5 Practices for Orchestrating Productive Task-Based Discussions in Science

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Introduction

In 2013, Achieve, Inc. published the Next Generation Science Standards (NGSS). In this document, science educators draw on decades of student learning research to establish conceptual learning goals and identify key disciplinary practices (see fig. 0.1) that should form the basis of a coherent science education in kindergarten through grade 12. NGSS presents an ambitious vision for science instruction "in which students, over multiple years of school, actively engage in scientific and engineering practices and apply crosscutting concepts to deepen their understanding of the core ideas in these fields" (NRC 2012, pp. 8–9).

Science Practices for K–12 Classrooms

1. Asking questions
2. Developing and using models
3. Planning and carrying out investigations
4. Analyzing and interpreting data
5. Using mathematics and computational thinking
6. Constructing explanations
7. Engaging in argument from evidence
8. Obtaining, evaluating, and communicating information

Fig. 0.1. Science practices for K–12 classrooms. From *The Next Generation Science Standards* (Achieve, Inc. 2013).

Instructional Challenges

Clearly, teachers face many challenges in attempting to make this vision a reality in kindergarten–grade 12 classrooms. One such challenge is the *selection and/or design of instructional tasks* that will provide opportunities for students to learn canonical science ideas while also participating in disciplinary practices. Many readily available science learning tasks enable students to do one or the other—learn science content or engage in disciplinary practices—but not both. Moreover, it is common for tasks to constrain or direct students' work to such a degree that their participation in science practices is merely perfunctory. For example, in task A (fig. 0.2) students graph the data provided in order to identify a pattern (i.e., notice which cities have average temperatures that fall in the desirable range during various times of the year). However, the task does not prompt students to notice differences in the cities' climate patterns or to propose an explanation for this pattern. While task A does ask students to use data to answer a question, it also provides detailed instructions about how to represent and analyze the data. Figure 0.3 shows the "correct" data representation for this task. It is therefore unlikely that students will vary greatly in the way they approach the task and, consequently, there will be little opportunity for them to engage in argument from evidence or motivation for them to communicate information with one another.

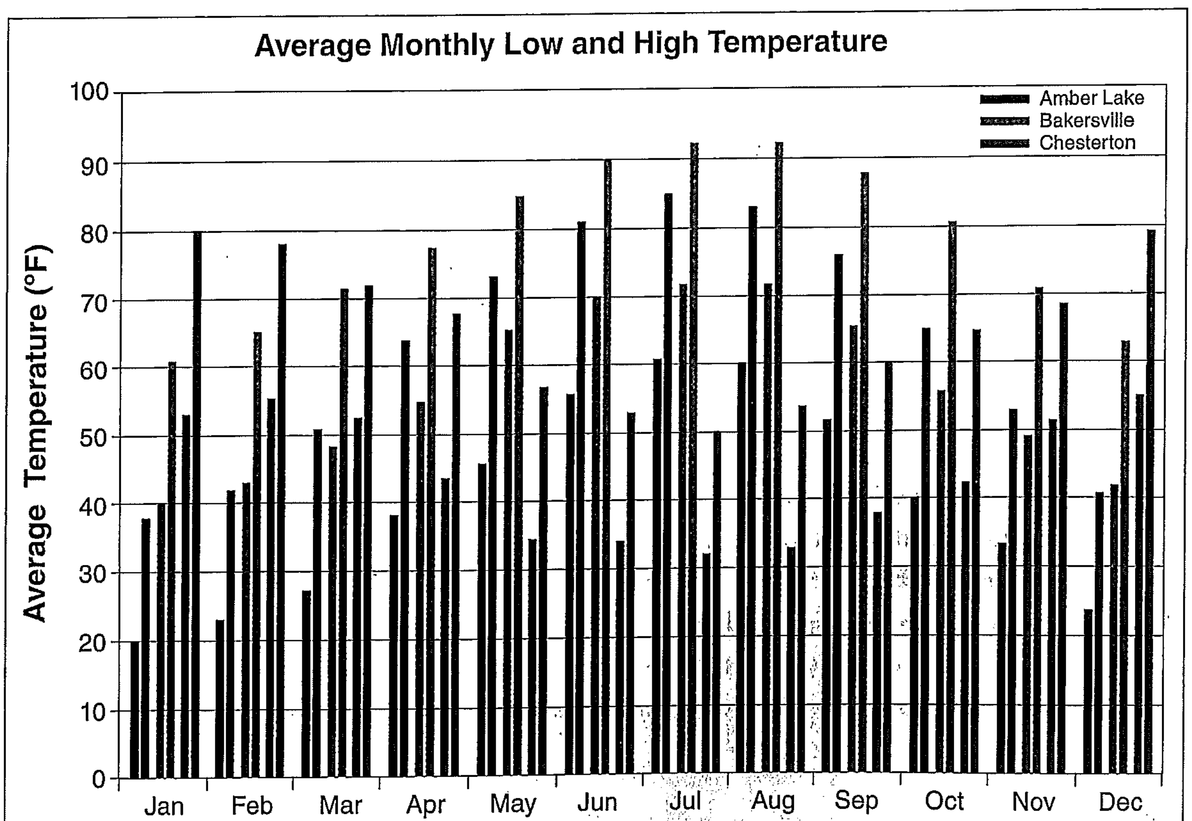
Task A

Jeremy is planning ahead for his vacation next year. He has decided that he'd like to travel to a place where he can enjoy outdoor camping, hiking, and fishing with his Labrador retriever, Sadie. Jeremy's tent is rated for temperatures above freezing (32°F). Sadie prefers not to be too active when the temperature is over 70°F.

Create a bar graph that shows the average monthly high and low temperatures in each city. Identify where and when Jeremy should go on vacation.

	Amber Lake		Bakersville		Chesterton	
	Mean Low Temperature °F	Mean High Temperature °F	Mean Low Temperature °F	Mean High Temperature °F	Mean Low Temperature °F	Mean High Temperature °F
January	20	38	40	61	53	80
February	22	42	43	65	54	78
March	28	51	49	72	52	72
April	38	64	56	78	44	68
May	47	73	65	85	35	57
June	56	81	70	90	34	53
July	61	85	73	92	32	50
August	60	83	72	92	34	54
September	52	76	67	88	38	60
October	41	65	57	81	42	65
November	33	53	49	72	52	69
December	24	41	42	63	54	79

Fig. 0.2. Task A, an earth science task for students in grade 6



A teacher who is using task A in the classroom, and who also wishes to enact the vision put forth in the NGSS, would need to modify the task so that students would have a reason to consider the underlying science ideas and an opportunity to reason about those ideas with one another. Task B (fig. 0.4) is an example of such a modification.

Task B

Jeremy is planning ahead for his vacation next year. He has decided that he'd like to travel to a place where he can enjoy outdoor camping, hiking, and fishing with his Labrador retriever, Sadie. Jeremy's tent is rated for temperatures above freezing (32°F). Sadie prefers not to be too active when the temperature is over 70°F.

Using the data provided, create a representation that will help you to show which city Jeremy should visit and at what time of year (spring, fall, winter, or summer). You may represent your data in any way you choose. You may choose to represent all or only some of the data, as long as you can use your representation to justify your recommendations for Jeremy's vacation (where to go and when to go there).

Fig. 0.4. Task B prompts students to select and represent data for the purpose of making an argument.

Using the same data set as task A, this modified task prompts students to create a representation *for the purpose of convincing others* of the validity of their recommendation. In order to complete the task, students need to decide what data to use, whether or how to transform the data, and how to represent it. There are many ways in which students could approach the task and provide a reasonable answer that they could justify using the given data. For example, students might compute an average high and low temperature for each season (fig. 0.5); use a bar graph to plot only the high and low temperature values for the cities during months when the temperature range is acceptable (fig. 0.6); or plot the temperature range for each city during every month of the year, including horizontal lines on the graph that indicate the acceptable temperature range for Jeremy's vacation (fig. 0.7).

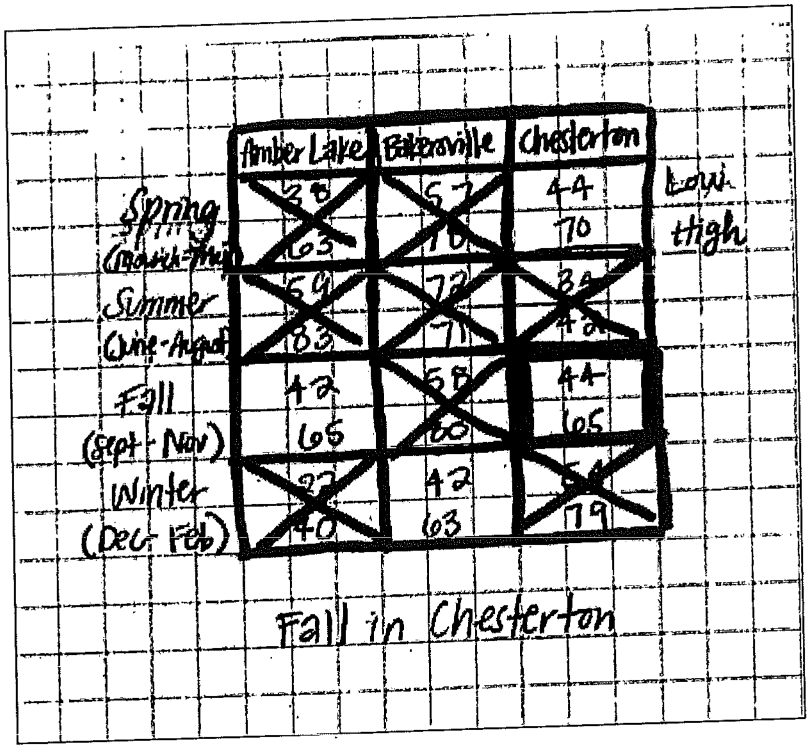


Fig. 0.5. This group of students computed the average high and low temperature in each season for all three cities. They then selected fall in Chesterton as the most desirable time and location for Jeremy.

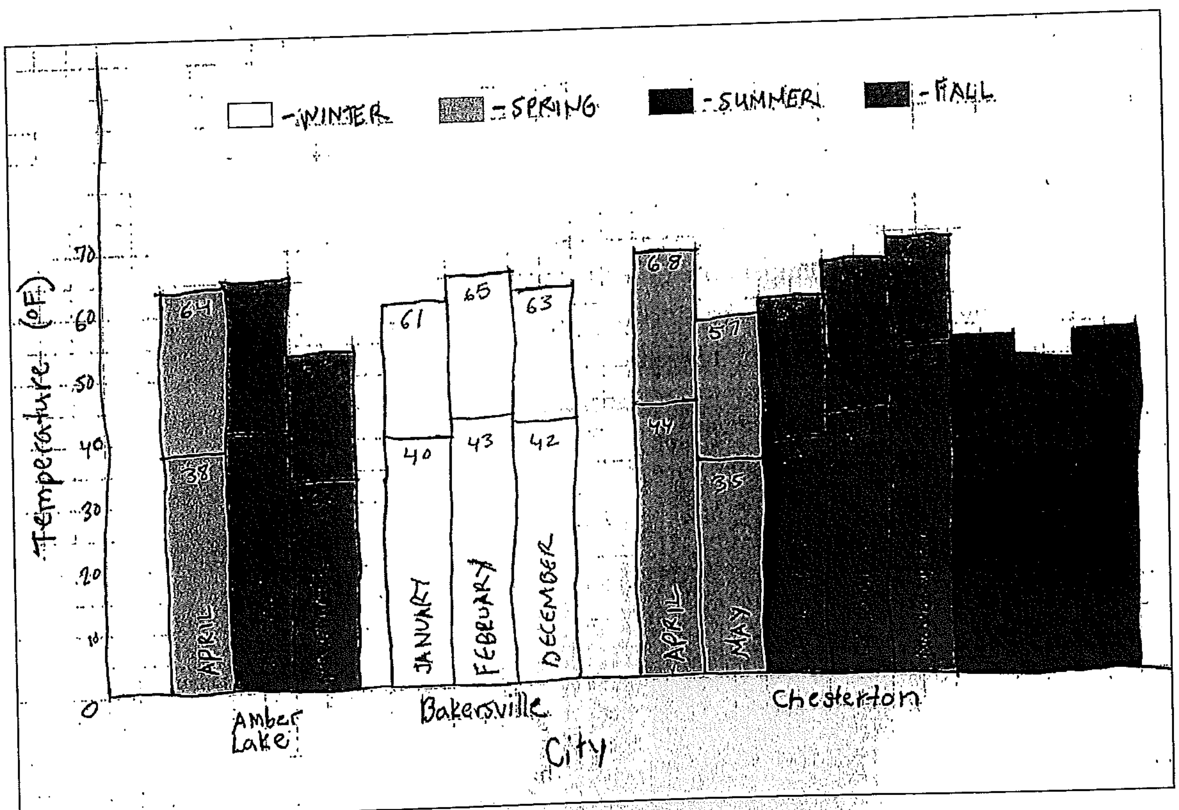


Fig. 0.6. These students identified all the months in each city when the high and low temperatures were within the desirable range. They used a bar graph to plot the data for each of the potential vacation sites and times.

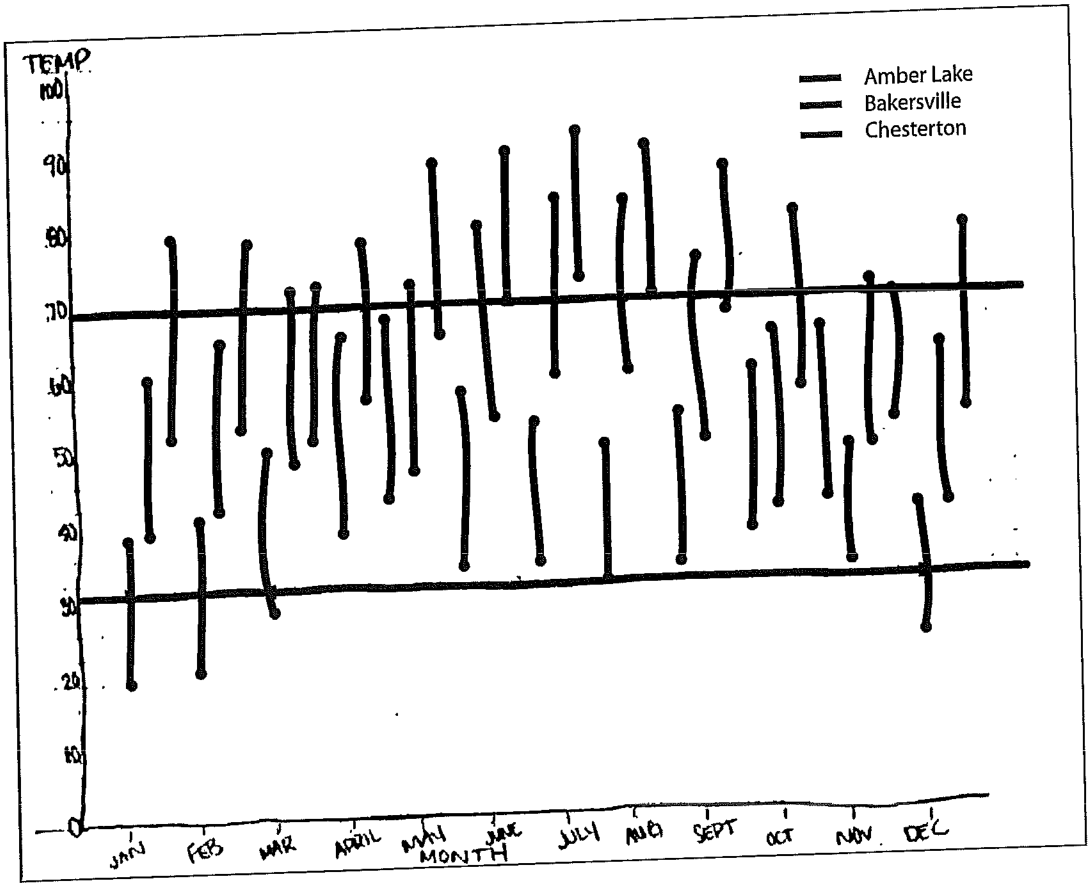


Fig. 0.7. This group chose to plot the temperature range for each city throughout the year. In their oral presentation, they explained that Jeremy could go to any city with a temperature range that falls between the two black horizontal lines (drawn at 32°F and 70°F) during a particular month.

Through a purposefully orchestrated discussion of various representations, the teacher could provide students with an opportunity to notice a key pattern: The Northern and Southern Hemispheres experience the seasons at opposite times of the year. Thus, task B may enable students to engage in science practices while also learning important disciplinary content. In task A, students are not asked to notice or describe this pattern. Instead, they must simply graph the data and name a single location and month where the temperature range falls within Jeremy's requirements.

Task B not only provides students with opportunities to make authentic choices about how to analyze and represent data, but it also requires them to rationalize or defend their answers to the problem of where Jeremy ought to take his vacation. Tasks of this kind can pose a particularly thorny challenge for teachers, that of *enabling and supporting productive discussion that is grounded in students' own work*. More than a decade ago, Cazden noted that the nature of talk in the classroom "can have considerable cognitive or social significance" (2001, p. 53) for students, and she urged teachers and teacher educators to think seriously about promoting equitable and active student engagement in classroom discourse. She also warned that "it is easy to imagine talk in which ideas are explored rather than answers to teachers' test questions provided and evaluated; in which teachers talk less than the usual two-thirds of the time and students talk correspondingly more. . . . Easy to imagine, but not easy to do. Observers have a hard time finding such discussions, and teachers sometimes have a hard time creating them even when they want to." (Cazden 2001, p. 54)

Despite the difficulty involved in orchestrating them, it is clear that robust discussions in the classroom are essential if students are to have opportunities to simultaneously engage in science practices and learn canonical science content. In the example of task B, the opportunity for students to present and compare their problem solutions resulted in a productive discussion that began when students noticed that Chesterton's warmest months occurred at the opposite time of year from Amber Lake and Bakersville. (This is a pattern that the class noticed after the group whose work is shown in fig. 0.7 shared their representation.) Once the class had noticed this general pattern, two questions emerged that led to further productive investigation: "Does spring always occur in March, April, and May?" and "Where are these cities located in the world?" By providing the students with task B and supporting the discussion that emerged when they shared their solutions, the teacher was able to help students learn that cities in the Northern and Southern Hemispheres experience the seasons at opposite times of the year at the same time that they were engaged in analysis and representation of data and communication of information.

Summary

Two crucial instructional challenges associated with the ambitious science education vision within the NGSS are (1) *designing and/or selecting instructional tasks* that provide opportunities for students to simultaneously engage with science practices and learn core concepts; and (2) *providing and managing opportunities* for students to talk productively with one another about their problem-solving approaches, solutions, models, etc. Such discursive interactions are at the heart of many of the targeted science practices in the NGSS (e.g., asking questions, constructing explanations, engaging in argument from evidence, and communicating information).

While establishing productive classroom talk remains a challenge for teachers (see Davis, Petish, and Smithey 2006), new tools and approaches have made this goal achievable, even for novice teachers. In this book, we describe how we have drawn upon groundbreaking work in mathematics education (Smith and Stein 2011) to implement an instructional model that enables teachers to learn how to notice and support student thinking through classroom discussion.

CHAPTER 1

Laying the Groundwork: Setting Goals and Selecting Tasks

The knowledge, beliefs, and resources that teachers have all make a significant impact on their planning. For example, most teachers consult the available curriculum materials when setting learning goals and selecting tasks; and many teachers draw upon their understanding of their students' interests, academic strengths and weaknesses, social and cultural resources, etc., when planning lessons. The Next Generation Science Standards (NGSS), first published in 2013, are another factor that will now play a significant role in shaping instructional choices. In order to meet the goals of the NGSS, teachers will need to provide opportunities for students to engage in scientific practices (SPs) while exploring important phenomenological patterns and developing explanatory (conceptual) knowledge. The NGSS are based on a view stated in a report from the National Research Council (NRC) that "science is not just a body of knowledge that reflects current understanding of the world; it is also a set of practices used to establish, extend, and refine that knowledge. Both elements—knowledge and practice—are essential" (NRC 2012, p. 26).

In this chapter, we will discuss the general features of learning goals and tasks that are consistent with the vision of the NGSS, with the understanding that teachers will need to draw from a variety of resources to select and/or modify tasks to meet NGSS goals. Furthermore, while we acknowledge that teachers plan tasks to support a variety of activity structures (e.g., interactive lecture, collaborative group work, independent seatwork) within their classrooms, we focus here on tasks that teachers might use to engage learners in productive whole-class discussions. Later, in chapters 3 and 4, we will describe specifically how teachers might use the five practices to orchestrate such discussions and when, in a coherent arc of lessons, teachers might choose to conduct a Five Practices discussion (as described in chapter 6).

Identifying Instructional Goals

A teacher needs to have clear goals for what he or she is trying to accomplish in a lesson. It is important to develop goals in sufficient detail to support planning (e.g., selecting a task that is consistent with the desired outcomes) and instruction (e.g., responding to students as they engage in a lesson in order to help them advance toward the desired goals). Hiebert and colleagues argue that this level of specificity is critical to effective teaching:

> Without explicit learning goals, it is difficult to know what counts as evidence of students' learning, how students' learning can be linked to particular instructional activities, and how to revise instruction to facilitate students' learning more effectively. Formulating clear, explicit learning goals sets the stage for everything else. (2007, p. 51)

Figure 1.1 lists four potential goals for a series of sixth-grade lessons about Moon phases. Goals A and C are examples of **learning goals**—statements that describe what students will *know or understand* as a result of instruction. Goal A is extremely general, stating only that students will learn about the topic of Moon phases. It does not provide insight into the specific scientific ideas that students will develop. In contrast, goal C offers detail about the phenomenological patterns (the length of the Moon phase cycle, the order in which the phases appear, etc.) and explanatory knowledge (the Moon orbits the Earth; the relative positions of the Earth, Moon, and Sun account for the phase that is visible from Earth) that students should derive during the lessons.

Goal A:	Students will learn Moon phases.
Goal B:	Students will be able to describe Moon phases and explain why we (on Earth) see them.
Goal C:	Students will learn that we (on Earth) see different phases of the Moon throughout a one-month cycle. Following a New Moon, the Moon appears as a Waxing Crescent. Then we see the First Quarter, Waxing Gibbous, Full, Waning Gibbous, Third Quarter, and Waning Crescent Moons in successive order. The Moon orbits the Earth at rate of one complete revolution each month. The relative position of the Earth, Moon, and Sun determine how much of the illuminated portion of the Moon is visible from Earth. (For example, when the Moon is at the position in its orbit such that the Earth is directly between it and the Sun, people on Earth can see the entire illuminated face of the Moon. This phase is called the Full Moon.)
Goal D:	Students will use two- and three-dimensional models to demonstrate the relative positions of the Earth, Moon, and Sun during various Moon phases. For any particular arrangement of these celestial bodies, students will explain to their peers why the Moon would appear in a particular phase to observers on Earth.

Fig. 1.1. Four different goal statements for a series of sixth-grade lessons about Moon phases

Goals B and D provide information about what students will be *able to do* as a result of instruction. Thus, these are **performance goals**—statements that describe observable and measurable instructional outcomes. Like goal A, goal B is quite general. It states that students will be able to describe and explain Moon phases, but it leaves one wondering, "What *aspects* of Moon phases should students describe? What *specific patterns* should they account for? What is an *acceptable or sufficient explanation* for Moon phases? *How* will students explain Moon phases?" Goal C provides some of the specificity that is missing. It describes in detail the *specific patterns* that students should learn as well as *what information an explanation should include*. However, goal C does not address the issue of *how* students will offer their explanations. Goal D makes this clear by providing a specific description of what students will be *able to do* following the lesson. The specificity of learning goal C and performance goal D provides the teacher with clear targets that can guide the selection of tasks and the use of the five practices to support robust discussion during instruction.

Formulating clear learning and performance goals is an essential first step in lesson planning. Most K–12 teachers draw from curriculum materials when planning, and the format of such materials influences how teachers use them in significant ways. For example, some curriculum materials are provided in **scope and sequence format,** listing particular ideas or topics with which students should engage at various points in an academic year (see fig. 1.2, left side). Other curriculum materials specify certain tasks or instructional activities that teachers should implement (see fig. 1.2, right side). Regardless of the format of the curriculum materials provided, teachers should begin their planning by articulating learning and performance goals in sufficient detail to select and/or modify instructional tasks and to guide and support instruction and assessment.

Scope and Sequence	Lesson-Level Description
Unit 1: Force and Motion *A force is required to change an object's speed and/or direction.* **Unit 2: Patterns in the Sky** *The Earth is part of a larger Sun, Moon, Earth system. Objects in the sky have patterns that can be observed.* **Unit 3: The Water Cycle** *When liquid water disappears, it turns into a gas in the air. It can reappear as a liquid when cooled or as a solid when cooled further. Tiny droplets of water or ice in clouds fall to the ground as precipitation.*	**Unit 2: Patterns in the Sky** *Day 1* Read *The Big Dipper and You* by Edwin C. Krupp. Discuss the patterns that students have noticed in the sky. *Day 2* Introduce the major constellations visible in North America during each season. Use teacher's CD-ROM (chapter 3, section 1) to show images of major constellations. *Day 3* Planetarium field trip.

Fig. 1.2. Examples of curriculum resources for a third-grade science teacher. These topics and major ideas were adapted from the Pennsylvania Standards Aligned System, which is used statewide as a K–12 curriculum guide.

A third-grade teacher working from the Scope and Sequence shown in the left side of figure 1.2 might begin planning for unit 2 by asking: *What specific patterns should students notice?* The teacher might consult the NGSS and determine that students in grade 3 should know that the Sun appears to rise and set every twenty-four hours, and that throughout any particular day, it appears low on the eastern horizon, gradually climbs higher in the sky, and then sinks below the western horizon. These specific patterns are learning goals for unit 2. Knowing these learning goals, the teacher can then select tasks that will provide students with opportunities to notice these patterns (either through inquiry or more direct instruction).

Alternatively, if the teacher's curriculum is provided on a lesson level, as in the right side of figure 1.2, then he or she might begin by carefully reviewing each lesson task and asking, *What patterns should students notice as they participate in this task? What ideas or facts will students become familiar with?* After reading *The Big Dipper and You,* the teacher might conclude that the students will learn what the Big Dipper constellation looks like, as well as where and when it appears in the sky. Next, the teacher should formulate specific learning goals (e.g., the Big Dipper is a constellation that contains seven stars). The teacher may also want to consult the NGSS to determine whether other important learning goals should be addressed in the lesson. Having formulated these specific learning goals, the teacher is now able to make purposeful decisions about whether or how to modify a task and/or what types of scaffolding would assist students in their engagement of the task.

TRY THIS!
Select an instructional task provided within your curriculum. Identify the specific learning goals and performance goals described within the material. Develop detailed learning and/or performance goals if they are insufficiently described, or absent.

Assessing Tasks by Category and by Cognitive Demand

A variety of tasks might prompt productive discussions in science classrooms. We will focus here on three categories of tasks in particular: (1) *experimentation;* (2) *data representation, analysis, and interpretation;* and (3) *explanation.* Experimentation tasks involve students in designing, critiquing, and/or carrying out an experimental protocol. The second category of tasks involves students in representing, analyzing, and/or interpreting data. Jeremy's vacation task (fig. 0.4 on page 3), for example, fits into this category, as it involves students in representing data (constructing a graph) and interpreting patterns in the data. The last category of tasks includes those that involve students in providing explanations for patterns or phenomena. When used together, tasks in these three categories can provide opportunities for students to engage in all eight of the NGSS science practices (Achieve, Inc. 2013), an idea we discuss in greater detail in chapter 6.

One way of characterizing instructional tasks is to describe the level of cognitive demand required of students who engage in them (Doyle 1983; Stein, Grover, and Henningsen 1996). A task that requires students to *invest significant effort in making sense of the underlying science phenomena or concepts* is a high cognitive demand task. It is important to distinguish cognitive demand from other types of challenges associated with instructional tasks. For example, a task might be difficult for students because the text is complex (making it challenging for students to read the task with comprehension) or because the mathematics required to complete necessary computations is beyond their skills. A task that is challenging for reasons such as these is not necessarily cognitively demanding. For example, a teacher may ask students to read a section of text that is written at an advanced reading level beyond that of her students, and to answer a series of questions afterwards. If the questions merely ask students to copy information from the text, then the task, while challenging for struggling readers, is of low cognitive demand—there is no significant requirement for sense making related to the underlying content or phenomena. The challenge lies solely in the work of decoding and comprehending the text.

Teachers often make the mistake of assuming that students who struggle with textual or mathematical challenges are unable to successfully engage with cognitively demanding tasks. This is not the case. It is important for all students to have opportunities to learn science by participating in tasks that require them to think hard about the ideas and phenomena they are encountering. It is the responsibility of the teacher to select or design such cognitively demanding tasks while providing appropriate scaffolds to minimize the barriers that text or mathematical challenges might pose to participation.

Students' engagement in any of the three categories of science tasks described above—*experimentation; data representation, analysis, and interpretation;* and *explanation*—can be robust (involving a high level of cognitive demand) or perfunctory, depending upon the features of a particular task and the choices that the teacher makes during its enactment. In general, tasks that require students to make and justify choices about approaches or strategies involve high cognitive demand. In contrast, tasks that students can complete using an algorithmic approach, or those that require them to simply state an answer without providing a rationale, involve low cognitive demand. In the following sections, we describe some additional specific features of these three categories of tasks that contribute to the cognitive demand placed on students as they engage with them.

Experimentation Tasks

Experimentation tasks are ubiquitous in science classrooms. Usually, students follow a detailed protocol as they conduct their experiment. "Measuring Fast Plant Growth" (fig. 1.3a) is an example of this type of low-level experimentation task. Note that, first of all, the procedures that students must complete are described clearly and in detail; and, secondly, the task does not include an explicit connection to the underlying question that the experiment is designed to address. It is easy to imagine students following these procedures without having to engage in any sense making.

In contrast, "Choosing Materials for Umbrellas" (fig. 1.3b) is an experimentation task that involves a high level of cognitive demand. In this task, students are explicitly reminded of the purpose of the investigation (to determine how various materials perform when exposed to water). This encourages students to connect their hands-on activity with the underlying ideas. They are also told that they will have to design a protocol that "everyone has to understand." In other words, they will engage in the task with the anticipation of an audience for their work, one that will be a critical judge of it. Finally, this task involves students in making reasoned choices about the tools they will use in the experiment as well as how to use them. All of these features—explicit connection to purpose, an audience, and the need to make choices—contribute to the high cognitive demand of this task.

In addition to task features, the placement of an experimentation task in the overall instructional sequence also has an impact on its cognitive demand. In traditional science classrooms, students conduct experiments after the teacher has provided some didactic instruction about the underlying concept. In such a context, the experiment serves to provide confirming evidence of the concept already introduced. For example, a high school biology teacher might ask her students to read the text chapter about meiosis and sexual reproduction and then give a lecture in which she describes the mechanisms of independent assortment and fertilization. Students may subsequently engage in a virtual lab in which they are provided with parental organisms with known genotypes and prompted to predict the phenotypes of the offspring. After completing their predictions (which involves "running" the processes of independent assortment and fertilization, usually with a representational tool such as a Punnett square), students perform the indicated crosses and record data about the offspring. Finally they calculate the resulting phenotypic ratios (e.g., 3:1 dominant:recessive when both parents are heterozygous and one allele is completely dominant over the other). An experimentation task such as this one provides opportunities for students to *carry out an investigation* (NGSS Science Practice 3; see fig. 0.1 on page 1), *analyze data* (SP 4) by examining the phenotypic ratios of offspring, and *use mathematics* (SP 5). However, we would argue that this is a relatively low cognitive demand task because students are told exactly what to look for before beginning the experiment (ratios that are evidence of independent assortment and fertilization) in

Experimentation Tasks

a

Context
7th grade Biology

The teacher chose this task because she wanted the students to participate in data collection. Specifically, she wanted them to have an opportunity to make and record measurements over time. She chose Fastplants because she wanted students to learn that there is variation in "normal" growth in a population of plants, but that the general trend can be described by an s-shaped growth curve.

Measuring Fastplant Growth

1. Gently tie a piece of yarn around the base of each plant in your container. Be sure to use a different color yarn for each plant.
2. Prepare a length of measuring string:
   a. Cut a 24-inch segment of white string.
   b. Using a Sharpie marker, place a mark ½-1 inch from one end of the string.
3. Every two days measure the stem length of each plant:
   a. Place the black mark on your measuring string against the bottom of the plant stem. Make sure the black mark is right where the plant stem emerges from the soil.
   b. Gently run the string up the stem, stopping at the base of the highest flower cluster.
   c. Use your fingers to mark (by pinching off) the place where the stem ends.
4. Now use a meter stick to measure the length of the string from the black mark to the place where you have pinched.
5. Record each stem length measurement (in cm) in your data table:

Plant Height (cm)

	Plant 1 Green	Plant 2 Red	Plant 3 Blue	Plant 4 Yellow
Day 4	1.4	1.9	0.92	2.2
Day 6	3.2	3.8	2.4	4.6
Day 8	6.1	6.8	4.5	7.3

b

Context
3rd grade science

The teacher designed this task to provide students with an opportunity to gather data by performing and recording measurements. She also wanted students to participate in selecting measurement tools and designing the protocol so that they would learn about the importance of specificity and consistency in measurement. She embedded this task in a unit that focused on the properties and functions of materials so that students could also learn that some types of fabrics are better than others at repelling water.

[task by Elaine Lucas-Evans]

Choosing Materials for Umbrellas

The StayDri Company has asked our class to help them with product development. StayDri makes products that people use to protect things from getting wet. For example, one of their most popular products is a travel umbrella. The umbrella is a good product because it keeps rain off of people and it dries very fast after you bring it indoors.

StayDri wants us to test 8 different materials for a new and improved umbrella.

IMPORTANT FEATURES

The new umbrella needs to –

a. Keep water off of people or things that are underneath it; and
b. Dry quickly once it is out of the rain.

TESTING MATERIALS

We have the following tools available for testing the umbrella materials:

Water	Beaker	Markers
Water dropper	Food coloring	Ruler
Squirt bottle	Filter paper	Stopwatch

How will your group test each material to see how well it keeps water off of things?

Write out the steps of your test and draw pictures.

Remember:

- Everyone has to be able to understand how you will do your test.
- Your test has to be fair. All of the materials have to be tested in the same way.

Fig. 1.3. Two examples of experimentation tasks: a low-level task (*a*), and a high-level task (*b*)

addition to precisely how to generate the data (which crosses to perform). Placing the experimentation task *before* the lesson in which the underlying causal mechanism is described can increase the cognitive demand for students. Moreover, experimentation that precedes explanation is consistent with the learning cycle, a framework we will discuss in greater detail in chapter 6.

Data Representation, Analysis, and Interpretation Tasks

Tasks that fall into this second category can also have features that add to or decrease the cognitive demand for students. The "Temperature Patterns" task (fig. 1.4a) is a low-level task because, while it does involve students in representing and analyzing data, it does not ask them to make any choices about how best to represent the data, nor does it prompt students to provide justification for their assertion about "where and when Jeremy should go on vacation." The task below it, "Environmental Factors Impacting Rate of Transpiration" (fig 1.4b), is a high-level data task. It requires students to examine data to identify patterns that are not immediately obvious in the table provided. In fact, students will have to use mathematical processes to transform the data (i.e., calculate the change in mass over time) in order to make patterns evident. Other features of this task that contribute to high cognitive demand include (*a*) students have to determine on their own the best way to represent the data that is relevant; and (*b*) students must prepare a written description of the patterns that will be convincing and understandable to the "Zoo Board." As we saw with "Choosing Materials for Umbrellas," the anticipation of an audience increases cognitive demand because it requires students to consider their representational and linguistic choices and to make explicit the data/claim connections and the justification for their approaches.

Explanation Tasks

Science students are often asked to provide explanations. The most significant differences between high- and low-level tasks of this type are, first, whether the student must provide a rationale for the explanation (e.g., support the claims he or she makes with evidence); and, second, whether the student constructs the explanation (e.g., it is the result of meaning making) or whether the student is simply repeating an explanation that he or she has been told previously. For example, during a series of lessons about Moon phases, a teacher might explain that the reason we see the Moon changing phase is that it revolves around the Earth each month, and as it does so, different parts of the illuminated side of the Moon are visible from Earth. Later, the teacher might ask her students, "Explain why we see Moon phases." Students who remember the teacher's explanation can simply repeat or rephrase it in answer to her prompt. Thus, the explanatory task places low cognitive demand on these students. In contrast, "The Frog Problem in Bakersville Park" (fig. 1.5) is an explanatory task that places high cognitive demand on students. In this task, students are asked to explain what is causing the frog deformities in the park's lakes. To construct this explanation, students are prompted to "use the data . . . to support or challenge one of the hypotheses." They have multiple options for how to approach the problem (i.e., they can draw from the different data sources, transform or represent the data as needed, etc.). Similar to the task "Environmental Factors Impacting Rate of Transpiration," the Frog Problem task is also made more challenging because the data with which students are asked to reason are complex (e.g., units are not consistent and therefore students cannot simply compare quantities). Moreover, the task is challenging for students because it requires them to determine the most effective way to transform and represent data in order to persuade their peers of the validity of their argument.

Data Representation, Analysis, and Interpretation Tasks

a

Context
6th grade Earth Science

The teacher selected this task in order to give his students an opportunity to create and read bar graphs.

Temperature Patterns

Jeremy is planning ahead for his 2015 vacation. He has decided that he'd like to travel to a place where he can enjoy outdoor camping, hiking, and fishing with his Labrador retriever, Sadie. Jeremy's tent is rated for temperatures above freezing (32 °F). Sadie prefers not to be too active when the temperature is over 70°F.

Create a bar graph that shows the average monthly high and low temperatures in each city. Identify where and when Jeremy should go on vacation. (See data for Task A, Fig. 0.2).

b

Context
9th grade Biology

The teacher designed this task to provide students with an opportunity to make choices about how to transform data (e.g. calculate the change in mass over time) and represent it in order to show trends that would enable them to answer a specific question. She embedded the task in the context of a unit on respiration and thus highlighted key Learning Goals related to the role of water in plant transpiration.

[task by Helen Snodgrass, KSTF Fellow]

Environmental Factors Impacting Rate of Transpiration

Dear scientists of Prep HS,

We are writing you as fellow scientists in need of some help. At the zoo, our expertise is mainly in the area of animals and we currently have a question about our plants that we hope you can help with.

In different areas of the zoo, plants experience variable growth conditions. Some areas are more humid or shadier than others, etc. We need to develop a plan to provide the correct amount of water to our plants. That watering plan has to take into consideration the rate of transpiration of the plants under different conditions. Our grounds crew has gathered some data about the plants over a 5-day period during which the plants received no water. We would like you to use this data to develop a report about how different environmental growth conditions impact rate of transpiration.

Once we receive your report, we can develop a watering plan that will enable us to keep our zoo habitats thriving! We need to present this data to the Zoo Board at its next meeting. **Please look over the data for any patterns you see and create a graphical representation so that we can show the board members what patterns you have identified. Also, it will be very important to have some written description of what you found out so that our Zoo Board members will be convinced that our watering plan is grounded in good science.**

Thank you for your help. We are looking forward to hearing from you.

Deborah Smith
Director of the Zoo

Variable Condition	Standard Growth Conditions	Mass (g) Day 1	Mass (g) Day 2	Mass (g) Day 3	Mass (g) Day 4	Mass (g) Day 5
---------	64-87°F 75% humidity 8-10 hours of sunlight/day 10 mph winds	16.0	13.2	11.0	9.9	9.0
90% humidity	64-87°F 8-10 hours of sunlight/day 10 mph winds	17.0	16.8	16.6	16.4	15.3
2 hrs of sunlight	64-87°F 75% humidity 10 mph winds	12.9	12.5	11.9	11.4	11.1
40 mph winds	64-87°F 75% humidity 8-10 hours of sunlight/day	16.3	12.6	9.8	7.7	5.1

Fig. 1.4. Two examples of data representation, analysis, and interpretation tasks: a low-level task (*a*), and a high-level task below it (*b*)

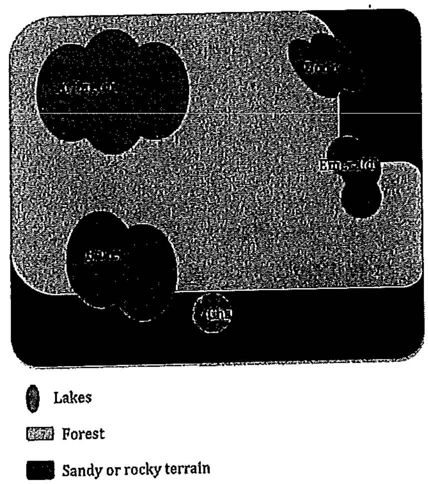
Explanation Task

Context
5th grade science

The teacher designed this task to provide students with an opportunity to draw on data to make and defend claims. She embedded the task in a unit about ecosystems, anticipating that students would draw upon their understanding of how organisms interact with and are dependent upon living and non-living factors in their environments. She wanted them to build on this knowledge to learn that parasites (or other pollutants in an ecosystem) can be particularly problematic for organisms that are exposed during early stages of development. After the students presented and discussed their claims, she took time to emphasize this new Learning Goal before closing the lesson.

The Frog Problem in Bakersville Park

Visitors to Bakersville Park have been noticing some strange looking frogs in and around some of the ponds!



Around Baker, Charles, and Emerald ponds, they have been seeing frogs with too few or too many legs! None of the deformed frogs have been spotted around Arlington or Dodd ponds, though.

Local scientists are wondering: ***what is causing these strange deformities?***

They have two hypotheses:

1. There is some kind of chemical pollution in Baker, Charles, and Emerald ponds that is causing the frogs to be deformed.
2. There is a disease-causing organism (a bacterium or parasite) in these ponds that is causing the deformities.

Use the data that the scientists have collected to support or challenge one of the hypotheses.

DATA

Concentration of Chemical Pollutants in Bakersville Park Ponds

	Fertilizer Pollution Level (ppm)	Pesticide Pollution Level (ppm)
Arlington	37	11
Baker	43	17
Charles	34	8
Dodd	41	22
Emerald	28	21

ppm = parts per million

Presence of Tremadode Larvae in Frogs

	number of frogs that were NOT infected	*number of frogs that were infected*	**Percentage** of Frogs Infected by Trematodes
Arlington	24	1	4
Baker	16	9	36
Charles	14	11	44
Dodd	23	2	8
Emerald	15	10	40

Fig. 1.5. An example of an explanation task with high cognitive demand

The Teacher's Role

As noted in the outset of this chapter, we are particularly interested in instructional tasks that (*a*) provide students with opportunities to learn key science ideas while also engaging in important disciplinary practices; and (*b*) are robust enough to support a productive whole-class discussion following students' engagement in the tasks. By "productive whole-class discussion" we mean one in which students share ideas, focus on meaning making, and develop new or richer understandings of key concepts. To support such discussion, the teacher must ensure that the following conditions are met:

1. The task places **high cognitive demand** on students, and the teacher's instruction serves to maintain, rather than remove or minimize, that demand.
2. Students are able to engage in the task in **multiple ways** that are productive (i.e., that contribute to the achievement of the learning goals). This is important because the whole-class discussion provides an opportunity for students to share their ideas and to listen critically to others. If all students have the same ideas or take the same approach to a task, they have no incentive to attend closely to one another, and no opportunity to make comparisons or connections. Moreover, providing a task in which students can engage in different ways helps to promote equity in the classroom, enabling all students to draw upon their particular experiences and cognitive resources to participate in the learning context.
3. Students **produce artifacts** while engaged in the task. Artifacts may include written text or drawings that serve multiple purposes. First, they function as a tool to support the students' thinking (and their communication about their thinking when working with others) during the task. Second, they provide the teacher with important information about the students' ideas and with opportunities to ask questions that can help to redirect or push student thinking. Finally, the artifacts serve as a tool to focus and support the subsequent whole-class discussion. They capture key elements of students' work and therefore function to center the discussion on those features.

Teachers include many different types of activity structures in their classrooms (e.g., lecture, seatwork, collaborative group activities). Some activity structures are more useful than others as precursors to whole-group discussion. For example, collaborative group work is an activity in which students are able to generate a variety of ideas or approaches related to a task and to produce artifacts that capture those ideas. In contrast, lecture and note-taking are activities that do not meet the conditions described above for supporting productive whole-class discussions. Figure 1.6 depicts many common activity structures used by science teachers. It indicates that those involving small groups of students working collaboratively are most appropriate for setting up a Five Practices discussion.

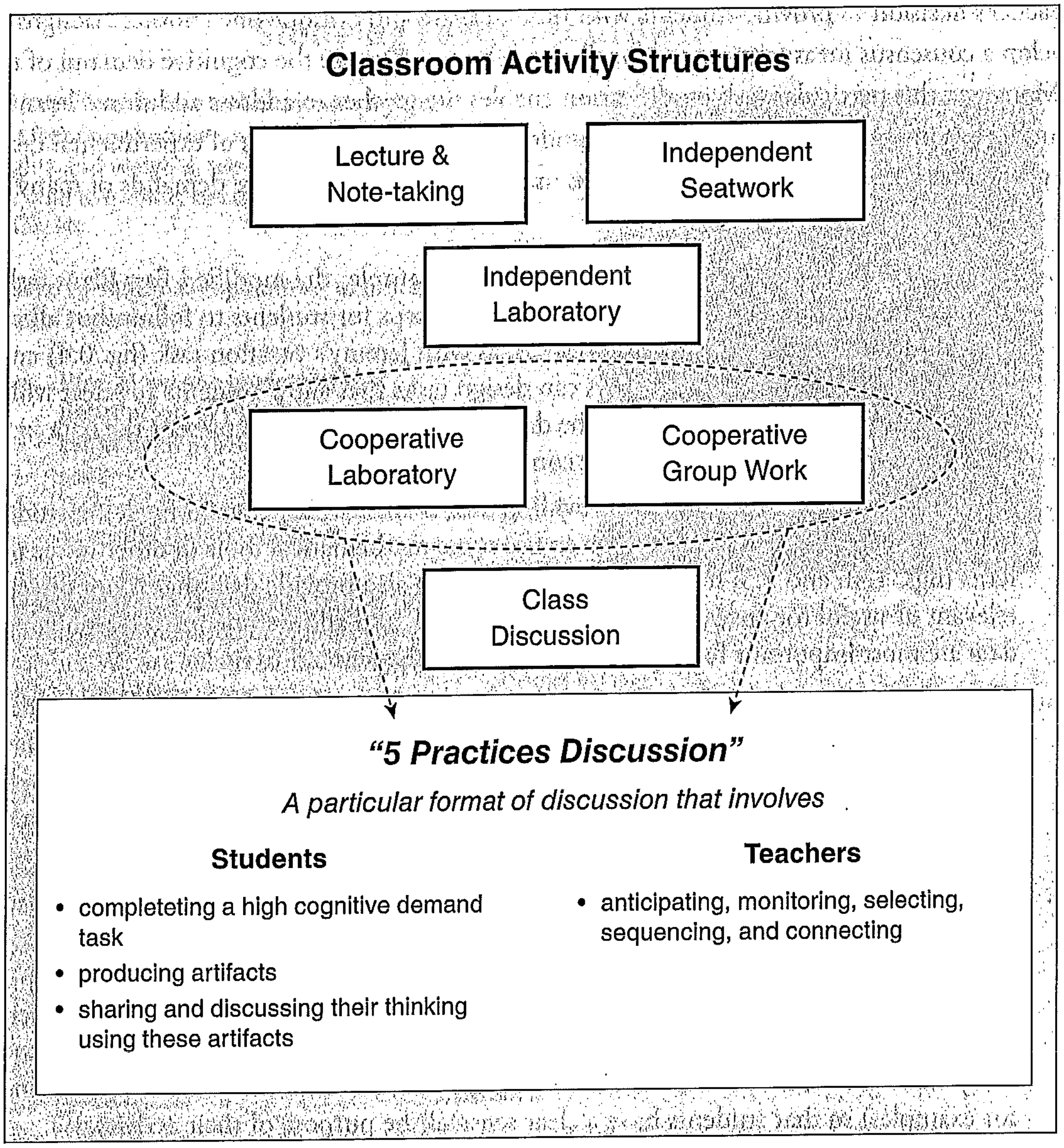


Fig. 1.6. An assortment of common classroom activity structures. Cooperative group activities (including laboratory tasks) are the ones most likely to support productive whole-class discussion.

Modifying Tasks

Science teachers select instructional tasks from curriculum materials such as science kits and textbooks, as well as from a variety of online resources. Often, teachers find that the tasks that are readily available place low cognitive demand on students (similar to the tasks shown in figs. 1.3a and 1.4a). In such situations, teachers can make specific modifications to tasks, or strategic choices about the enactment of tasks, that will serve to increase their cognitive demand. For example, a teacher whose curriculum materials include "Measuring Fast Plant Growth" (fig. 1.3a) might decide to alter the task so that students are responsible for developing the measurement protocol themselves, such as shown in the task "Studying Fast Plant Growth" (fig. 1.7). By providing students with a variety of tools and asking them to design their own measurement protocols, the modified task requires students to make meaning of their actions rather than simply follow rote directions.

The teacher's decision to provide students with time to share and critique one another's designs (and to develop a consensus measurement protocol) also serves to increase the cognitive demand of the task. Moreover, this particular task modification enables the teacher to address additional learning goals in the lesson—goals related to students' understanding of key features of experimental design. Some general design strategies that teachers can use to increase the cognitive demands of many different types of tasks include:

1. *Eliminate or minimize prescriptive directions.* For example, the modified Fast Plant task (fig. 1.7) does not provide a highly detailed set of steps for students to follow, but allows them to develop those steps themselves. Or, as with Jeremy's vacation task (fig. 0.4) and the Frog Problem task (fig. 1.5), teachers can design tasks that allow students to select which data to represent, how to transform the data, and/or how to best represent the data in order to support a particular claim or conclusion.
2. *Provide complex data.* Rather than providing data that is already transformed, ask students to analyze data that will require them to use some mathematical tools in order to see patterns (figs. 1.4b and 1.5, for example). Teachers can also provide data that is not directly relevant or useful for answering the questions posed, and allow students to reason which data are most important for supporting the claims they intend to make.
3. *Give students an audience.* Providing an opportunity for students to present their work and to critique that of peers increases the cognitive demand of tasks. This implementation approach forces students to consider the linguistic and representational choices they make to express their ideas, and it requires them to make connections across ideas while actively listening to peers.
4. *Re-sequence tasks.* As noted earlier, traditional science instruction often involves a didactic lesson in which students receive information about causal mechanisms or concepts followed by a laboratory exercise in which they generate empirical evidence that supports these concepts. A teacher can provide more opportunities for students to engage in sense making by placing the exploratory laboratory first in the sequence of lessons. Such exploratory laboratory exercises must still be firmly grounded in a question (see figs. 1.3a and 1.7 for examples) so that students have a clear sense of the purpose of their activity.

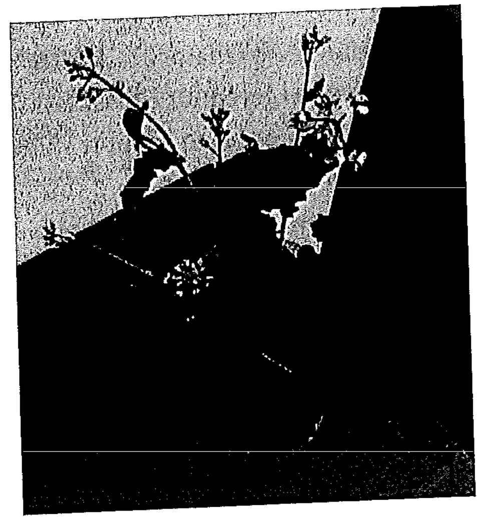
TRY THIS!

Choose a task from one of the three categories described in this chapter. Identify (1) the existing features of the task that would place high cognitive demand on students, and (2) specific modifications you might make to the task in order to increase its cognitive demand.

Maintaining Cognitive Demand during Task Enactment

Task selection and design are crucial to ensuring that students have opportunities to engage in high cognitive demand work. However, a teacher's choices during the enactment of a task also have a significant impact on the cognitive demand that students experience. Moreover, researchers in the field of mathematics have shown a positive relationship between teachers' ability to maintain high cognitive demand of tasks during enactment and student learning (Stein and Lane 1996; Hiebert and Stigler 2004; Boaler and Staples 2008).

Studying Fastplant Growth



We know that individual humans vary quite a lot from one another — we are different heights and weights; we have different skin, hair, and eye color; the thickness of our hair varies, etc.

Is there variation in populations of other types of organisms?

- **Would we see variation in a population of plants?**
- **What kind of variation would we see?**
- **How would we measure and describe that variation?**

Over the next few weeks you will be investigating variation in a population of plants called Wisconsin Fastplants. We are going to track ***changes in stem length*** as the plants grow.

Today we will decide how we are going to measure stem length in Fastplants.

SMALL GROUPS
[20 minutes]

1. Obtain a Fastplant from under the grow lights.
2. Select from the available tools:

   Measuring tape
   Bamboo skewers
   String
   Scissors
   Markers
   Colored tape
   Meter stick
   Ruler
   Lego blocks
   Pipe cleaners

3. Determine how you will use the tool/s you've chosen to measure Fastplant stem length.
4. Write our your measurement protocol in enough detail so that others will be able to use the protocol in a reliable way (i.e. everyone needs to be able to use it exactly the same way).

   Include pictures to help others understand your measurement protocol.

WHOLE CLASS
[20 minutes]

- We will share our protocols with the class and determine whether there are any details missing.
- We will agree on one way of measuring our plants throughout this investigation.

Fig. 1.7. In this modified version of the task "Measuring Fast Plant Growth" (fig. 1.3a), students are given clear instructions to connect the data collection task to an underlying question ("How would we measure and describe that variation?"). They also have choices about what tools to use and how to use them to obtain measurement data as well as the opportunity to share and critique approaches with peers. These modifications serve to increase the cognitive demand of the task.

The table in figure 1.8 summarizes some of the key features and teacher actions that contribute to low and high cognitive demand enactments of three types of tasks in science. For example, teachers who provide opportunities for students to share and critique will help to maintain the high cognitive demand of explanatory tasks. Teachers' actions, it should be noted, often serve to *lower* the cognitive demand (even for robust tasks), and it is therefore crucial that teachers are purposeful about their actions in order to support students' engagement in challenging tasks (Stein, Grover, and Henningsen 1996). In chapters 2 through 5, we will present a more detailed look at how the Five Practices framework and its deliberate strategies to elicit and support student talk can help teachers to ensure students' productive engagement in high cognitive demand tasks.

	Low Cognitive Demand		High Cognitive Demand	
	Tasks	***Teacher Actions***	***Tasks***	***Teacher Actions***
Experimentation	Students— • follow a **highly specified** procedure. • do not make choices about what data to collect or how to collect it. • are not engaged in being critical about the data collection procedure.	The teacher— • does not help students understand that data collection is occurring in the service of answering a question. • introduces the experiment after she/he has already provided didactic information on the underlying concepts.	Students— • must **make decisions** about **what** data to collect and/or **how** to collect it. • **compare/contrast or critique** experimental protocols, considering issues such as reliability and "fit" between data gathered and the underlying question driving the experiment.	The teacher— • ensures that students understand how their data collection must help them achieve the goal of answering a particular question.
Data Representation, Analysis, and Interpretation	Students— • **follow specific instructions** about how to transform (e.g., calculate the mean temperature) and/or represent data (e.g., draw a bar graph). • **answer specific questions** about the data (e.g., *In which city is the average monthly temperature highest?*).	The teacher— • accepts only very specific representation types or strategies. (i.e., multiple solutions or strategies are not possible). • does not press for students to justify their answers using the data representations.	Students— • **seek to describe general** (e.g., the S-shaped growth curve of Fast Plants) and specific (e.g., trematode infection is 4–5 times higher in Charles, Emerald, and Baker ponds than in other ponds) **patterns** that are evident in the data. • **select** what data to represent and/or **how** to represent it. • **compare/contrast** various representations, considering issues such as the ease with which various patterns or relationships can be visualized.	The teacher— • provides opportunities for students to share and discuss a variety of data representations. • requires students to provide a rationale for the choices they have made related to transforming or representing data. • requires students to identify specific data or elements of data representations that provide evidence for the patterns/trends they've identified.

	Low Cognitive Demand		High Cognitive Demand	
	Tasks	***Teacher Actions***	***Tasks***	***Teacher Actions***
Explanation	Students— • **provide explanations without justification** or specific connection to data. • **repeat factual knowledge** previously learned.	The teacher— • requests discrete answers to questions without justification (e.g., *What causes a solar eclipse?* [answer] *The Moon blocking the Sun.*)	Students— • **provide explanations** with justification. • are engaged in **developing new explanatory knowledge.** • are critical of the explanations offered by others, requesting clarification and supporting evidence when appropriate. • **draw upon a variety of representational tools** (e.g., diagrams, tables, simulations) to communicate with peers.	The teacher— • presses students to provide explanations and to justify their assertions. • provides opportunities for students to share and critique one another's explanations. • encourages students to use a variety of tools to communicate.

Fig. 1.8. The task features and teacher actions that contribute to low or high cognitive demand

CHAPTER 2

Introducing the Five Practices Model: Contrasting the Practices of Two Teachers

In this book's introduction, we indicated that while robust classroom discussions are essential if students are to simultaneously engage in science practices and learn canonical science content, they are difficult to orchestrate. Why is it so challenging for teachers to orchestrate productive discussions? Research tells us that students learn when they are encouraged to become the authors of their own ideas *and* when they are held accountable for reasoning about and understanding key ideas (Engle and Conant 2002). In practice, doing both of these at the same time is very difficult. By their nature, high cognitive demand tasks that engage students in experimentation; data representation, analysis, and interpretation; and explanation (as discussed in chapter 1) do not lead to cookie-cutter products. Rather, teachers can and should expect to see varied (incorporating both correct and incorrect ideas or strategies) responses to a task during the discussion phase of the lesson. In theory, this variety is a good thing because students are "authoring" (or constructing) their own ways of making sense of the situations presented.

The challenge rests in the fact that teachers must also align the many disparate ideas and approaches that students generate in response to high cognitive demand tasks with the learning goals of the lesson. It is the teacher's responsibility to move students collectively toward, and hold them accountable for, the development of a set of ideas and processes that are central to the discipline—those that are widely accepted as worthwhile and important in science as well as necessary for students' future learning of science in school. If the teacher fails to do this, the balance tips too far toward student authority, and classroom discussions become unmoored from accepted disciplinary understandings.

The key is to maintain the right balance. Too much focus on accountability can undermine students' authority and sense making and, unwittingly, encourage increased reliance on teacher direction. Students quickly get the message—often from subtle cues—that engaging in science practices means using only those strategies that have been validated by the teacher or textbook; correspondingly, they learn not to use or trust their own reasoning. Too much focus on student authorship, on the other hand, leads to classroom discussions that are free-for-alls.

Successful or Superficial? Discussion in Kelly Davis's Classroom

In short, the teacher's role in discussions is critical. Without expert guidance, discussions in science classrooms can easily devolve into the teacher taking over the lesson and simply telling students what to do and how to do it, or into the students presenting an unconnected series of show-and-tell presentations, all treated equally and illuminating little about the canonical science ideas that are the goal of the lesson. Consider, for example, the following vignette, featuring a seventh-grade teacher, Kelly Davis.

ACTIVE ENGAGEMENT 2.1

As you read the Case of Kelly Davis, identify the instances in it of student authorship of ideas and approaches, as well as any instances of holding students accountable to the discipline.

Growing Fast Plants: The Case of Kelly Davis

Ms. Davis wanted her grade 7 students to have an authentic experience collecting and representing data. To achieve this, she had students gather data on the growth of Wisconsin Fast Plants over an eleven-day period. (More information on these plants, which were developed by a program at the University of Wisconsin–Madison, is available at www.fastplants.com.) Each group of students tracked the growth of six Fast Plants by measuring their height every few days. They gathered data beginning on the day the plants were ten days old and ending when they were twenty-one days old.

Following data collection, Ms. Davis asked the students to create a representation of their data on poster paper that would enable them to answer the following question: "How tall is a typical Fast Plant on a certain day in its life cycle?"

Ms. Davis told her students that they could represent their data any way they wanted. She also told them they could either use their raw data (the actual values they recorded) or else transform the data in some way. She emphasized that, however they chose to represent their data, they needed to be able to explain what values they plotted, how they got those values, and why their representation helps to answer the question "How tall is a typical Fast Plant on a certain day in its life cycle?"

As students worked in groups, Ms. Davis walked around the room making sure that students were on task and making progress on the activity. She was pleased to see that students were using many different approaches to represent their data—different formats (bar graphs and line graphs) and different mathematical measures of central tendency (mean, median).

She noticed that students in two of the groups were having some difficulty accurately representing their data. Students in group 3 decided to calculate the mean plant height at each data collection point but made mathematical errors in their calculations, and students in group 4 used inconsistently spaced units when constructing their line graphs. Ms. Davis told both these groups that they had an error in their poster and that rather than presenting, they needed to listen carefully to the presentations from the other groups and should try to determine what they needed to fix. Ms. Davis was not too concerned about these errors, however, since she felt that once several correct representations were shared, students in groups 3 and 4 would see what they did wrong and learn new strategies for creating correct graphs in the future.

When most of the students were finished, Ms. Davis called the class together to discuss their work. She began the discussion by asking for volunteers to share their posters, being careful to avoid calling on the students with incorrect graphs. Over the course of the next fifteen minutes, groups 1, 5, 7, 9, 2, 6, and 8 volunteered to present their representations to the class (see fig. 2.1). They described *typical* by using conventional methods such as the mean, median, and range, as well as less common approaches such as looking at the average of two middle plants each day.

During each presentation, Ms. Davis made sure to ask each presenter to explain what values they had plotted, how they got the values, and the height of a typical plant. She also made sure that after each presentation she asked the class if they had any questions for the group presenting. A few students from group 5 (who just picked one of their six lines as typical without finding an average) asked questions about how other groups had calculated the mean (group 8) and the median (group 2).

She concluded the class by telling students that the question "How tall is a typical Fast Plant?" could be answered in many different ways and that now, when they encountered a question like this, they could pick the way they liked best because all of these approaches gave them an answer.

Analyzing the Case of Kelly Davis

Some would consider Ms. Davis's lesson exemplary. Indeed, Ms. Davis did many things well, including allowing students to construct their own way of representing data and stressing the importance of students' being able to explain how their representation helped determine the height of a typical Fast Plant. Students worked in small groups and publicly shared their representations with their peers. They also had opportunities to engage in science practices related to data representation (SP 4) and communication of information to others (SP 8). All in all, students in Ms. Davis's class had the opportunity to become the "authors" of their own knowledge.

However, a more critical eye might note that the string of poster presentations did not build toward important ideas in science. While students did engage in disciplinary practices (e.g., analyzing and interpreting data), the lesson was narrowly focused on representing the data and did

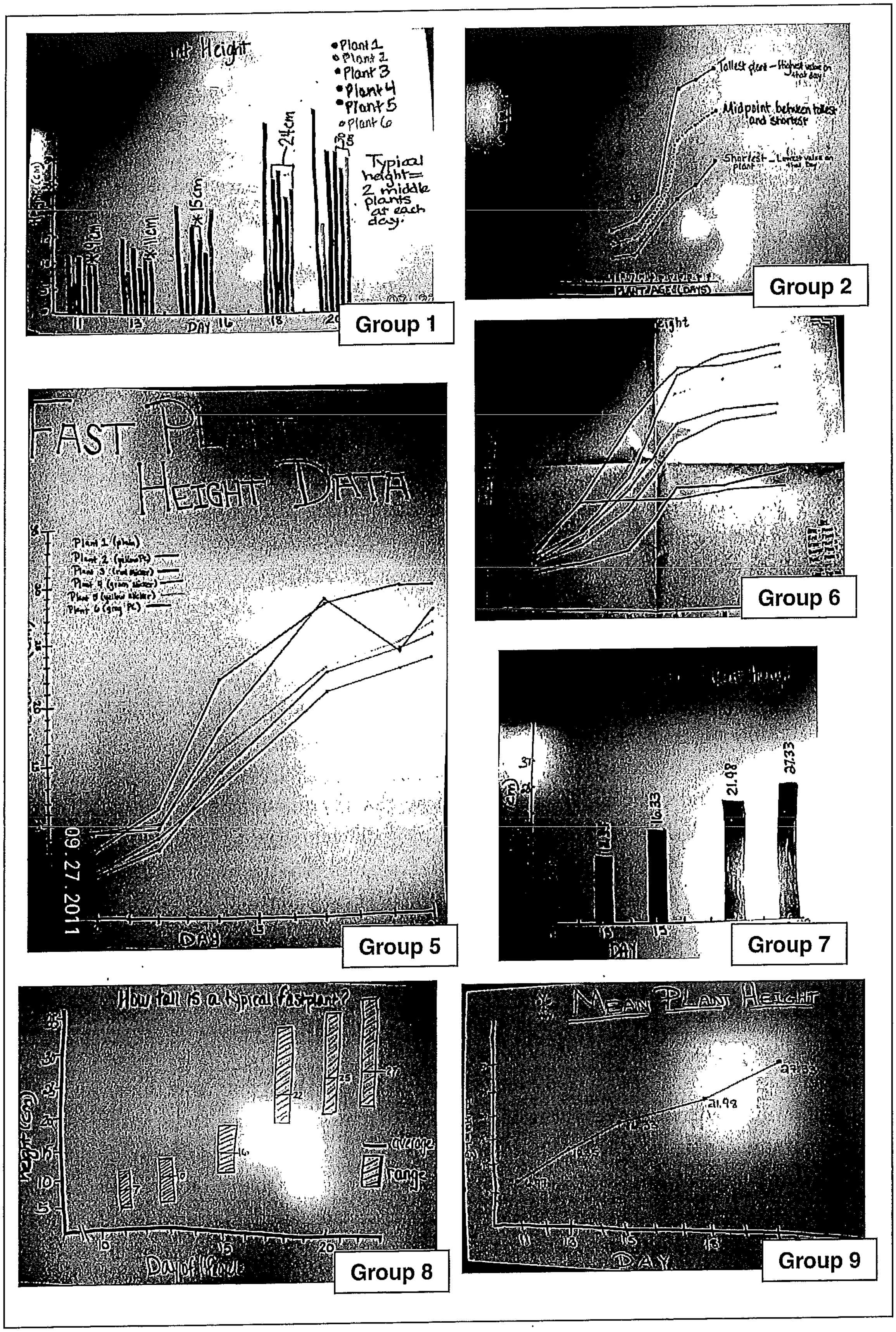


Fig. 2.1. Posters produced by students in Kelly Davis's class

not include support for students to learn key science ideas related to "typical" growth patterns. Such ideas could include how populations of organisms are diverse, so a range, rather than a single value, is generally better able to capture "typical"; or how the Fast Plant growth curve is almost always S-shaped due to the ways in which the plant is utilizing energy resources at different points in its life cycle. In addition, although Ms. Davis observed students as they worked, she did not appear to use this time to assess what they understood about their representations or to select particular students' work to feature in the whole-class discussion. Furthermore, she gathered no information regarding whether groups 3 and 4, who did not accurately represent their data, were helped by the student presentations. Had they diagnosed the faulty reasoning in their approaches?

In fact, we argue that much of the discussion in Ms. Davis's classroom was show-and-tell, in which students with accurate representations each took turns sharing their posters. The teacher did minimal filtering of the ideas that each poster helped to illustrate, nor did she make any attempt to highlight those ideas. The teacher also did not draw connections among different representations or tie them to important disciplinary methods or ideas. She gave no attention to weighing which representations might be most useful, efficient, accurate, and so on, in describing the height of a typical plant. All were treated as equally good.

In short, providing students with a high-level task and then conducting show-and-tell discussions cannot be counted on to move an entire class forward in their understanding of how to engage in science practices or their understanding of the key science ideas underlying the task. By arbitrarily sequencing one group presentation after another with limited teacher/student commentary and providing no help in drawing connections among methods or tying those methods to shared disciplinary concepts, Ms. Davis gave her students no motivation to attend to or understand their classmates' methods. Indeed, this kind of practice has been criticized for creating classroom environments in which nearly complete control of the agenda is relinquished to students. Some teachers misperceive the appeal to honor students' thinking and reasoning as a call for a complete moratorium on teacher shaping of the quality of students' thinking. As a result of the lack of guidance with respect to what teachers *could* do to encourage rigorous thinking and reasoning, many teachers are left feeling that they should avoid telling students anything.

In sum, Ms. Davis did little to encourage accountability to the discipline of science. How could Ms. Davis have more firmly supported student accountability without undermining student authority? The single most important thing that she could have done would be to set a clear goal for which crosscutting concepts and core ideas she wanted students to learn from the lesson. Without a learning goal in mind that went beyond "representing data," the various graphs presented were only discussed at a surface level. Key ideas in the discipline that could have been explored were not on the teacher's radar. If, however, she had targeted the learning goal that *typical growth in Fast Plants—and many populations of organisms—is described by range and shape*, she might have monitored students' work with this in mind, noticing whose work illustrated the range and shape particularly well. This assessment of student work would have allowed her to be more deliberate about which groups she selected to present during the discussion phase. With an array of purposefully selected representations presented, Ms. Davis would then have been in a position to steer the discussion toward a more satisfying conclusion.

The Case of Kelly Davis illustrates the need for guidance in shaping classroom discussions and maximizing their potential to extend students' thinking and connect it to important science concepts and core ideas. In the next section we offer this guidance by elaborating the Five Practices model, a practical method for orchestrating and managing productive classroom discussions.

The Five Practices Model

We think of the Five Practices model as skillful improvisation. The practices that we have identified are meant to make student-centered instruction more manageable by moderating the degree of improvisation required by the teacher during a discussion. Instead of focusing on in-the-moment responses to student contributions, the practices emphasize the importance of planning. Through planning, teachers can anticipate likely student contributions, prepare responses that they might make to those contributions, and decide how to structure students' presentations to further their learning agenda during a lesson. We turn now to an explication of the five practices.

The five practices were designed to help teachers use students' responses to advance the scientific understanding of the class as a whole during task-based discussions. They provide teachers with some control over what is likely to happen in the discussion as well as more time to make instructional decisions by shifting some of the decision making to the planning phase of the lesson. The five practices are—

1. ***anticipating*** how students are likely to respond to a task;
2. ***monitoring*** what students actually do as they work on the task in pairs or small groups;
3. ***selecting*** particular students to present their work during the whole-class discussion;
4. ***sequencing*** the student work or products that will be displayed in a specific order; and
5. ***connecting*** different students' responses and connecting the responses to key scientific ideas.

Each of these practices are described in more detail in the following sections, which illustrate them by identifying what Ms. Davis *could have done* in the Growing Fast Plants lesson (presented earlier in this chapter) to move student thinking more skillfully toward the goal of understanding that typical growth in Fast Plants—and in many populations of organisms—is described by range and shape.

Anticipating

The first practice is to actively envision how students might approach the instructional tasks or activities on which they will work. This involves much more than simply evaluating whether a task is at the right level of difficulty or of sufficient interest to students, and it goes beyond considering whether or not they are likely to get the "right answer." Anticipating students' responses involves developing considered expectations about how they might interpret a problem, the array of strategies—both correct and incorrect—that they might use to tackle it, and how those strategies and interpretations might relate to the concepts, representations, procedures, and practices that the teacher would like his or her students to learn.

Anticipating requires that teachers engage in the task or activity themselves, and consider different ways it could be approached or interpreted. Sometimes teachers find it helpful to expand what they might be able to think of individually by working on the task with colleagues, reviewing responses to the task that might be available (e.g., work produced by students in the previous year, or sample responses that are published along with tasks in supplementary materials), and consulting research on student learning of the scientific ideas embedded in the task. One resource for educators is the National Science Digital Library (NSDL), located at http://nsdl.org. NSDL provides information for educators and researchers on learning in science, technology, engineering, and mathematics (STEM). Their Science Literacy Maps are available to educators as a resource on specific math and science concepts. These maps clearly indicate specific benchmarks correlated to National Science Education Standards (NRC 1996), make connections between concepts across grade levels, and detail how those concepts build on one another. The maps also provide teaching and learning resources as well as document research-based student misconceptions for certain concepts.

Prior to the lesson, Ms. Davis needed to consider the various representations that students might use in answering the question she posed and give some thought to which ones would best highlight the two key features of determining what is typical in a population—range and shape. In addition, she needed to identify common errors students make. When they create graphs, students sometimes use a scale that is not consistent, or they graph dependent and independent variables on the wrong axes. In calculating measures of central tendency, students may make a number of errors. When finding the mean, they may add wrong or divide by the wrong number; they may forget to put data in order before finding the middle value when determining the mode; and they may think there can be only one median. By knowing in advance the errors students are likely to make, Ms. Davis would have been prepared to ask specific questions to help get students back on track rather than hoping that any misunderstandings would be alleviated by simply seeing correct approaches.

Monitoring

Monitoring the responses students produce involves paying close attention to their thinking and strategies as they work on the task. Teachers generally do this by circulating around the classroom while students work either individually or in small groups. Carefully attending to what students do and say as they work makes it possible for teachers to use their observations to decide on what and whom to focus during the discussion that follows (Lampert 2001).

One way to facilitate the monitoring process is for the teacher, before beginning the lesson, to create a list of anticipated student solutions or ideas that will help in accomplishing the lesson goals. The list, such as the one shown in the first two columns of the chart in figure 2.2 for the Growing Fast Plants task, can help the teacher keep track of which students or groups produced or brought up particular solutions or ideas that he or she wants to capture during the whole-group discussion. The "Other" category in the second column provides the teacher with the opportunity to capture ideas that he or she had *not* anticipated.

As discussed earlier in the chapter, Ms. Davis's lesson provided limited, if any, evidence of active monitoring. Although Ms. Davis knew which groups produced correct graphs and that a range of representations had been used, the fact that all seven groups with accurate graphs presented, regardless of the fact that they did not all uniquely contribute something to the discussion, suggests she had not considered the specific learning potential available in any of the responses. What Ms. Davis could have done while students worked on the task is shown in the right-hand column in the chart in figure 2.2.

Typical	Representation Type and Group Number	Notes and Order
Not specified	___ Bar √ Line—*group 5* ___ Box-and-whisker ___ Other	*Plotted data for all plants.*
Mean	√ Bar—*group 7* √ Line—*group 6; group 9* ___ Box-and-whisker √ Other—*group 8*	*Groups 7 (#2) & 9—plotted only mean.* *Group 6—plotted all individual plants and mean. (#1)* *Group 8—showed range and mean in a modified bar graph. (#3)*
Median	√ Bar—*group 1* ___ Line ___ Box-and-whisker ___ Other	*Identified "typical" as the mean value of the two plants "in the middle" of the data set.*
Mode	___ Bar ___ Line ___ Box-and-whisker ___ Other	
Range	___ Bar √ Line: *group 2* ___ Box-and-whisker √ Other: *group 8*	*Group 2—plotted highest, lowest, and middle value.* *Group 8—showed range in the bars. Also showed mean. (#3)*
Shape	___ Bar √ Line—*groups 2, 5, 6* ___ Box-and-whisker ___ Other	*Can see an S shape best in these. No group indicated this shape is "typical." (#1)*
ERRORS	√ Calculation—*group 3 (mean)* √ Graphing—*group 4 (inconsistent units across x-axis)*	

Fig. 2.2. A sample chart for monitoring students' work on the Growing Fast Plants task

Monitoring involves more than just watching and listening to students. During this time, the teacher must also ask questions that will make students' thinking visible, help them to clarify their thinking, ensure that members of the group are all engaged in the activity, and press them to consider aspects of the task to which they need to attend. Many of these questions can be planned in advance of the lesson, on the basis of the anticipated responses. For example, if Ms. Davis had anticipated that students would use a line graph (groups 2, 5, and 6; see fig. 2.1), then she might have been prepared to question the students regarding what they noticed about the shape of the graphs and what they thought the shape meant. Questioning a student or group of students while they are exploring the task provides them with the opportunity to refine or revise their thinking prior to whole-group discussion, and it provides the teacher with insights regarding what the students understand about the task and the ideas embedded in it.

Selecting

Having monitored the available student responses, the teacher can then select particular students to share their work with the rest of the class in order to get particular ideas on the table, thus giving the teacher more control over the discussion (Lampert 2001). The selection of particular students and their approaches or ideas is guided by the goals for the lesson and the teacher's assessment of how each response will contribute to those goals. Thus, the teacher selects certain students to present because of the concepts or core ideas in their responses.

A typical way to accomplish "selection" is to call on specific students (or groups of students) to present their work as the discussion proceeds. Alternatively, the teacher may let students know before the discussion that they will be presenting their work. In a hybrid variety, a teacher might ask for volunteers but then select a particular student that he or she knows is one of several who have a particularly useful idea to share with the class. By calling for volunteers but then strategically selecting from among them, the teacher signals appreciation for students' spontaneous contributions, while at the same time keeping control of the ideas that are publicly presented.

Returning to the Case of Kelly Davis, if we look at the solutions that were shared, we note that groups 5 and 6 had similar line graphs and groups 7 and 9 each graphed the mean height of the plants at each time point (although they used different types of graphs). Therefore, Ms. Davis might have considered only sharing one graph from each of these sets and spending more time discussing them.

Sequencing

Having selected particular students to present, the teacher can then make decisions regarding how to sequence the presentations. By making purposeful choices about the order in which students' work is shared, teachers can maximize the chances of achieving their goals for the discussion. For example, the teacher might want to have the response produced by the majority of students presented before those developed by only a few students in order to validate the work that the majority did and make the beginning of the discussion accessible to as many students as possible. Alternatively, the teacher might want to begin with a strategy that is more concrete (using drawings or concrete materials) and move to strategies that are more abstract. This approach—moving from concrete to abstract—serves to validate less sophisticated approaches and allows for connections between approaches. If a common misconception underlies a response offered by several students, the teacher might address it first so that the class can clear up that misunderstanding and work on developing more successful ways of tackling the task. Finally, the teacher might want to have related or contrasting ideas presented right after one another in order to make it easier for the class to compare them. Again, during planning the teacher can consider possible ways of sequencing anticipated responses to highlight the ideas that are key to the lesson. Unanticipated responses can then be fit into the sequence as the teacher makes final decisions about what is going to be presented.

More research needs to be done to compare the value of different sequencing methods, but we want to emphasize here that deliberate sequences can be used to advance particular goals for a lesson. Returning to the Case of Kelly Davis, we point out one sequence that could have been used: group 6 (line graph of raw data), group 7 (bar graph of average), and group 8 (bar graph that shows the average and range). This ordering begins with the most widely used representation (a line graph) that uses raw data and ends with a representation (bar graph) that shows both the average height as well as the range of heights at all time points, a sequencing that would help with the goal of accessibility.

Connecting

Finally, the teacher can help students to draw connections between their responses and other students' approaches as well as connections to the key ideas in the lesson. Rather than having discussions consist of separate presentations of different ways to respond to a particular problem, the goal is to have student presentations build on one another to develop powerful ideas.

Let's suppose that in the Case of Kelly Davis the sequencing of student presentations was group 6, group 7, and group 8, as discussed above. Students could be asked to compare the responses of groups 6 and 8 to see how they are the same and how they are different. This move could highlight the fact that if you fit a line to the top and bottom of the bars in group 8's poster, you would get graphs very similar to the tallest and the shortest plant represented in group 6's poster. Students might also notice that while the range can be seen in both graphs, it is easier to determine it from group 8's graph. Students could compare group 8's poster with group 7's poster to see that while both show the average height of the plants, group 8's poster shows the entire range of values without showing every single value (as shown in group 6's poster).

It is important to note that the five practices build on each other. *Monitoring* is less daunting if the teacher has taken the time to *anticipate* ways in which students might approach a task. Although a teacher cannot know with 100 percent certainty how students will engage with a particular task prior to the lesson, many approaches can be anticipated and thus easily recognized during monitoring. A teacher who has already thought about the science concepts and ideas represented by those solutions can turn his or her attention to making sense of those approaches that are unanticipated. *Selecting, sequencing,* and *connecting,* in turn, build on effective *monitoring.* Effective monitoring will yield the substance for a discussion that builds on student thinking, yet moves assuredly toward the goal of the lesson.

Investigating the Five Practices in Action

Above, we presented the five practices for orchestrating a productive discussion and considered what Ms. Davis' class *might* have looked like had she engaged in these practices and how use of the practices in advance of and during the lesson *could* have had an impact on students' opportunities to learn key science ideas. In this section, we analyze the teaching of Nathan Gates, a seventh-grade teacher who has spent several years trying to improve the quality of discussions in his classroom.

The vignette that follows provides an opportunity to consider the extent to which the teacher appears to have engaged in some or all of the five practices before or during the featured lesson and the ways in which his use of the practices may have contributed to students' opportunities to learn.

ACTIVE ENGAGEMENT 2.2

Read the vignette "Growing Wisconsin Fast Plants: The Case of Nathan Gates" and identify places in the lesson where Mr. Gates appears to be engaging in the five practices. Use the line numbers to help you keep track of the places where you think he used each practice.

Growing Wisconsin Fast Plants: The Case of Nathan Gates

In Mr. Gates's seventh-grade life science class, the early units of the course focus on natural variation and patterns of growth in organisms. In order to study these patterns and variation, students were gathering data on the growth of Wisconsin Fast Plant *(Brassica rapa)*. At the end of this lesson arc, Mr. Gates wanted his students to understand three scientific ideas:

1. Natural variation exists in any population of organisms. To identify patterns and correlations, one needs to use mathematical tools that make it possible to describe "typical" growth (including the spread of values that can be considered typical). Typical growth in Fast Plants is described by range and shape. This is often the case in populations of organisms.
2. Fast Plant growth is characterized by an S-shaped growth curve, where stem length increases slowly for the first ten to twelve days and then increases quite steeply for about seven more days. Following pollination (around day 18), the stem growth slows considerably.
3. The growth patterns of Fast Plants can be explained by considering where the plant is "spending" its energy resources at various stages of its life cycle and how that is advantageous (e.g., following pollination the plant does not invest energy resources in additional flower production or stem growth, but instead uses its energy to nurture the growth of seed pods and seeds).

In addition to these learning goals, Mr. Gates also developed performance goals to aid in assessing students' progress during and after instruction. His performance goals for this lesson were:

1. Students will be able to analyze their Fast Plant data in order to identify typical growth in their plants.
2. Students will be able to draw a graphical representation of their Fast Plant data by identifying the typical growth pattern of their plants.
3. Students will be able to describe the growth of a typical Fast Plant by identifying a range of stem length and a general shape of the growth curve.

In preparation for this unit and in consideration of time, Mr. Gates planted Fast Plant seeds in containers to allow time for seed germination. He planted six plants in each container. On day 10, the students received individual plant containers. Students decided to measure "growth" of the plants every two to three days for eleven days, marking a piece of string to indicate the plant height and then putting the string on a ruler to get the height in centimeters. Once students had finished collecting data on the plants, Mr. Gates wanted them to create a representation for their data that would enable them to answer the question: "How would we describe the growth of a typical Fast Plant?"

Mr. Gates told his students that they could represent their data any way they wanted. He also told them they could use their raw data (their actual recorded values) or transform their data in some way, which would be depicted in the representation. He emphasized that students needed to be able to explain: (1) what values they plotted; (2) how they got those values; and (3) why their representation helps to answer the question, "How would we describe the growth of a typical Fast Plant?" In this first discussion about the Fast Plant data, he hoped to focus primarily on learning goals 1 and 2.

As students worked on the task in their groups, Mr. Gates circulated among the eight groups, made note of the different approaches the students used and asked clarifying questions. In addition, he pressed students to think about what information they needed to create their representations, why they chose to represent their data the way they did, and how they could describe typical Fast Plant growth using their representation.

Mr. Gates noted that the groups were using different approaches to represent their data—different formats (bar graphs, pictures, line graphs) and measures of central tendency (e.g., mean, range). He thought that group 1 had the most unusual approach of all, choosing to represent their data by creating pots for each plant indicating the length of each plant in the pot at the indicated time points. Mr. Gates noticed that although this approach provided information about plant height, there might be some difficulty in interpreting the representation.

After about thirty minutes of small-group work, Mr. Gates decided that it was time to begin a discussion of the students' work. He reviewed his notes that indicated what each group had done:

Group 1	*picture of six pots that show the height of the plant at each time point (plants not drawn to scale)*
Group 2	*line graph that shows the height of four plants at each time point—the two "extreme" plants were not included*
Group 3	*line graph that shows the height of only two plants at each time point*
Group 4	*bar graph that shows the height on the horizontal axis and the number of plants on the vertical axis*
Group 5	*box-and-whiskers plot that shows the range and the median for each time point*
Group 6	*bar graph that shows the shortest and tallest plant at each time point*
Group 7	*line graph that shows the height of each plant at each time point*
Group 8	*bar graph that shows the average height of the six plants at each time point*

Although he instructed each group to hang their poster on the wall, he quickly decided to focus the discussion on the representations produced by group 7, group 1, group 8, and group 5. He felt that this set would highlight a range of approaches for representing the data and, he hoped, make clear that some representations provided more insight into typical plant growth than others.

He began by asking Ryanne from group 7 to share her group's work with the class. Since three of the groups had produced line graphs, this seemed like a good place to start. Although there were four members of the group, it had been a few days since Ryanne had shared ideas during a whole-class discussion, and Mr. Gates wanted this student to have an opportunity to demonstrate her understanding.

Once Ryanne reached the front of the room, she explained that her group measured the height of each plant and found that from day 13 to day 21 the plants grew a lot. So, she explained, they chose to represent their data in a line graph that depicted the growth of all six of their Fast Plants in a different color as shown in figure 2.3.

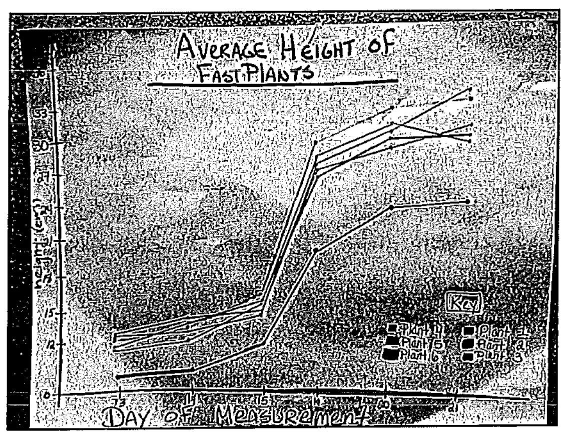


Fig. 2.3. The line graph produced by group 7

Mr. Gates then posed a question to the class: "What are some things you notice about the representation group 7 has created?" Several students shared their ideas:

Juan: You can easily see the day of measurement and the height of the plants.

Mr. Gates: Okay, Juan, where do you see that?

Juan: The graph has axes that are labeled and there is a key so we can tell which plant is which.

Mr. Gates: Okay, so the x and y axes allow us to understand what data is represented. Class, do we agree with that?

Trina: I do, and you can also see the height of all the plants on any day they were measured.

Mr. Gates: Okay, so what does this graph tell you about the plants' growth?

Trina: The plants get taller over time.

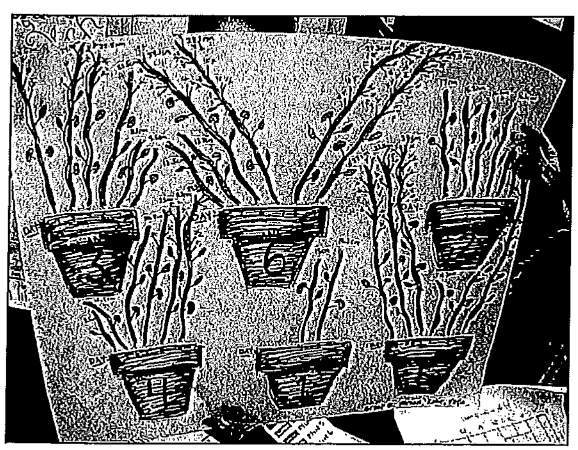
Mr. Gates: Okay, the plants get taller over time. What else?

David: Some plants are growing faster and taller than others.

Tessa: The plants start out growing slowly, then they really grow a lot, and then they sort of don't grow much.

At this point, Mr. Gates asked the class if they could "see" what Tessa described in the graphs. Marcela, from group 8, volunteered, "Each of the graphs has the same basic shape that sorta looks like an S." Mr. Gates asked the class whether the line graphs that groups 2 and 3 had produced (which were displayed for all to see) had this same general appearance. The students all nodded in agreement. Moses, from group 3, commented, "Yeah, no matter whether it's a tall plant or a short plant, it still has the same shape." Mr. Gates noted, "So, could we say that an S-shaped growth curve is typical for Fast Plants?" Many students again nodded their agreement. England added, "You can really see from all the line graphs that the plants have an S-shaped growth curve over the time that we measured them." Mr. Gates explained that it was typical for these plants to grow slowly at the beginning of their life cycle, followed by a steep increase in growth that can be seen in these graphs. Although the idea *typical growth* had not been specifically raised by the first group, by building on what Tessa had noticed about the plants, Mr. Gates was able to get students to consider an S-shaped growth curve as a way to describe typical growth.

Mr. Gates thanked Ryanne for her contribution, and then asked Peter from group 1 to explain his group's representation (shown in fig. 2.4). Peter explained that their group also chose to represent the height of each plant just like Ryanne's group, but they didn't make a graph. He explained that each pot represented a plant and that each of the stems in the pot represented the height the plant was on a certain day.



Mr. Gates asked the class what they noticed about group 1's graph. The following exchange unfolded:

Mitch: Um, well, it's hard to see the measurements and hard to compare the plants.

Mr. Gates: Okay, Mitch says that it is hard to see the measurements and difficult to compare the plants with this representation. Does anyone else agree?

Students: Yes!

Mr. Gates: Okay, Marie, you said yes, what makes this representation difficult for you to understand?

Marie: I think the pots and the leaves and the plants make it really confusing. The days aren't in order and I don't think the stems in the pots are equal to the real pots. So it is hard to compare across pots. It is really unorganized.

Mitch: I agree. Ryanne's group's graph is easier to read. We can see stuff easily. You can see how tall each plant is each day they measured and you can compare the heights of the plants on the same day.

Mr. Gates: Okay, Mitch says we can see stuff easily in the graph. What does that tell us about representing scientific data?

Peter: I guess graphing our data would have made it easier for everyone else to see. And, they would have an easier time making comparisons from one day to the next. But it's pretty the way we did it! And you can see other stuff like when we got flowers.

Mr. Gates: Okay, Peter, great points. You were showing more information than just height because you drew the flowers in, too. And, it might be very easy for you to see and understand your own data in a representation like this, but it can be difficult for others to interpret. This very idea is why in science it is important to use standard representations, like a line graph or even a bar graph, to represent data. It allows us to easily see and interpret the data, especially when it is data that we didn't collect.

Mr. Gates then commented that several groups, including groups 1 and 7, graphed all their data. He indicated that graphing all the data is a great way to represent all the information but that if there were a lot of data it might become confusing. He then explained that some groups chose to represent their data a little differently. He called on Tristan to explain the representation produced by group 8 (shown in fig. 2.5).

Tristan explained that they thought it would be easier to take the average of all six plants in order to get the "typical" growth. So, they figured the mean plant height for each day and created a bar graph to show the means. Tristan said that for day 10 the average plant height was 10.32 cm and the mean increases from there.

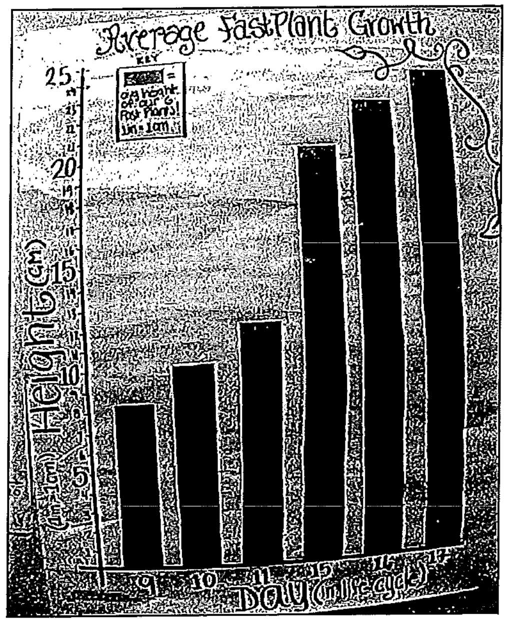


Fig. 2.5. The bar graph from group 8

Mr. Gates thanked Tristan for his explanation. He then asked for a volunteer to explain what the mean is and how group 8 found it. NeeNee explained that you find the mean by adding the heights for all the plants and dividing that number by the total number of plants. Mr. Gates then asked if someone could explain what the mean tells us. Allison volunteered, "The mean tells you the average height of the plants. Like, on that day the plants can be expected to be around that number. You use the actual data and calculate the mean." The discussion then continued:

Mr. Gates: Thank you, Allison. Did everyone hear her? She said that mean is a measure that is calculated based on the raw data. Now, what do you think might happen to group 8's data if on day 10, one plant started to grow really fast and was much taller than any other plant?

Phaedra: So, what happens if there is a really tall plant in the pots compared to all the others?

Mr. Gates: Yes, what might happen to the mean if there happened to be a really tall plant compared to all the other plants? Would the mean be any different?

Phaedra: Well, with even just one really tall height, you would have a bigger sum when you add all the heights together, so the mean would be bigger, too.

Mr. Gates: Let's think about what Phaedra just said. She said if one of the plants were much taller than the rest, the mean would increase. How do you feel about this idea, Mikhail?

Mikhail: Well, it makes sense that having a larger number increases the mean. If one of the numbers changed from 9 to 29, that's a 20-cm difference. That's huge. The mean would definitely be bigger.

Karen: Yeah, but if you had a really tall plant, then it might not look like the rest of them. The mean might not tell you what a typical plant looks like.

Tristan: You mean using the mean might not tell you what a typical plant looks like?

Karen: Yeah.

Mr. Gates: Okay, so if we had a really tall plant, or even a plant that is really short, that would influence the mean. When we have data that are really different from the other data we call them outliers. Outliers can distort the mean.

Patrice: So are you saying that the mean is not a good thing to use if we want to describe a typical plant?

Mr. Gates indicated that Patrice has asked a really important question—how do you describe a *typical* plant? He explained that the mean provides valuable information but that you just have to be aware of the outliers. He asked Katie from group 2 to explain what they did. Katie said, "We were worried about the fact that we had one plant that was really tall and one that was really short and the other four were very close together. So we just graphed the four that were close together and thought that any one of them could be considered typical."

Mr. Gates said that group 5 used an approach that used all the data but tried to deal directly with the issue of typicality. He called on Bri from group 5 to explain their representation (shown in fig. 2.6). Bri explained that her group thought it might be important to show the variation in height among the plants for each day measured and to show where the median height was on each day, and so they decided to make a box-and-whiskers plot. Mr. Gates asked Bri to explain the plot and her group's thinking behind it. Bri explained that if they wanted to know what is typical for a Fast Plant on day 14, for example, she could tell them that the heights ranged from 12 to 26 cm, that the median was 19 cm, and that 50 percent of the plants had heights between 16 and 24 cm.

Mr. Gates commented that showing a range of data could be very helpful in describing typical growth. He explained that because every organism, every plant, is different, heights and growth vary, but there is an expected height that we can see for each day. In other words, he explained, we can expect that most Fast Plants would fall within a certain range of heights in their growth cycle.

Mr. Gates asked the students what Bri and her group needed to do in order to convert their data into a box-and-whiskers plot, because he wanted to make sure they understood both how to create the plot and how to read it. Students discussed ordering the data for each time point, finding the low and high values (the whiskers), and determining the median, as well as the values that separated the top quarter and bottom quarter (edges of the box).

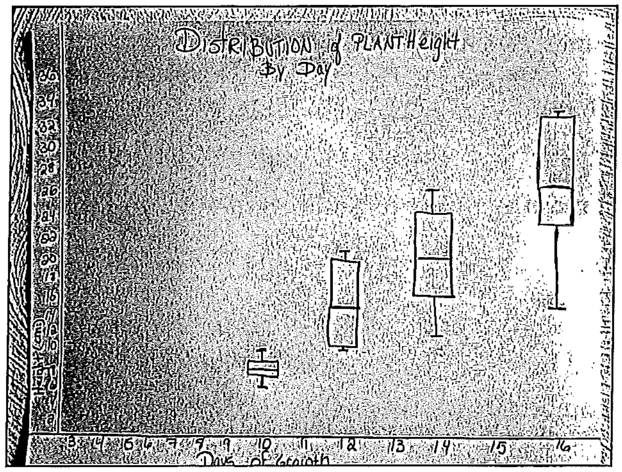


Fig. 2.6. The box-and-whiskers diagram from group 5

With only a few minutes left in the class, Mr. Gates told students that for homework he wanted them to answer the question "How can you account for the S-shaped growth curve?" In other words, why might these plants typically grow in this way? He told students that he expected a written answer to the question and a rationale for their conclusions. He decided to use this question to launch a discussion in the next class, and hopefully make progress on learning goals 2 and 3.

Analyzing the Case of Nathan Gates

Although we could identify many aspects of the instruction in Mr. Gates's classroom that may have contributed to his students' opportunities to learn, we will focus our attention specifically on his use of the five practices. In subsequent chapters, we will analyze a broader set of actions that, in combination with the five practices, help account for the success of the lesson. We will begin by considering the five practices and whether there is evidence that Mr. Gates engaged in some or all of them. Then we will consider how his use of the practices may have enhanced his students' opportunities to learn.

Evidence of the Five Practices

As we indicated in chapter 1, determining clear and specific goals for the lesson and selecting a task that aligns with the goals are the foundation on which the five practices are built. Hence, Mr. Gates's identification of the three scientific ideas that he wanted his students to learn (lines 6–19) and his selection of a task that had the potential to reach these goals (lines 31–37) positioned him to use the Five Practices model effectively.

Anticipating

Because the vignette focuses primarily on what happened *during* a classroom episode, we have limited insight into the planning Mr. Gates engaged in prior to the lesson and the extent to which he anticipated specific solutions to the task. However, the fact that he wanted students to know that the typical Fast Plant growth is described by shape and range suggests that he had considered the possibilities for representing the data that would highlight both of these attributes—namely, line graphs and box-and-whiskers plots, respectively. In addition, Mr. Gates's decision to begin the next class with a discussion of student responses to the question "How do you account for the S-shaped curve?" (lines 235–37) suggests that he considered how particular representations (such as line graphs) would help in accomplishing this goal for the lesson.

Monitoring

Mr. Gates monitored students working in their small groups (lines 46–59). Through this monitoring he was able to determine the approaches that specific groups were using (lines 46–48; 52–57), ask questions to help students make progress on the task (lines 48–51), and recognize that the representation used by group 1 was difficult to interpret (lines 57–59). His monitoring of the students' work provided information about their thinking that he needed in order to make decisions about which representations to focus on during the discussion.

Selecting

By referring to notes he had made during the monitoring process (lines 61–77), Mr. Gates knew which groups had produced specific representations. Armed with this information, he decided to have particular groups (7, 1, 8, and 5) present posters that would highlight different information about the plants, thus providing grist for the discussion of what needs to be considered in determining what is typical (lines 78–83). In addition, he decided that he wanted students to consider the representation produced by group 1 (see fig. 2.4) so that they could see that some representations made it challenging to identify patterns and correlations in the data.

Sequencing

Mr. Gates selected Ryanne from group 7 as the first presenter, since the representation produced by her group (line graph) had been used by several groups and therefore was likely to be one to which other students in the class could readily relate (lines 84–86). In addition, he wanted to give Ryanne a chance to participate actively and publicly in class (lines 86–89) as it had been several days since she had done so. By selecting Ryanne, Mr. Gates was able to both highlight a popular strategy and make sure he was providing his students with equitable opportunities to demonstrate competence.

While Mr. Gates doesn't explain precisely why he chose to have groups 1, 8, and 5 present their posters in that order, we might infer his intent from the way the discussion unfolded. Specifically, he started with a graph (fig. 2.3) that was similar to ones produced by other students in the class. This graph portrayed all the data that had been collected, allowed for comparisons across plants, and showed the shape of the curves (an important feature in explaining how the plants use their resources over their life cycle). He next selected a representation that also used all the data but that made any type of comparison challenging. This highlighted for students the need to use standard representations (lines 156–161).

Mr. Gates then asked group 8 to present. The graph produced by this group (fig. 2.5) was different from the others in that it featured only the average height of the six plants at each measurement point rather than all of the data. This provided an opportunity to talk about the mean, how outliers might affect the mean, and how the mean might not be the best measure of what is typical (lines 173–207). Mr. Gates concluded the presentations with a discussion of the poster created by group 5 (fig. 2.6). This poster had some of the features of those presented earlier—it used a measure of central tendency (like group 8), and it showed the range of values (like group 7)—but also some important differences. First, the group used the median as a measure of "average" instead of the mean. Since outliers do not affect the median, this value separates the data into the top and bottom 50 percent. In addition, the low and high values are included so the range of data can be easily determined. The representation also made clear where most of the data fell—between the top and bottom edges of the box. Hence, Mr. Gates was able to make the point that showing a range of data can be helpful in describing typical growth (lines 224–28). He may have decided to end the discussion with this poster because it brought together several ideas that had been discussed in earlier posters and that were important to understanding the growth of Fast Plants, and it was a more sophisticated strategy that might not have been accessible to all groups without first analyzing simpler graphs.

Connecting

Through the questions that Mr. Gates asked during the discussion and the ways in which he pressed students to clarify what they had done and why, he helped students make connections with the scientific ideas that were the target of his instruction. Specifically, Mr. Gates indicated that he wanted his students to understand three scientific ideas: (1) Typical growth in Fast Plants is described by range and shape; (2) Fast Plant growth is characterized by an S-shaped growth curve, where stem length increases slowly for the first ten to twelve days and then increases quite steeply for about seven more days; and (3) The growth patterns of Fast Plants can be explained by considering where the plant is "spending" its energy resources at various stages of its life cycle and how that is advantageous.

Mr. Gates pressed students to "see" if they could describe the phenomena that was articulated by Tessa (lines 112–13), which resulted in the identification of the basic S shape and the realization that the same persisted regardless of the height of the plant. In addition, through the analysis of several graphs, Mr. Gates was able to highlight the point that Bri made in describing group 5's poster: Showing a range of data is important (lines 224–25). By questioning students about the carefully sequenced work he was able to help them understand two key ideas (learning goals 1 and 2) that were targets for the lesson. While no progress was made on goal 3 during the course of this one lesson, the assigned homework was intended to serve as a launching point of this conversation the following day.

Mr. Gates did not make explicit connections among the student graphs in the lesson. However, during the discussion of group 1's poster, Mitch spontaneously referred to group 7's graph, commenting that it was easier to read (lines 146–48), and Peter added more specificity to the discussion by indication that group 7's poster made it easier to make comparisons (lines 151–54).

Relating the Practices to Learning Opportunities

Did Mr. Gates's use of the five practices contribute to his students' learning? Although we have no direct evidence of what individuals in the class learned, we see a group of students who appear to be engaged in the learning process. Over the course of the lesson, the teacher involved fifteen different students (half of the students in the class) in substantive ways. Mr. Gates repeatedly targeted key ideas related to the goals of the lessons as he guided his class in discussing four different representations in some depth. The final question that he gave for homework (lines 235–37) provided individual students with an opportunity to make sense of what had transpired during class and to make connections that would provide the teacher with insight into their thinking.

The Five Practices model gave Mr. Gates a systematic approach to thinking through what his students might do with the task and how he could use their thinking to accomplish the goals that he had set. Although we analyzed the practices in action—what the teacher did during the lesson—we argue that to do what he did during the lesson, he must have thought it all through *before* the lesson began. We will explore how to engage in such planning in subsequent chapters.

The Science Practices in the Case of Nathan Gates

On page 1 in the introduction (fig. 0.1), we listed the eight Science Practices set forth in the Next Generation Science Standards (NGSS) (Achieve, Inc. 2013). Here, we analyze the opportunities Mr. Gates's students had to productively engage in many of these science practices. As the lesson began, students had an opportunity to plan and carry out an investigation (SP 3) as they measured the growth of their Fast Plants (lines 32–34). During their investigations, students collected and represented data on plant height (lines 34–41). As students constructed their representations, they interpreted and analyzed their data (SP 4) in various ways, including using measures of central tendency (lines 52–54). Additionally, Mr. Gates asked the students to construct an explanation (SP 6) detailing how their representation answered the question that guided the investigation (lines (48–51). In designing the task in this way, Mr. Gates provided students with an opportunity to use mathematics and engage in computational thinking (SP 5) as they described the growth of a typical Fast Plant.

Once the whole-class discussion began, we saw students asking questions (SP 1) about typicality and how outliers affect the mean stem length (lines 185–86, 199, 204–5). Furthermore, as each student communicated his/her group's findings (lines 90–96, 130–34, 168–73, 216–32), Mr. Gates prompted students to critically examine and evaluate the work of their classmates (SP 8). Finally, the homework Mr. Gates assigned gave students an opportunity to use what they learned during the task and whole-class discussion to construct an explanation (SP 6) about the Fast Plants' growth based on the S-shaped curve (lines 235–37).

The way in which Mr. Gates selected, designed, and implemented the Fast Plants task provided multiple opportunities for students to engage in the NGSS Science Practices. In doing so, students talked productively with one another about the science content, which focuses on the NGSS disciplinary core ideas MS-LS1.B (Growth and Development of Organisms) and MS-LS1.C (Organization for Matter and Energy Flow in Organisms) (Achieve, Inc. 2013) through a detailed analysis of their data and variety of representations.

Conclusion

Mr. Gates avoided a show-and-tell session in which solutions are presented in succession without much rhyme or reason, often obscuring the point of the lesson. By carefully considering the story line of his lesson—what he wanted to accomplish and how different representations would help him get there—he was able to skillfully question his students and position them to make key points. So, with the lesson always firmly under his control, the teacher was able to build on the work produced by students, carefully guiding them in a sound direction.

The Case of Kelly Davis discussed in the beginning of this chapter provides a contrast to Mr. Gates's instructional approach. Although the students in Ms. Davis's class used a range of interesting approaches, what the students were supposed to learn from the sequence of presentations was not clear, other than that "the data can be represented in many different ways." The students took with them no clear understanding about science concepts and ideas from this experience.

The five practices build on each other, working in concert to support the orchestration of a productive discussion. It is the information gained from engaging in one practice that positions the teacher to engage in the subsequent practice. For example, a teacher cannot select responses to share in the whole-class discussion if she or he is not aware of what students have produced (the teacher needs to monitor to be able to select and sequence). And a teacher can't make connections across strategies and to the goal of the lesson if she or he has not first selected and sequenced strategies in a way that will help advance the storyline of the lesson. In the next two chapters we explore the five practices in more depth, building on the descriptions provided in this chapter.