PROBLEM-BASED LEARNING IN THE EARTH AND SPACE SCIENCE CLASSROOM

K–12

TOM J. MCCONNELL
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NSTA press
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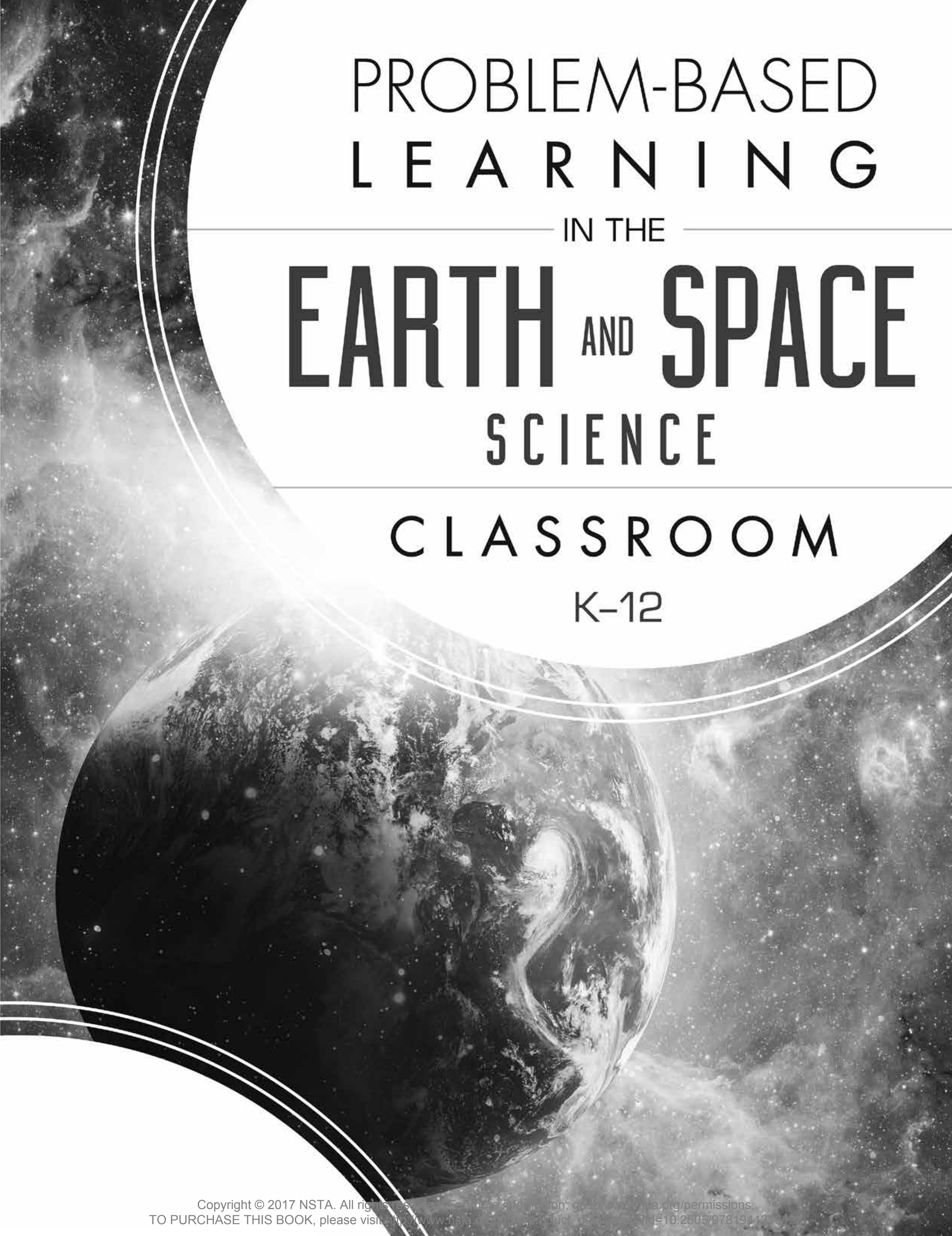

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PREFACE

In science education, there are numerous strategies designed to promote learners' ability to apply science understanding to authentic situations and build connections between concepts (Bybee, Powell, and Trowbridge 2008). Problem-based learning (PBL) (Delisle 1997; Gijbels et al. 2005; Torp and Sage 2002) is one of these strategies. PBL originated as a teaching model in medical schools (Barrows 1986; Schmidt 1983) and is relevant for a wide variety of subjects. Science education, in particular, lends itself to the PBL structure because of the many authentic problems that reflect concepts included in state science standards and the *Next Generation Science Standards* (*NGSS*; NGSS Lead States 2013).

The Problem-Based Learning Framework

PBL is a teaching strategy built on a constructivist epistemology (Savery and Duffy 1995) that presents learners with authentic and rich, but incompletely defined, scenarios. These "problems" represent science as it appears in the real world, giving learners a reason to collaborate with others to analyze the problem, ask questions, pose hypotheses, identify information needed to solve the problem, and find information through literature searches and scientific investigations. The analysis process leads the learners to co-construct a proposed solution (Torp and Sage 2002).

One of the strengths of the PBL framework is that learners are active drivers of the learning process and can develop a deeper understanding of the concepts related to the problem starting from many different levels of prior understanding. PBL is an effective strategy for both novices and advanced learners. PBL is also flexible enough to be useful in nearly any science context.

One of the challenges for teachers and educational planners, though, is that implementing PBL for the classroom requires advance planning. An effective problem should be authentic, and the challenges presented in the problems need to be both structured and ill-defined to allow genuine and productive exploration by students. Dan Meyer (2010) suggested that these problems help students learn to be "patient problem solvers." For most instructors, getting started with PBL in the science classroom is easiest with existing problems. However, there are very few tested PBL problems available in print or on the internet. Valuable resources exist that describe in general what PBL is, how to develop lessons, and how PBL can help students, but curriculum resources are much harder to find.

In this book, we present a discussion of the PBL structure and its application for the K–12 science classroom. We also share a collection of PBL problems developed as part of the

Problem-Based Learning Project for Teachers (PBL Project), a National Science Foundation–funded professional development program that used the PBL framework to help teachers develop a deeper understanding of science concepts in eight different content strands (McConnell et al. 2008; McConnell, Parker, and Eberhardt 2013). Each content strand had a group of participants and facilitators who focused on specific concepts within one of the science disciplines, such as genetics, weather, or force and motion. The problems presented in this book were developed by content experts who facilitated the workshops and revised the problems over the course of four iterations of the workshops. Through our work to test and revise the problems, we have developed a structure for the written problem that we feel will help educators implement the plans in classrooms.

Because the problems have been tested with teachers, we have published research describing the effectiveness of the problems in influencing teachers' science content knowledge (McConnell, Parker, and Eberhardt 2013). The research revealed that individuals with very little familiarity with science concepts can learn new ideas using the PBL structure and that the same problem can also help experienced science learners with a high degree of prior knowledge to refine their understanding and learn to better explain the mechanisms for scientific phenomena.

Alignment With the *Next Generation Science Standards*

To ensure that the problems presented here are useful to science teachers, we have included information aligning the objectives and learning outcomes for each problem with the *NGSS* (NGSS Lead States 2013). The *NGSS* present performance expectations for science education that describe three intertwined dimensions of science learning: science and engineering practices (SEPs), disciplinary core ideas (DCIs), and crosscutting concepts (CCs). The *NGSS* emphasize learning outcomes in which students integrate the SEPs, DCIs, and the CCs in a seamless way, resulting in flexible and widely applicable understanding.

The learning targets for the PBL problems included in this book were originally written with attention to the science concepts—what the *NGSS* call DCIs. The aim of the PBL Project was to enhance teachers' knowledge of these core ideas. But implicit in the design of the PBL process is the need for learners to use the practices of science and make connections between concepts that reflect the CCs listed in the standards. PBL problems align well with the *NGSS* because these real-world situations present problems in a similar framework: SEPs, DCIs, and CCs are natural parts of the problems. We describe the alignment of the PBL problems with the *NGSS* in more detail in Chapter 2. As states begin to adopt these standards or adapt them into state standards, Chapter 2 should help teachers and teacher educators fit the problems within their local curricula.

Intended Audiences and Organization of the Book

As mentioned earlier, the PBL problems in this book have been shown to be effective learning tools for learners with differing levels of prior knowledge. Some of the teachers who participated in the PBL Project used problems from the workshops in their K–12 classrooms, and facilitators with the project have also incorporated problems from this collection into university courses.

Chapter 2 discusses the alignment of the PBL problems and analytical framework with the *NGSS*. Chapter 3 describes strategies for facilitating the PBL lessons. In Chapter 4, we share tips for the classroom teacher on grouping students, managing information, and assessing student learning during the PBL process.

Chapters 5–8 present the problems we have designed and tested. Each chapter includes problems from one content strand (Earth's landforms and water, rock cycle and plate tectonics, weather, or astronomy), alignment with the *NGSS*, the assessment questions we used to evaluate learning, model responses to the assessments, and resources for the teacher and students that help provide relevant information about the science concept and problem. To help you locate the problems that are most appropriate for your classroom, we have included a catalog of problems (see p. xi); the catalog is in tabular format and will let you scan the list of problems by content topic, keywords and concepts, and grade bands for which the problems were written.

We hope that this collection of problems will serve as a model for educators who want to design and develop problems of their own. For instance, there are problems included in this book that relate to the local landforms and examples that reflect contexts relevant to Michigan, where the PBL Project was located. A teacher in a place that does not share similar conditions may find that his or her students cannot relate to the scenario described in the problem. In these cases, we encourage teachers to modify and adapt problems to fit contexts familiar to their own students. Chapter 9 discusses features of an effective problem that can help guide the efforts of teachers wishing to create their own PBL lessons. As you modify and implement lessons from these books, you can begin to develop your own problems that meet the needs of your students.

This book is the second volume in a series; the first volume presented life science problems. We present Earth and space science problems in this volume, and we will offer problems specifically written for teaching physics in the next volume to be published. The fourth volume will contain tips and examples for planners of teacher professional development programs.

Safe and Ethical Practices in the Science Classroom

With hands-on, process- and inquiry-based laboratory or field activities, the teaching and learning of science today can be both effective and exciting. Successful science teaching needs to address potential safety issues. Throughout this book, safety precautions are described for investigations and need to be adopted and enforced in efforts to provide for a safer learning and teaching experience.

Additional applicable standard operating procedures can be found in the National Science Teachers Association's Safety in the Science Classroom, Laboratory, or Field Sites document (*www.nsta.org/docs/SafetyInTheScienceClassroomLabAndField.pdf*).

Disclaimer: The safety precautions of each activity are based in part on use of the recommended materials and instructions, legal safety standards, and better professional practices. Selection of alternative materials or procedures for these activities may jeopardize the level of safety and therefore is at the user's own risk.

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CATALOG OF PROBLEMS

Problem	Page Number	Keywords and Concepts	Grade Band			
			Grades K–2	Grades 3–5	Grades 6–8	Grades 9–12
CHAPTER 5: EARTH'S LANDFORMS AND WATER						
1. An Eagle's View	70	Landforms, geologic forces, plate tectonics		•	•	
2. Diving With Dolphino	80	Landforms, geologic forces, plate tectonics	•	•	•	
3. Water, Water Everywhere	90	Water cycle, erosion, gravity, heating and cooling	•	•	•	
CHAPTER 6: ROCK CYCLE AND PLATE TECTONICS						
1. Keweenaw Rocks	108	Rock cycle, formation of rocks, plate tectonics, divergent margin, rift zone			•	•
2. Lassen's Lessons	118	Rocks as evidence of past events, plate tectonics, convergent boundary, subduction zone, metamorphic rocks			•	•
3. San Andreas	129	Plate tectonics, transform boundary, subduction zone, strike-slip fault			•	•
CHAPTER 7: WEATHER						
1. Northern Lights	148	Seasons, motion of Earth around the Sun	•	•		
2. Water So Old	159	Water cycle	•		•	
3. Leave It to the Masses	172	Air masses, weather, and weather forecasting			•	
CHAPTER 8: ASTRONOMY						
1. E.T. the Extra-Terrestrial	191	Moon phases			•	
2. Obsidian Sun	201	Solar eclipse			•	
3. Copper Moon	210	Lunar eclipse			•	
4. Morning Star, Evening Star	218	Movement of planets relative to Earth			•	

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3

FACILITATING PROBLEM-BASED LEARNING

The experience of being the teacher in a science classroom during a problem-based learning (PBL) activity is a bit different from what you might experience for other types of lessons. In some learning activities, your role is that of content expert or presenter of information. The students might be involved in recording information, listening, or perhaps applying new ideas. Alternatively, students might be carrying out some kind of science investigation as you direct and guide with questions. These roles are certainly appropriate, but PBL requires something different.

In PBL, the teacher definitely steps away from the lead role and instead becomes a *facilitator.* Educators use this term a lot in teaching, but for our model of PBL, we believe this role is accentuated. The facilitator's role is to provide minimal information but to provide resources and ask questions to guide the process. The students become more active participants in the discussion and even take the lead in identifying next steps and issues that need to be explored.

These new roles take practice—for both teacher and students. Students need to take risks in sharing and defending their ideas using information and evidence. Your role requires skillful questioning to guide without leading, and just as important, the ability to say nothing and let students explore their own ideas to find their misconceptions. In this chapter, we will use a vignette format to provide examples of what you might see in a classroom in which PBL is being taught, with a focus on how the teacher can guide discussions during the lesson. We will also share tips and strategies for successful facilitation of a PBL lesson; additional tips are provided in Chapter 4, "Using Problems in K–12 Classrooms." Some of what we share in this chapter is the result of our research on effective facilitation of PBL (Zhang et al. 2010), and some is based on our personal experience and teaching styles.

Remember, as you implement the lessons you select from this book, you may find that you need to practice your role as a PBL facilitator, and it takes time and practice to learn how to respond to students' ideas on the fly.

Moves to Make as You Go Along: Stage-Specific Advice

Facilitating PBL problems feels very different from traditional teaching and may require some strategies that are not part of your normal routine. Throughout this chapter, we will offer some "moves" you can plan to make. These are deliberate tactics to help your students think and talk about the problem they are analyzing, and the tips help you move into facilitator mode. It can be hard to remember that your role has shifted. You need to hold in some of your expertise and let your students struggle a bit with the challenges of solving a real problem. It is hard to do this, because you want to help them, but in the long run, stepping into the role of facilitator will help your students gain confidence and skills they need to think critically. And that's an important goal!

At the same time, there are times when the teacher needs to share his or her knowledge of the concept. This may mean giving some examples of phenomena that demonstrate a process or explaining how certain ideas are connected. The teacher also may need to ask questions to informally assess students' understanding or clarify what a student means by a comment or question. These moves are important in facilitating students' analysis of a PBL problem and in helping students make sense of the information they are finding. Part of the art of facilitation is learning when to use your content knowledge and when to hold back and let students explore an idea. For the beginning facilitator, we recommend patience: If in doubt, let students work for a bit, and then share your expertise.

Explaining Discussion Guidelines

Because you and your students may be experiencing PBL for the first time, it is important to set some guidelines for a PBL lesson. Discussion about real-world problems may reveal some strong opinions, some misconceptions, and some differences in beliefs and values that may be difficult for younger learners to understand. Before you start a PBL lesson, at least until your students learn to operate in this new type of lesson, setting some guidelines will help you manage the discussion and keep the conversation on task and respectful.

In the first section of the vignette, Ms. Sampson shows the class a list of guidelines for discussing PBL problems. These guidelines are useful in creating a climate in which participants are able to share ideas, pose questions, and propose hypotheses. They may also help to create a culture of open discussion in your classroom. Throughout the vignette in this chapter, we have tried to indicate how the science and engineering practices (SEPs) and the crosscutting concepts (CCs) from the *Next Generation Science Standards* (*NGSS;* NGSS Lead States 2013) appear in this lesson. See Chapter 2, "Alignment With Standards," for a complete list of the SEPs and CCs.

Ms. Sampson's Science Classroom: Discussion Guidelines

Ms. Sampson has been planning since the summer to try a new lesson idea. Today she's starting a PBL activity that she thinks will take about three days for her seventh-grade science class to complete. The topic is weather forecasting in her "Weather" unit, and today's activity follows some readings about weather and a video about the importance of weather forecasts.

Ms. Sampson: Class, today we're going to prepare you to make a weather forecast. As we work, you will take the role of a team of meteorologists, and you need to learn some information that will help you report the forecast on TV. We are going to use problem-based learning to look at this topic, so we need to set some discussion guidelines.

She projects a slide with the guidelines and discusses the list (see Box 3.1).

Box 3.1. Guidelines for Discussion

1. Open thinking is required—everyone contributes!
2. If you disagree, speak up! Silence is agreement.
3. Everyone speaks to the group—no side conversations.
4. There are no wrong ideas in a brainstorm—respect all ideas.
5. A scribe will record the group's thinking.
6. The facilitator/teacher will ask questions to clarify and keep the process going.
7. Support claims with evidence or a verifiable source.

Helping Students Function in a Self-Directed Classroom

This recap of discussion guidelines is important to help students start to manage their own learning. Although the PBL framework introduced in Chapter 1 is a good foundation for critical thinking, students may not have experience using a structured process for solving problems. In essence, we are making the metacognition needed to support learning more explicit (Bandura 1986; Dinsmore, Alexander, and Loughlin 2008) in a process that will help students develop the type of self-directed learning abilities we hope all our students can achieve.

The guidelines are important in helping students develop the habits of scientific discourse. A conversation in a scientific context is different from a conversation with friends about sports, music, politics, books, or other topics. So to help our students learn to function in a scientific community, or even just to understand the process behind scientific claims they might read about in an online news source, they need to know how we share and develop ideas in science.

At the same time, the guidelines are a reminder to the facilitator about his or her role in the discussion. As the facilitator, one of the most difficult tasks is avoiding the urge to give "right answers" to your students. But it is important for you to set an example by respecting new ideas or ideas you are uncertain about. Your role, especially at the beginning of a PBL problem, is to ask questions to clarify, to solicit responses from students who may be hesitant to share ideas, and to be the "referee" when the class rejects one student's ideas before any evidence has been discussed.

Recording Information

In the guidelines that Ms. Sampson shares, she mentions the "scribe." It is important to have a durable record of the ideas students generate. The written copy of the ideas students generate is also important as a "map" that students and the teacher can follow to see the development of their understanding. In a sense, posting the ideas as a list makes the learning "visible." The facilitator will use this list to make choices about guiding questions, information search strategies, and activities that can support the type of learning each particular class needs.

In some cases, you may wish to have a student serve as the scribe, but this may pull that student out of the conversation. It is difficult to create or share your own ideas when you're busy writing others' ideas on the board, and your students are probably not able to juggle those tasks. In our experience, it is best if you, the facilitator, can record students' statements, questions, and hypotheses on large sheets of paper, on the board or projected on the screen so all students can see the lists (see Figure 3.1).

TECHNOLOGY TIP

SMART boards (interactive whiteboards) and similar technology are a good option for recording group discussions! They allow you to record a "page" of notes, move to a new page, and return to previous notes when needed.

You can create areas in your recording space for each of the three categories of ideas in the PBL framework ("What do we know?" "What do we need to know?" "Hypotheses"), but we suggest you use large pieces of paper taped to the board or the wall. This will let you add pages as the students' list of ideas grows. You can make notations or cross off statements and hypotheses as the students find new information, but it is important to have those items to look back at during the process of working through the problem. Students can see how their understanding develops, question why they think an idea is true, and connect the evidence with their new understandings. The large pieces of paper or electronic files will also allow you to move back and forth between different sections, if you teach the subject more than once per day.

Figure 3.1. Recording Learners' Ideas in the PBL Framework

Launching the Problem

Once you have established discussion guidelines and procedures, it is time to launch the problem. For this stage, you can have students arranged in small groups, seated on the floor in a circle, seated in desks, or whatever arrangement works best for you.

In Chapters 5–8, each PBL problem begins with an overview that describes the key concepts of the problem and aligns the problem with the three dimensions of the *NGSS* (NGSS Lead States 2013). This alignment includes a table describing the SEPs, disciplinary core ideas, and CCs addressed in the lesson. Keywords and a context for the problem are also offered to help you identify the problems that are most appropriate for your curriculum.

Following the overview and alignment page, each problem includes the text for The Story arranged in two parts. Page 1 is the part of the story you will use to launch the activity. Most of the stories are short and can be printed on a half sheet of paper. In some cases, you might project the story on the screen, but we find that it is helpful to give each student or group a hard copy so they can refer to it as they work through the analytical framework. You may choose to print one copy per student or let pairs or small groups read from the same page.

Start by handing out the copies of Page 1, and ask your students to read the story quietly. You might need to make accommodations for English-language learners or special needs students. Once everyone has had time to read through the story, ask one person to read the story aloud. This may seem redundant, but it is actually a very important step. Our research has shown that groups that read both silently and aloud at the start of the story generate a significantly higher number of ideas, questions, and hypotheses than groups that only read the story silently. We posit that in the first reading, students are working to comprehend the story, and in the second reading, they begin forming their own ideas in their minds. The time to process the story and think quietly seems to be important in supporting the discussion in the group as they move forward. The vignette sections that follow provide examples of how this process looks in the classroom setting.

Ms. Sampson's Science Classroom: The Launch

Ms. Sampson: OK, class, today's PBL is called Leave It to the Masses. Here is Page 1. Please read this story quietly. I'll give you about two minutes.

She hands out Page 1 of the Leave It to the Masses problem. (See Chapter 7, p. 174, to read the story.) As her class reads, she tapes three large pieces of paper to the board, labels them "What do we know?" "What do we need to know?" and "Hypotheses," and gets her colored markers ready. After two minutes, she asks for a volunteer to read the story. David volunteers, stands, and reads the story aloud.

Ms. Sampson: Thanks for volunteering, David. Now that you've heard the story, let's look at our three categories on the board. What do we know about the story right now?

The class is quiet for a minute, but she notices the students look like they are thinking.

Andrea: We are going to have to explain four different weather maps on TV.

Ms. Sampson writes Andrea's comment on the "What do we know?" paper.

Ms. Sampson: OK, good. What are the four maps?

Andrea: Temperature, wind, Doppler radar, and a map with highs and lows marked.

Jamal: What is Doppler radar? I hear that a lot, but is that different from other radar?

Ms. Sampson: OK, "Doppler radar" goes under "What do we need to know?"

Marcus: The story says air masses take on the characteristics of the surface if they stay there for very long.

Mai: And the map with highs and lows … I'm not sure what the highs and lows are showing.

Ms. Sampson: Mai, I can add that to the "What do we need to know?" page, too. Good question!

David: Well, down here it says something about high pressure. Warmer air is less dense, so it has lower pressure than cooler air.

Ms. Sampson adds David's comment to the "What do we know?" list.

Carmela: There's also a definition of air mass. It's a body of air with similar temperature and moisture properties. I'm not sure what "body of air" means … doesn't it all mix?

Ms. Sampson: I can put that under "what we know," but do you want to put something about "body of air" under "need to know"?

Carmela: Yeah, that's a good place for that.

Ms. Sampson: Great! OK, let's keep going. What else do we know?

The class continues to add more ideas to the pages on the board.

Moves to Make: "Unpacking Ideas"

During a discussion in the three-column framework described earlier, students are very likely to bring up terms and concepts that need to be "unpacked." *Unpacking* is a term commonly used in education and business conversations, but it is not always clear what unpacking an idea entails. In essence, students are using one of the SEPs as they analyze and interpret the information they are given (SEP 4: Analyzing and Interpreting Data). Students also use this stage to define the problem (SEP 1: Asking Questions and Defining Problems).

Let's focus on an example from the preceding vignette section. Mai brings up an idea to include in the "What do we need to know?" column:

> **Mai:** And the map with highs and lows … I'm not sure what the highs and lows are showing.
>
> **Ms. Sampson:** Mai, I can add that to the "What do we need to know?" page, too. Good question!

The concept of "highs and lows" is certainly important to the problem about forecasting weather. But it is clear from Mai's question that not all the students in the class are familiar with it or know why it is relevant to weather forecasting. Ms. Sampson steers this comment to the "What do we need to know?" list and moves on.

It may be easy to imagine a discussion of highs and lows later in the lesson, but another useful strategy would be to "unpack" the concept right away. This can be done with questions that draw on what the students know about it already. These questions could be asked during the initial discussion, or they could wait until the class starts to explore the "What do we need to know?" list in more detail. But there are a couple of different ways to handle the discussion unpacking the concept.

Let's compare a "teacher as expert" approach with a "teacher as facilitator" approach (see Table 3.1, p. 24). In the "expert" role, the teacher shares what she knows, and the students become passive recipients. In the "facilitator" example, Ms. Sampson pulls information from the students, and the students' role shifts to either the expert or the problem solver who recognizes the need to find information. In the latter example, the students are active learners and consumers of ideas, a role we want students to master.

In the facilitator example, the students get much of the same information, but they have either discovered or remembered the information on their own and in their own words. The students have begun to develop some independence in learning and are practicing the skills used by proficient problem solvers. Independent learners can do more than just recall and repeat ideas. They synthesize ideas from information they are given or collect themselves (SEP 4: Analyzing and Interpreting Data). To demonstrate deep

Table 3.1. Comparison of "Teacher as Expert" Approach With "Teacher as Facilitator" Approach

TEACHER AS EXPERT	TEACHER AS FACILITATOR
Mai: And the map with highs and lows … I'm not sure what the highs and lows are showing. **Ms. Sampson:** The highs and lows are areas where there is either high or low barometric pressure. **Denise:** How can some areas have different pressures? Won't they all mix? **Ms. Sampson:** Well, each air mass has its own characteristics. Some have cool and dry air, and that means they have high pressure. Areas with warmer, wetter air have lower pressure. **Mai:** How do they end up so different? **Ms. Sampson:** That's because of the uneven heating of Earth's surface. Here, let's take a look at a diagram to explain that.	**Mai:** And the map with highs and lows … I'm not sure what the highs and lows are showing. **Ms. Sampson:** Mai, I can add that to the "What do we need to know?" page. Good question! Does anyone else have more information about that? **David:** Well, down here it says something about high pressure. Warmer air is less dense, so it has lower pressure than cooler air. **Denise:** And dry air is denser than wet air. **Ms. Sampson:** OK, so it sounds like we're talking about high and low pressure, right? What else do you know about high- and low-pressure air? **Steven:** Hey, when there is a low coming toward us, they usually say it's going to rain or storm. **Marcus:** Yeah, those are the Hs and Ls on the weather map. But I'm not sure how air can have different pressures in different areas. Or even wetness or temperature. Won't the air all mix? **Denise:** Well, there's this other part of the story that I think is important here. It says that if an air mass stays in an area for long, it takes on the characteristics of the surface below. So I'm guessing if air is over a desert, it gets hot and dry. If it's over a big lake, it gets wetter. And it sounds like that tells what the pressure will be. **Mai:** Oh, so is that why we always get more rain and snow next to Lake Michigan? Does the air get wetter there?

understanding, students should be able to synthesize information by connecting ideas in the context of a real problem instead of repeating bits of disconnected facts. In the expert example, Ms. Sampson is hinting toward the concept of high- and low-pressure air masses, but we cannot tell if students are building their own understanding of the concept and the problem.

Generating Hypotheses

As students work through the analytical discussion of Page 1, they are likely to state ideas that reach beyond "What do we know?" and "What do we need to know?" In the next section of the vignette, watch for the comment that suggests an inference. Sometimes these are subtle, but as the facilitator, you can point out the step the student has made and suggest adding this new idea to the list of "Hypotheses."

As a facilitator, you will need to pay attention to the questions students ask during the discussion. One common pattern is that learners will present an idea as a question when they have some uncertainty about the statement. A student may suggest a question to add to the "What do we need to know?" list, but the question is actually a tentatively worded hypothesis. Let's look at an example of this.

Ms. Sampson's Science Classroom: Generating Hypotheses

Ms. Sampson: OK, class, you've cleared up some ideas about air masses, so let's keep working. Any other things we need to learn about or ideas about this problem we should add?

Angie: I have a "need to know" thing. Can we use temperature and air pressure to predict when a storm is going to happen? I think we can, but I'm not sure.

Ms. Sampson: Good question, Angie, but I think I hear a hypothesis in that statement. You're asking if temperature and pressure are good predictors, but if we reword that, can we make this a hypothesis?

Angie: I'm not sure if I'm right, though. I'm not sure this is a good hypothesis.

Ms. Sampson: But that's OK, Angie! Remember, a hypothesis is a proposed answer to a question that can be tested, and if the evidence eventually shows that it's not correct, that's alright! So do you want to try to build a hypothesis from your question?

Angie: I guess so. I'm not sure how to start it, though. "I predict that temperature and air pressure are the …" Is that the way to state it?

Carlos: Shouldn't we use the same kinds of words we use in other labs? "*If, then,* and *because*?"

Ms. Sampson: That's what we use when we're going to change a variable and see what the result is, Carlos, but that's a start. Who remembers what we use when we're observing events instead of changing a variable?

Alyssa: Isn't that when we use the "I think that …" kind of hypothesis?

Ms. Sampson: Yes, that's right, Alyssa! So, Angie, use that as a start. "I think that …"

Angie: OK. "I think that temperature and air pressure are the best data for predicting when a storm is going to happen."

Joseph: It needs a "because" statement.

Ms. Sampson: Yeah, what would be the "because" part?

Angie: Because it usually gets colder before a storm, and the weatherman said the air pressure drops before a storm.

Ms. Sampson: Good! That's our first hypothesis. Can you tell me more about what's going on with temperatures?

Andrea: OK, so a warm air mass moving over cold air creates a thunderstorm?

David: No, that's not what happens. I don't think that's right.

Ms. Sampson: Remember, we're making hypotheses. We need evidence before we can reject a hypothesis, so I think we need to include it on the "Hypotheses" page.

Carlos: I have a different hypothesis. I believe the best way to predict a storm is to look at wind speeds and air pressure. And colder air is denser than warm air, so I don't think cooler air means a low-pressure area is coming.

Ms. Sampson: You need to put it in hypothesis form, too!

Carlos: How about this? "I believe wind speed and air pressure are the best ways to predict a storm, because the air pressure drops and the winds pick up right before a storm."

In this example, a student initiated the first hypothesis, but it began as a "What do we need to know?" question. Note the way that Ms. Sampson directed the discussion toward the "Hypotheses" column in the analytical discussion and pointed out that Angie's question seemed to include a hypothesis. This is a very common pattern in the discussion of Page 1 with most problems, and you need to watch and listen for those types of questions. One cue is to look for a "because" statement in the question. For instance, if a student says, "I want to know if wind speed predicts storms, because it always seems to get windy just before it storms," this suggests a hypothesis. The "because" indicates a connection between cause and effect (CC 2: Cause and Effect: Mechanism and Explanation) or a rationale for a possible solution to the problem. (SEP 6: Constructing Explanations and Designing Solutions). The teacher could easily leave the question worded as it is, but it helps to move it to the "Hypotheses" column. Students can then "test" the hypothesis as they do information searches later in the lesson.

The strategy Ms. Sampson used was to point out the purpose of a hypothesis and mention that the question asked sounded like a testable question. She then asked students to rephrase the question rather than doing the rephrasing herself. This puts more control over the process in the hands of the students so they must practice this skill. Ms. Sampson is truly taking the role of facilitator by steering students with questions and letting the students generate the final version of the hypothesis. This facilitating includes reassuring Angie that it was okay to hypothesize and later find that the hypothesis is not supported. You've probably seen students' reluctance to be "wrong" on a hypothesis, and PBL helps them get over that fear.

It helped that Ms. Sampson's class had learned a deliberate pattern for writing hypotheses in other lessons. If you have been working on SEP 3 (Planning and Carrying Out Investigations), your students will likely have begun learning this skill as well. In your class, part of the scaffolding you will do with students is to help them learn to ask questions, write hypotheses, build data tables, and write explanations. PBL gives you yet another context in which students can use those same practices, so you have the flexibility to insert your particular format for structuring these elements of the science process.

Angie's hypothesis took quite a bit of scaffolding. Students contributed bits and pieces and made connections with the class "standard" for hypothesis writing. It was not an automatic process at first. This is typical of students who are still learning to think like scientists. Carlos was able to phrase his hypothesis in the appropriate format much more quickly because he was part of the process of working out that format during the discussion about Angie's hypothesis. This is also a common event. Students very quickly adopt the structure when the class works through the process out loud and can see the hypothesis on the list as a reference for later discussion.

If no students come up with hypotheses on their own, the teacher needs to help students think about making some predictions or proposed solutions. As the list of "What do we know?" and "What do we need to know?" items grows, a facilitator can ask something like, "So what do you think is the answer to the challenge at this point?" This is usually enough to get the ball rolling with the first hypothesis.

Our experience suggests that once the first hypothesis emerges, other students become more comfortable suggesting possible solutions or hypotheses. In other cases, students may need a prompt from the facilitator. You can elicit hypotheses by asking, "So what do you *think* is the answer to the challenge?" or "Do you have any hypotheses about a solution?" If students are really having trouble framing an initial hypothesis, you can ask if they think there is a relationship between any of the things listed under "What do we know?" Defining relationships is often the beginning of a hypothesis. Such initial hypotheses may not be complete answers to the challenge, but they start the ball rolling.

Introducing Page 2

As your students work through the PBL analytical framework and the information on Page 1, there will be a moment when the students start to run out of new ideas to put in the three categories of the framework. They will exhaust the "What do we know?" ideas and address most of the learning issues on the "What do we need to know?" page. The list of hypotheses might be short, but the generation of these ideas will slow down. *When that happens, your job as the facilitator is to transition into Page 2.*

Page 2 continues the Page 1 story and adds new information that will help students work toward a solution to the challenge statement at the end of Page 1. Introducing Page 2 should work very much the way introducing Page 1 did; students will read Page 2 quietly, then a student will read it aloud. Once that happens, the class can repeat the analytical process, adding new ideas to the same three categories of the PBL framework.

One major difference in the way to handle information relates to the new content on Page 2. You may find that "What do we need to know?" items on your list will be answered with the Page 2 story, or that the hypotheses generated in the first discussion will be rejected based on the new information. You can certainly add new questions and hypotheses as well as "What do we know?" statements, but we strongly recommend that you keep the first set of ideas on the board and visible to students. As you answer items in the "need to know" list, cross them out but leave them on the list. Some facilitators keep a list of "summarized knowledge" under each question to connect the "need to know" items with the new information they use to answer the questions. When you learn enough to eliminate a hypothesis, don't delete or erase it, but cross it out. Having those ideas visible is helpful when students look at the path they have taken from their initial ideas to the final solution for the problem. Processing their own ideas this way gives students a way to know *why* the solution works, not just that this is the right answer. It also builds a habit for students to show their thinking and their work. You might even find that when students begin to adopt the PBL skills as habits, they apply them in other subjects as well!

Ms. Sampson's Science Classroom: Introducing Page 2

Jason: So we know there are different kinds of air masses, but I still don't know which of these are related to storms or severe weather or whatever they call it.

Ms. Sampson: So do you want to put that under "What do we need to know?"

Jason: Yeah, I think so.

Ms. Sampson: OK, got it. What else can we add to our lists?

(long pause)

Andrea: I think we need to find out if storms all have the same wind direction.

Jamal: We already have something about wind direction under "What do we need to know?"

Ms. Sampson: Yeah, I think we have that covered. Any other ideas? Or new hypotheses?

(long pause)

Ms. Sampson: OK, then it sounds like you're ready for more information, right?

(Multiple students): Yeah! We need more information.

Ms. Sampson: Alright then, here's Page 2. Let's do what we did with Page 1. Read the story to yourself, and then we'll read it out loud.

She hands out Page 2, the class reads it quietly, and Devin reads Page 2 aloud.

Ms. Sampson: OK, good. Now let's add new pages for "What do we know?" "What do we need to know?" and "Hypotheses." We need to talk about each of these pages again with the new information we have. So … what do we know NOW?

Will: Well, we have five days of weather maps that can show how the highs and lows move.

Rose: And there are lines on the maps with arrows and half circles on them.

Marcus: Wait, I'm not sure what those are. I think we need to put those lines under "need to know."

David: Those are fronts. My dad told me about those once when I asked him about it when we were watching the weather. There are hot and cold fronts, and that's what the lines show.

Marcus: Yeah, but which one is which?

David: Umm … I can't remember. Ms. Sampson, which one has the arrows on the line?

Ms. Sampson: Good question! Let's put that under "need to know."

Tricia: Did you notice that wherever it rains, there's a front with the half circles? And there's an *H* on one side and an *L* on the other.

Jason: Does that relate to the hypotheses we wrote? Carlos said he thinks storms can be predicted by looking at pressure and wind.

Carlos: Yeah. That line shows where a high and a low meet. I think that's where storms happen.

Denise: We need to check that pattern. Put that under "What do we need to know?"

Vince: Yeah, but I think we can even look at some data about barometric pressure. We could build one in class and record data. I am pretty sure the air pressure will match temperatures. They both either go up or down together. I saw something the other day where it shows how to make a barometer to measure the air pressure. You get a U-shaped tube and put some liquid in it. And one end has to be open.

David: Cool! Can we build one? Maybe I can Google this and get the instructions. We can find some tubes in my grandpa's garage. He's got all kinds of junk we can use.

Ms. Sampson struggles to let the conversation work its course—they are getting off track and starting to talk about issues that are not important to the problem.

Alyssa: So maybe we just need to look at the map that shows winds. That's one of the maps we have to talk about. The weather map always has those arrows for the wind direction.

Mai: Yeah, that's the second part of Carlos's hypothesis. Is there a pattern that matches the weather?

Ms. Sampson: That's a good idea. If you think it's important, do you want to make that a hypothesis? Vince, we can add your hypothesis about the pattern with temperature and air pressure if you like.

Mai: Yeah! I believe air pressure and wind speeds tell the weather guy when air masses are going to … what's the word I want? Meet? It's like they crash into each other.

Sarah: Yeah, and on the maps, you can kind of see where the air masses are. And the fronts are usually on the edges.

Ms. Sampson: Let's put those under "need to know," Sarah. OK, I have that info recorded. Do we know any other new information?

Carmela: Yeah. The diagrams with the maps say that thunderstorms form when cold dry air pushes under warm, moist air and that the warm air rising is why a storm happens.

Angie: Wait, does that mean my hypothesis is wrong? I was thinking that cold air and low pressure go together.

Devin: Does that mean we cross out that hypothesis?

Ms. Sampson: We could, but can we just modify it with this new information?

Angie: Yeah, just switch what I said about warm and cold air, and we can keep it.

Moves to Make: What If Students "Go Down the Wrong Path"?

In this section of the vignette, we see Ms. Sampson guiding the class through the analysis phase of Page 2. Students listed the new ideas they got from Page 2, raising questions about ideas they didn't understand and offering new hypotheses. But we also see an example of students "going down the wrong path." Some conversations take off on tangents, like the comments about making a barometer, and others may follow incorrect hypotheses that the teacher knows are going to lead to a dead end.

As the teacher, you will encounter those moments when you want to comment to prevent the class from following a "wrong" hypothesis. You should already know what some viable solutions to the problem are, and you simply want to help your students find the right answers. But it is important *not* to interject comments that stop students' exploration of incorrect ideas. A hypothesis that is later rejected is a powerful learning experience and is likely to lead to enduring understandings. So you need to let students explore those ideas, even when your instincts tell you to steer them in a new direction. Teachers are likely to want to correct the inaccurate ideas right away, but the PBL framework emphasizes letting students find evidence that leads them to eliminate ideas on their own.

Note how Ms. Sampson handled it. She allowed the class to work through their ideas, and she included Vince's hypothesis in the list. You should avoid eliminating hypotheses for your class. Let students decide when an idea is rejected. That's a difficult thing for teachers to do, and it may take some practice, but it is important! In this case, Vince helped the process by introducing a new hypothesis to compete with Carlos's hypothesis. Including them both will allow students to compare them using evidence and information they collect. Eventually the students will have all the tools they need to decide which is the most viable hypothesis.

When you encounter this type of situation, be assured that it's normal in the PBL process. Each of the authors has experienced this, and we have felt the same internal conflict between providing content knowledge or letting students learn or discover for themselves. We've all learned to be patient, let the students drive the discussion, and wait for the learners to see all the information before we simply give answers.

But there are good strategies for redirecting the discussion! One suggestion is to establish a practice in which you, the teacher, are free to participate as a learner. This gives you permission to ask the same types of questions students should be asking. In this co-learner role, you can model critical thinking and questioning while using your comments to keep students on task and on track.

Here are some questions or statements, or "steering tools," you can use to keep your class discussion on track:

- "So how does that apply to the challenge for this problem?"
- "Maybe we should restate the question we are trying to answer."
- "Do we have a source that can verify that idea?"
- "What kind of evidence do we need to support that?"
- "How does this information from Page 2 relate to Page 1?"
- "That sounds like a 'need to know' issue."

Researching and Investigating

Once your students have completed the discussion of Page 1 and Page 2, you should have an extensive list of items under the three categories in the PBL framework: "What do we know?" "What do we need to know?" and "Hypotheses." On some of the lists, you may have crossed out questions you've answered or hypotheses you've ruled out. The information that is left should point to learning issues and predictions that have potential as solutions to the challenge presented on Page 1. Remember, the goal is to propose solutions to the challenge, so the research and investigation should focus on this goal.

The next step in the process of facilitation is to help the class develop a plan for gathering information or conducting an investigation that will answer the "What do we need to know?" questions that are still unresolved. In this phase of the PBL process, the teacher has some choices that will determine what the next part of the lesson will include. Is there an inquiry-based lab or hands-on investigation that would help students understand the concepts that underlie the problem? Will students use a computer lab or classroom computers to search for information on the internet? Are there text resources that can help them answer the questions? Should the teacher provide a limited set of readings to ensure that students find productive information? All of these may be appropriate choices!

Investigations

In some problems, there may be a hands-on activity, such as a model that students can build, that would help illustrate a concept. For instance, in the "Weather" chapter (Chapter 7), the Northern Lights problem is an ideal situation in which to use a simple sundial or to have students build a Solar Motion Demonstrator to track the movement of the Sun through the sky in any given month. This allows students to experience a real-world phenomenon and use data as one type of evidence in constructing their final solutions.

You may also have inquiry-based investigations your students can conduct to learn or reinforce specific concepts. Astronomy problems like E.T. the Extra-Terrestrial (see Chapter 8) may be an opportunity to insert your favorite demonstration, model, or simulation of Moon phases. Problems from Chapter 5, "Earth's Landforms and Water," provide a context for doing a lab on water infiltration through different types of soil.

One of your roles as the teacher is to plan for these investigations. You may have activities in your textbook resources that would be appropriate, or you may find or create new lab activities to meet your needs. In Chapters 5–8, we have provided some lab activities that fit with specific concepts, including instructions to help you plan and implement these activities.

An important component of any activity is safety. Students and teachers need to learn how to properly assess risks and take actions to minimize risks. Safety issues to be considered include the use of sharp objects, use and disposal of chemicals, and the presence of fire or burn hazards. Teachers are responsible for precautions such as wearing safety goggles or glasses, providing disposal containers for sharps and chemicals, and ensuring that students know where fire extinguishers and chemical showers are located.

Information Searches

Some problems are best addressed by helping students search relevant resources for answers to the learning issues they have identified. For teachers who need to integrate literacy standards into science teaching, the skills of finding and evaluating information from multiple sources are clearly featured in this part of the PBL process.

Sources for answering the learning issues your students have identified may include web searches, their science texts, books in the school's library, or magazines and newspapers. Although our first thoughts seem to turn toward technology as the go-to source, there are many text-based tools that are certainly appropriate. You can decide which are best suited for the context in which you are teaching based on access, convenience, or the "fit" for the topic at hand.

The search for information also offers multiple choices for scheduling. Perhaps you will have students work on this the same day they have analyzed Page 1 and Page 2, or you may need to plan this phase for the next day or as homework. The number of days you spend on this task also depends on your specific needs.

Ms. Sampson's Science Classroom: Beginning the Information Search

Ms. Sampson: Alright, class, you've created a good list of facts, hypotheses, and things we "need to know." Now we need to plan what information we'll look for next. Let's look at the "What do we need to know?" list. Are there specific ideas that groups will offer to find out more about?

The students talk softly with their groups about what they want to research.

Jamal: Our group wants to know about that Doppler radar question. Can we look for that?

Ms. Sampson puts Jamal's name next to "Doppler radar."

Ms. Sampson: You got it, Jamal! Your group can get started.

Denise: We'll look for information on fronts and air masses.

Ms. Sampson: OK, Denise, that's a good topic to look at.

Jason: What about the air pressure idea? Is that part of one of those others?

Ms. Sampson: I don't think so. Do you three want to look that up?

Jason: Yeah, we'll take that topic.

Rose: What about wind speeds? We need to figure out how the wind arrows on the map match fronts and air masses. We can search for that.

Ms. Sampson: Good idea! If you'll volunteer, you can do that. Alright then, folks! You need to get started with the time we have left today, and we'll continue working on this tomorrow.

Angie: Can we look stuff up at home tonight, too?

Ms. Sampson: Sure! But make sure you write down what sources you find and bring the list with you tomorrow. Remember, when we're done, each group is responsible for sharing what you find with the entire class. Be organized!

Teacher-Selected Sources

For some classes, "searching" for information may require more assistance from the teacher. In these cases, the teacher might pick a limited collection of resources and provide these resources to groups when they are ready to find answers to their learning issues. Perhaps the problem is complex enough that you want to steer students to specific sources. Maybe the information they need is not easily accessible to your students, either because very little is published online about the topic or because your school filters access to the necessary sites. Even the age or technology skills of your students may suggest that you should preselect the sources.

One strategy for doing this is to create sets of articles or websites that address specific topics. You can either give each group of students all of the sets or distribute each set to different groups. The latter option forces students to read and analyze the texts and share what they find with other groups. This type of communication is common among practicing scientists and addresses skills that students need to develop across the curriculum.

To help you select problems for which preselected sets of sources are useful, we strongly recommend that you work through each problem in advance. Think of the types of "need to know" issues you expect students to identify, and try searching for those concepts. If you can't find them easily, your students may also struggle to locate sources. Many of the problems in Chapters 5–8 include a Resources page (Page 3) with links to websites and references to other materials that are relevant to the science concepts.

Sharing and Resolving the Problem

When your students have completed the investigation or information search, the next phase includes sharing what they found. If each group has selected specific learning issues to research, this sharing is critical to the challenge presented to the class. No one group is likely to find all the information they need to solve the problem or build a complete solution to the challenge. But if they share information, the class can co-construct some solutions, much as project teams do in the workplace. This phase of the PBL process gives students a chance to hone their skills with SEPs 6–8: Constructing Explanations (for science) and Designing Solutions (for engineering); Engaging in Argument From Evidence; and Obtaining, Evaluating, and Communicating Information.

The class sharing session should still focus on the three pages of analysis the students created during the discussion of Page 1 and Page 2, especially the "What do we need to know?" and "Hypotheses" lists. The information search should address specific "need to know" items, and their findings should help in the evaluation and adjustment of some of the hypotheses as students apply what they have learned to the challenge presented in the story. Post the three lists on the board or on a wall for all to see and take a minute to recap what the class has done so far.

Each group should be asked to share. Although some students may be reluctant to speak in front of the class, building their comfort with such a task is an important learning goal. We find that when the presentation is informal, the task is less threatening. One way to promote sharing is to ask a student in each group to share one thing they learned. This leaves room for others in the group to share their ideas. Sharing their findings also helps students learn to pay attention to evidence and reliable sources.

As groups present what they found, it may also help to have other students take notes or record concepts in a journal or science notebook. They should also be encouraged to ask questions that help clarify ideas. Let your class know that the goal is not to stump or quiz each other, but to help the entire class understand the information.

If your class or specific groups did an investigation, this is a good time to have the class look at the procedures and results and talk about what the evidence means. If you have a standard procedure for presenting scientific explanations from an investigation, this is a perfect time to apply that structure. For instance, you can establish a procedure in which students share observations and data, identify patterns in the data, and suggest an explanation for the patterns. In the case of developing a solution for a problem, another approach is to describe the proposed solution, explain why it will work, and explain how evidence supports the ideas. If you have a structure you use for this in your current lab activities, you can use the same structure with your PBL lessons.

When all the information has been presented, you have options on how to construct solutions. One way to come to a final answer to the problem or challenge is to discuss the problem as a group. The focus on this should be the hypotheses created by the class. When a group wants to support a specific hypothesis, you can ask for a rationale: What evidence makes you think this is a good hypothesis? Other students should also be allowed to make counterclaims about a hypothesis or to present ideas that would refute the hypothesis or solution. This discussion can be a rich assessment of students' learning and ideas because it forces students to reveal the connections they make between concepts as they apply them to an authentic problem. Recording their ideas may be helpful if you wish to assess these connections, or you may choose to have a checklist so you can keep track of evidence of new learning.

In some of the classrooms in which we have observed teachers using PBL lessons, we have also seen another approach. Some teachers elect to have each group talk about the evidence they have found and create their own solution to the problem. This works best if each group was responsible for looking up more than one concept from the "What do we need to know?" list. It is helpful to set a time limit for this discussion, and you may want to have a structure for the group's response, as described earlier in this section. The teacher may also have a handout with general questions for the group to answer. This can include what hypothesis the group was investigating, what "need to know" issue they explored, what evidence they collected through research or experimentation, and how the evidence leads to a solution. The group then presents their ideas to the class, and other groups are encouraged to ask questions or explain what they see as problems in the solution.

In both of these scenarios, the next step is to ask for a solution to the challenge listed at the end of Page 1. This is the ultimate goal of the activity, so make sure you pay attention to the challenge. Students might present more than one solution. That's okay! In the real world, there may be multiple ways to solve a problem, and we want students to understand that. But when more than one solution is presented, you can ask the class to discuss the strengths and weaknesses of each solution, ask them to vote on the one they prefer, or ask each student to write a short response or exit ticket with a prompt something like the following: "Which solution do you think is the most useful? Explain why you chose this solution over the others." (See the "Assessing Learning" and "Responses to Assessment Data" sections later in this chapter for more information on exit tickets.)

Ms. Sampson's Science Classroom: Sharing and Building Solutions

Ms. Sampson: Today we're going to share the information you found about the Leave It to the Masses problem we've been working on. As you present, remember that you need to describe the answers you found clearly, and you should be ready to tell us where you found them. We'll use that information to see what we can cross out on the "need to know" list and how your information fits with our "Hypotheses" list. I need each group to share what they found. Jamal, I'd like your group to start, if you don't mind.

Jamal: OK. We looked up how Doppler radar works. First of all, we found out that Doppler radar towers are the things that look like giant golf balls, like that one over by the old schoolhouse on State Road 13. I always wondered what that was. And it works like regular radar because it bounces radar waves off of objects to find out how far away they are. But the difference is that this kind of radar measures how fast and what direction an object is moving. If an object is moving away, the waves coming back from it get farther apart. If the waves are getting closer together, it's moving toward you. They call that the Doppler effect. So it can tell if clouds or rain or whatever is moving. It can also tell the difference between clouds, light rain or heavy rain, or hail. It can tell how hard it's raining by the size of the drops, I guess.

David: I thought the Doppler effect was what makes a train whistle change pitch when it goes past.

Ms. Sampson: It's the same idea, David. Radar uses radio waves, and the train whistle is sound waves. But in both cases, the distance between waves changes. In the train whistle example, you hear that as a change in pitch. OK, Jamal, that's a good start!

Denise, Angie, and Mai share information their groups found about fronts and air masses, including information about the symbols on the weather map for cold and warm fronts, and how they form when two different air masses meet.

Ms. Sampson: Good information, girls! We can use that as we look at the weather maps.

Jason: But how do we know whether a cold or warm front forms when the masses of air have different temperatures?

Carlos: Yeah, does the cold meet the warm, or the other way around?

Ms. Sampson: Good question. Let's look at the diagrams of cold and warm fronts on Page 2 of the story again.

Andrea: Can we put them up on the screen? I think we can see the answer in them.

Ms. Sampson: Sure, use the document camera.

Andrea: Look at the arrows on the bottom of the page. If the cold air moves toward a warm front, it's a cold front, and the warm, moist air rises and forms big storm clouds. If the warm air moves toward a cold air mass, it's a warm front, and the clouds are different.

David: You mean it's the direction the masses are moving?

Ms. Sampson: That's what our information shows, so yeah, it's the direction the air masses are moving. And if that's the case, can we find out what direction air masses are moving so we can use that for a prediction?

Jason: Well, yeah, we can. The wind map has arrows and lines that show what direction the wind is moving, so that's what we should use, right?

Rose: Are you sure? I thought our weather always moves from west to east, so I'm not sure wind direction causes that.

Ms. Sampson: Let's look at the data. Can you see air masses moving if you think of each day's map as part of an animated movie?

Marcus: Try putting two or three days of maps on the document camera and let's look.

Ms. Sampson: OK. Here are three days. Are there air masses that look like they are moving?

Mai: Kind of. I think they all do.

Ms. Sampson: OK, now let's look at the wind maps with these same days.

Angie: Oh yeah! The arrows match the movement of the masses.

Rose: Hmm … I guess it does. And there's a high-pressure mass moving from south to north, sort of. That makes it pretty easy to see how air masses move. But they don't always move just west to east.

Ms. Sampson: OK, so I think we have a better understanding. Let's look at the rest of the information you found.

The class looks at a few more pieces of information and agrees that using the maps of temperatures and air pressure helps identify air masses, and the wind maps help predict movement of the air masses to determine how the interactions may cause changes in the weather.

Moves to Make: Correcting Misconceptions or Nonscientific Solutions

When your students are constructing and selecting solutions, they are considering information their class has shared, but they also are influenced by prior knowledge. Sometimes this prior knowledge is not accurate, and it is likely to be durable and difficult to change. These ideas can lead to solutions at the end of the analysis process that are not practical, fail to really solve the problem, create other problems, or omit concepts the teacher has identified as important learning goals.

So what should you do when that happens? Our first suggestion is to assume the role of a classmate by asking questions you know will force the class to think about an important concept or piece of evidence. When skillfully used, these kinds of questions can help students notice the problems with their claims. One of the most effective approaches is to have students compare a problematic claim to information they have listed under the "What do we know?" column of the analysis charts.

One of the strategies that can be very effective is to ask questions such as "Are there any 'what we know' statements that contradict this solution?" In the vignette, Ms. Sampson asked students to review the weather maps over three days to look for patterns in the movement. By asking students to compare their researched information with other facts and evidence, you can help them develop SEP 8: Obtaining, Evaluating, and Communicating Information. This is a critical practice in our world of abundant information. Students will be exposed to many claims and proposals in the news, at work, through advertising, and in legislative bills that need critical analysis against the available evidence. This also helps address at least two of the "Essential Features of Classroom Inquiry" listed in the National Research Council supplement to the *National Science Education Standards* (National Research Council 1996, 2000) by asking students to give priority to evidence as they form and evaluate explanations.

Another approach would be to ask students to list the strengths and weaknesses of each solution. As in the strategy above, this places students in the role of evaluators and requires comparison of solutions to evidence. This also models the type of analysis used in the workplace for problems related to science and engineering, as well as many other contexts. Remember, the phase of the PBL process in which students generate solutions highlights both synthesis and critical thinking, so having students engage in these types of thinking is important.

But what if this doesn't do away with a misconception? Or what if the class didn't grasp a key concept that makes a big difference in the problem? Scientifically incorrect ideas can be durable and may get in the way of students' assimilation of new ideas. Some of the peripheral information may draw students' attention as they create solutions. So the teacher needs to be prepared to correct ideas and guide the development of solutions during this final part of the PBL lesson.

When your students just aren't applying concepts accurately, you now have a chance to explain ideas. There are times when your students need you to be the expert. Although we suggest you be patient with students' own thinking process, you may need to step in and present information that students need. If needed, you can lecture, lead a discussion, show a simulation or an image, or introduce some type of activity to help guide the learning. A good example of this is illustrated in the vignette when Ms. Sampson explained the connection between Doppler radar and a familiar example of the Doppler effect. This phenomenon is a key concept in understanding how Doppler radar is used to view weather data. Direct teaching has its place in the classroom, and your content expertise is important. If Ms. Sampson felt her students needed more information about the Doppler effect, she could use this opportunity to present a short lecture or demonstration about waves, wavelength, and frequency, with examples relating to light, sound, and radio waves.

Assessing Learning

When implementing a PBL lesson, the teacher/facilitator should respond to the learning needs of his or her students as they emerge. Flexibility is key, but to be flexible the teacher needs information about what students are thinking. Assessment is an important part of the facilitation process. As you lead a class through PBL problems, you should be planning to assess and to use the information from your assessments to adjust your teaching.

The PBL process as we have described provides for continuous assessment. The process of analysis using the PBL framework allows the teacher to hear and see what students are thinking as they talk about their ideas and record information, questions, and hypotheses under the three columns of the analytical structure. Each comment from a student gives you insight into their understanding.

But be aware that what you hear in a group discussion may not reveal what every individual is thinking. In a whole-class discussion, the teacher sees a "group think" picture of what students know. There may be bits of information from a handful of students that seem to make sense when the entire group shares ideas, but you need to know what each student understands. It is helpful to have strategies that let you assess individual students rather than the entire group of students.

The need for individual assessments is even more pronounced if the activity takes more than one class period. As we developed our model in the PBL Project for Teachers, our facilitators found it very helpful to implement informal assessment strategies like exit tickets. These are very brief prompts asked before the end of a class period for which students write a short response. These prompts may focus on one idea the students learned, one idea they found confusing, or one question they have based on what happened in class. You might also ask students or groups to give a written summary of the information they found during their research, their choice of the "best hypothesis so far," or a drawing of the concept they are exploring.

Another form of assessment is the transfer task. *Transfer of knowledge* refers to the ability of students to apply knowledge of the concept in new contexts. For instance, students may know that air masses take on the characteristics of the surface where they develop, but they should also recognize that the extreme low pressure and high winds of a hurricane are more likely to form when an air mass is positioned above very warm ocean water where the moisture can evaporate and be contained in a warming air mass. The importance of transferring knowledge to new situations is supported by Schwartz, Chase, and Bransford (2012), who suggested that a deep understanding of a concept must be accompanied by transfer. To help you perform this type of assessment, the problems in Chapters 5–8 include transfer tasks. The transfer tasks are often used as a summative assessment, but they can also inform the choices the teacher makes about the next activities to include in a unit.

In Chapters 5–8, we also present open-response questions that we have developed and tested for each content strand. There are two types of these questions—general and application—to address the concepts and standards included for the problems in the content strand. We discuss the role of these assessments further in Chapter 4, as well as options for when to use the assessments and how to interpret responses.

Responding to Assessment Data

Assessment of learning is important, but you also need to consider how you can use the assessments to respond to students' needs. We've introduced a couple of assessment strategies that can help you select your next moves as a facilitator in the PBL lesson. But it may help to share some examples. These examples include exit tickets and group summaries of solutions to PBL problems.

Exit Tickets

This is a simple and quick way to collect information about your students' understanding and issues that need to be resolved. Exit tickets (Cornelius 2013) can ask one of several different kinds of questions, including "What's one thing you've learned?" "What about today's topic are you still confused about?" or "What's one question you have about today's lesson?" Each student then writes a short response and turns it in to the teacher at the end of class. The next step is for the teacher to read through the tickets to see if there are important issues that need to be handled in the next day's class.

The following vignette section provides an example of how this might work in Ms. Sampson's class.

Ms. Sampson's Science Classroom: Exit Tickets

Ms. Sampson asked her class to write exit tickets after Page 2, using the prompt "one question you have about the Leave It to the Masses problem."

Ms. Sampson: OK, I looked over the exit tickets you wrote yesterday, and I think we need to add something to the "need to know" list. Several of you wrote that you don't understand why dry air is denser than moist air. Can we add that to our list?

The class agrees, so this is added to a list of topics to be researched.

Another possible result might be …

Ms. Sampson: Your exit tickets tell me that there may be some questions about the connection between air pressure and the direction the winds move around a low-pressure area.

She explains that air is a fluid that moves like water and that the rotation of Earth helps create forces that push air around. As air moves, it is pushed toward a low-pressure zone by the higher pressure in other areas. She uses a 2-liter bottle of water to show how water moves more quickly if it swirls in a vortex as it drains out of the bottle when it is turned upside down. She relates the movement of air toward the low-pressure zone to the movement of the water, to help students visualize the concept.

Group Summaries

In the PBL Project for Teachers, we found that an entire class may agree to a solution, but some individuals may have a different level of understanding of the concept. One of the strategies we tested proved to be useful—group summaries.

In this assessment, each group is asked to write a summary of their group's proposed solution. The summary should include a description of the solution they think best solves the problem or answers the challenge, along with a rationale that explains what evidence they used to construct their solution (SEPs 6, 7, and 8). In the process of discussing and writing this summary, group members are able to solidify their understandings. When groups are asked to complete a summary, individual scores on content tests are often higher than if the summaries are not used.

The following vignette section offers an example of how this assessment might be implemented in Ms. Sampson's lesson.

Ms. Sampson's Science Classroom: Group Summary of Solutions

Ms. Sampson asked each group to write and turn in a summary of the solution they had developed on the second day of the lesson. In these summaries, she noticed an issue that needed to be explained. Her students wrote that cold fronts make rain, and warm fronts lead to sunny weather.

Ms. Sampson: Alright, kids, I saw in your solutions that many of you wrote that only a cold front creates rain and storms. And nobody mentioned what happens if two air masses move toward each other, and they both have the same "strength." Does anyone know what a stationary front is?

The students looked confused, so she asked them to view an online computer simulation that let them see animations of four different kinds of fronts. She gave groups time to try out each kind of front and take some notes.

Ms. Sampson: So what did you find out about fronts?

Sarah: This shows how each kind of front can make it rain.

Carlos: Yeah, and that stationary fronts make big storms.

Jeremy: So do occluded fronts. Did you see that big cloud that formed in that part of the simulation? I bet that makes a huge storm!

Mai: Yeah! My dad says that when a cloud makes that flat place on top, it's a really big thunderstorm.

Ms. Sampson: OK, those are some good observations. How do you think this relates to your weather maps?

Jason: It means we have to know about how strong an air mass is before we can predict the weather.

Angie: And it gives us a way to know if there is going to be a severe storm. We need to look at temperatures, and pressures, and winds, and patterns on the map. It's kind of complicated, but it's kind of important, too.

Ms. Sampson: That's a great comment! Now, let's go back to the computers and look at the simulation again. Let's see if we can use the shapes of clouds to identify what's happening in our weather right now.

Summary

Facilitating PBL requires a slightly different set of skills from direct teaching, and it requires practice. Your role as the facilitator means you need to be prepared for several possible paths students may take. Your role also shifts from a provider of information to a guide who needs to skillfully ask questions that allow students to reveal their own thinking, resolve their own misconceptions, and base their own ideas on evidence rather than an "expert" source. This questioning also requires you to moderate disagreements and keep students on task, so facilitating PBL lessons will feel very different from other lesson formats.

You will also need to anticipate what kinds of information, models, and explanations you should be ready to offer your classes. If you teach multiple sections of the same class, each may have very different needs, so you will find yourself selecting different responses. Assessment is a key factor; you need to know what your students are thinking!

Box 3.2 presents some tips to remember as you facilitate your PBL lessons.

Box 3.2. Dos and Don'ts of PBL Facilitation

Do …

- Use open-ended prompting questions.
- Count to 10 or 20 before making suggestions or asking questions.
- Allow learners to self-correct without intervening.
- Be patient and let learners make mistakes. Powerful learning occurs from mistake making. Remember that mistakes are okay.
- Help learners discover how to correct mistakes by clarifying wording, seeking evidence, or checking for discrepancies between ideas and evidence.

Don't …

- Take the problem away from the learners by being too directive.
- Send messages that they are thinking the "wrong" way.
- Give learners information because you're afraid they won't find it.
- Intervene the moment you think learners are off track.
- Rush learners, especially in the beginning.
- Be afraid to say, "That sounds like a learning issue to me" instead of telling them the answer.
- Rephrase learners' ideas to make them more accurate.

Source: Adapted from Lambros 2002.

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