of the seated students had the opportunity to even see the work of the students at the board. The teacher sought no input from the students in terms of pointing out others' errors and seemed to be only interested in the correct answer. After three sets of four students had come to the board and completed problems, she

directed them to put their books away and assigned them a page in their practice workbook.

An observer of a 6th grade mathematics class noted that the teacher did not seem to be trying to monitor if students understood what was going on in the lesson. “Her focus throughout the large group discussion was on getting through the sequence of questions she had prepared. The teacher did not seem tuned into whether the ‘big ideas’ made sense to the kids or not. She seemed pleased that she had answers to her questions and they were the answers she was looking for.”

Students in another 6th grade mathematics class were asked to complete a practice worksheet, which involved their measuring nine angles and identifying each as acute, right, obtuse, or straight. Said the observer, “instead of students being encouraged to make sense of mathematics, students were to follow directions. Students were not asked to explain their thinking—either during the whole-class discussion or on the assessment. Mathematics was presented as a set of rules and procedures.”

An observer of an 8th grade science lesson noted that the study of Newton’s Laws of Motion was appropriate and worthwhile science content, and was presented at a developmentally appropriate level. “However, the way in which the content was presented, with the students copying down the information then reciting facts back to the teacher, did not allow the students to engage with the content in a meaningful way. Instead, sense-making of the content was left up to each individual, and most likely did not happen.”

The mathematics content in an 8th grade algebra class was the simplification of radical expressions. Said the observer, “Although the teacher’s content was accurate, the students were engaged only in following the procedures. There was no sense-making of concepts—only understanding of the procedures to solve the problems.”

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.”

The student in this Algebra class who put the equation $6x + 7 = -14y$ into standard form on the board explained that she first subtracted 6x from both sides getting $7 = -14y - 6x$, which in standard form is: $-6x - 14y = 7$. Some students seemed confused, and asked the teacher if that was right. The teacher said it was, then solved it a different way, by first moving the y-term, getting the answer $6x + 14y = -7$. As she began solving it this way, some students seemed fixed on first moving the 6x—they didn’t understand that either way was correct. The teacher concluded “So you can have two different answers.” The observer noted that the teacher never mentioned that these two answers are mathematically equivalent.

The observer described what transpired in a high school earth science class after the teacher passed out a worksheet. "For each question, the teacher asked a student to read the question aloud, another student was called upon to attempt a short answer, then the teacher told the students exactly what he wanted while the class copied it down. The teacher even slowed down and repeated his answers verbatim for students who did not get it down the first time through. Neither time nor attention was given for students to grapple with the concepts inherent in the rock cycle and to make sense of it. In fact, the teacher instructed the students not to pay attention to the complexity of the interactions in the rock cycle, but rather to just copy down his simplified model. In this way he took out the conceptual nature of the content and replaced it with a list of terms that needed only to be remembered in the proper order."

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. "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."