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
7^{th} 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
3^{rd} 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

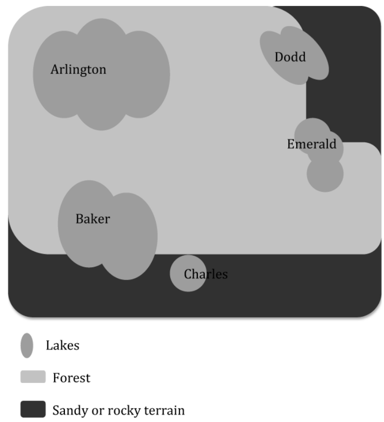
Context

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.

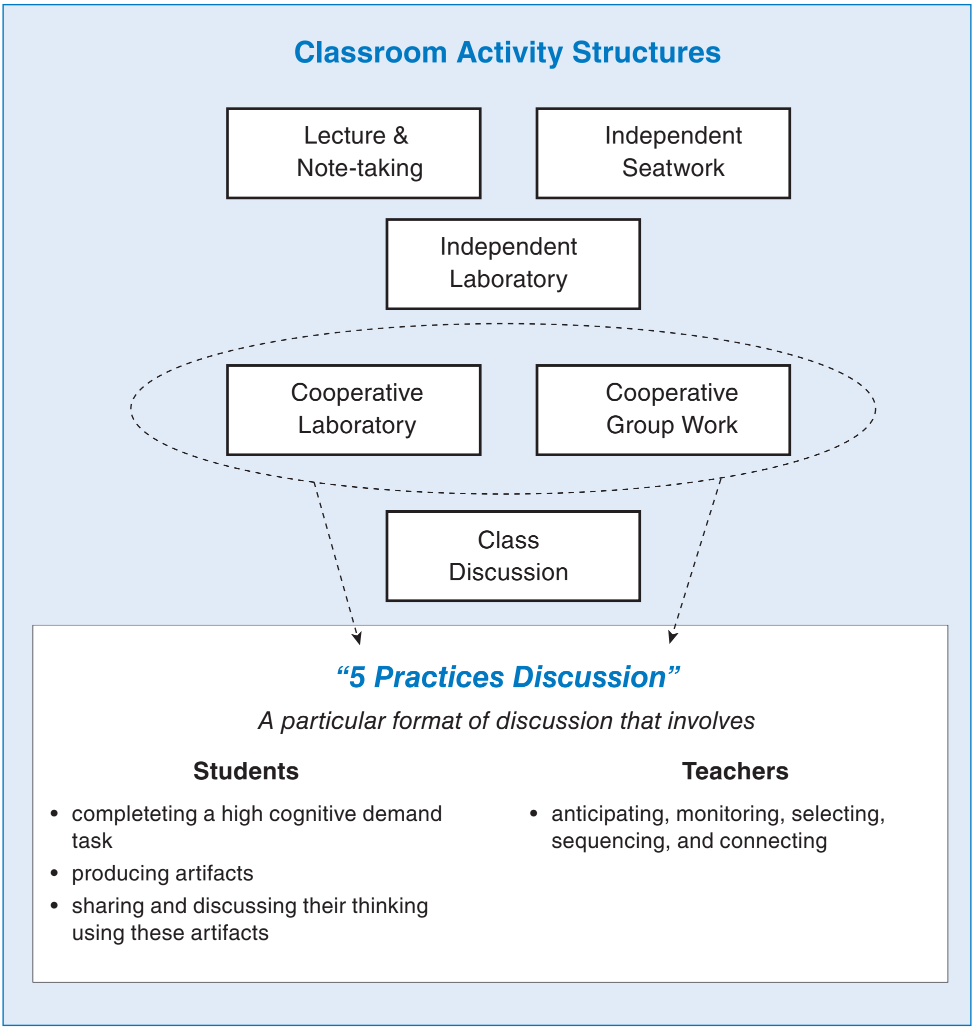


Fig. 1.6. An assortment of common classroom activity structures. Cooperative group activities (including laboratory tasks) are the ones most likely to support productive whole-class discussion.

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

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