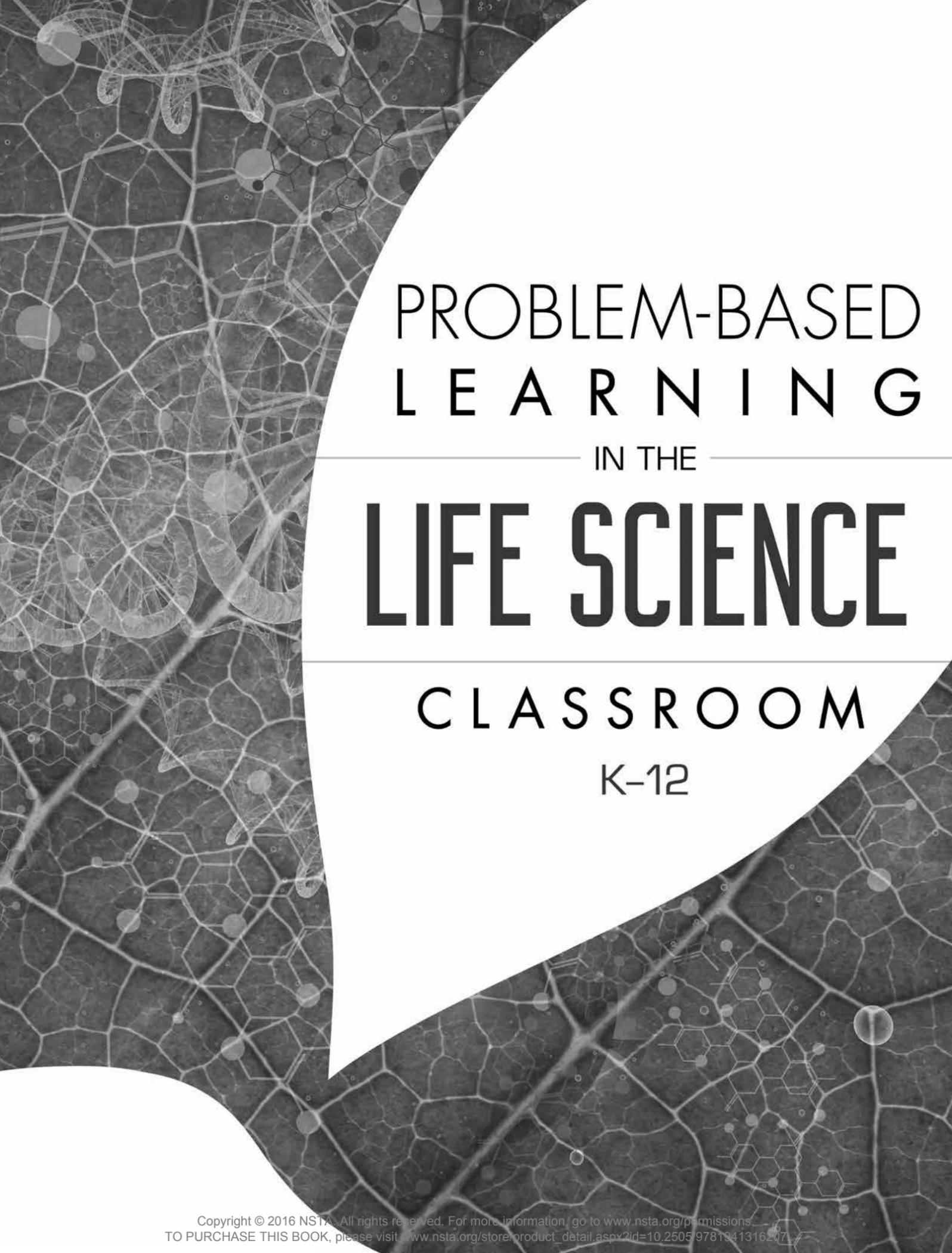# PROBLEM-BASED
LEARNING
IN THE
LIFE SCIENCE
CLASSROOM
K–12

TOM J. MCCONNELL
JOYCE PARKER
JANET EBERHARDT

NSTApress

National Science Teachers Association

PROBLEM-BASED LEARNING

IN THE

LIFE SCIENCE

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L E A R N I N G
IN THE
LIFE SCIENCE
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Arlington, Virginia

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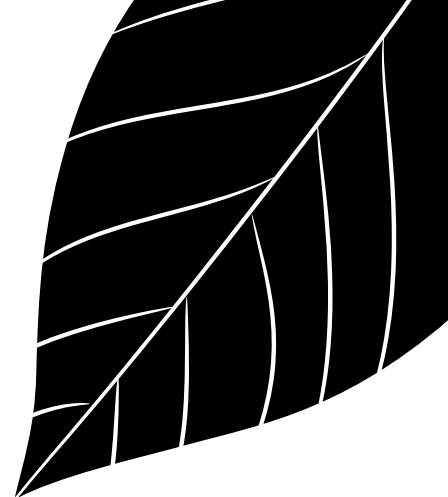
PREFACE

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 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 PBL Project for Teachers, 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*. 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 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* calls 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 or adapt these standards into state standards, Chapter 2 should help teachers and teacher educators fit the problems into 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 combining PBL with other activities in your curriculum, grouping students, managing information, and assessing student learning through the PBL process.

Chapters 5–8 present the problems we have designed and tested in four content strands: elementary life cycles, ecology, genetics, and cellular metabolism. For each problem, we include a table outlining alignment with the *NGSS*; interdisciplinary connections; resources and/or investigations that help provide relevant information about the science concept and problem; a teacher guide with the problem context, a model response to the challenge question(s) about the problem, and (in some problems) an activity guide; and assessment questions we used to evaluate learning, with model responses. To help you locate the problems that are most appropriate for your classroom, we have included a catalog of problems (pp. xiii–xiv); the catalog is in tabular format and will let you scan the list of problems by the topics, 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. Some of the problems in this book relate to local ecosystems 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 those cases, we encourage teachers to modify and adapt problems to fit contexts familiar to their own students. Chapter 9 discusses how teachers can modify the problems in this book or design their own problems for PBL lessons.

This book is intended as the first volume in a PBL series. We present life science problems in this volume, and we will offer problems specifically written for teaching Earth-space science and physics in future volumes. A fourth volume will contain tips and examples for planners of teacher professional development programs. As you modify and implement lessons from these books, you can begin to develop your own problems that meet the needs of your students.

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 provided for investigations and need to be adopted and enforced to provide for a safer learning and teaching experience.

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

Science teaching needs to deal with animals in a safe and ethical way. We encourage teachers to review the NSTA position statement Responsible Use of Live Animals and Dissection in the Science Classroom (*www.nsta.org/about/positions/animals.aspx*). For information on field trip safety, read the NSTA Safety Advisory Board paper called "Field Trip Safety" (*www.nsta.org/docs/FieldTripSafety.pdf*).

Please note that 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
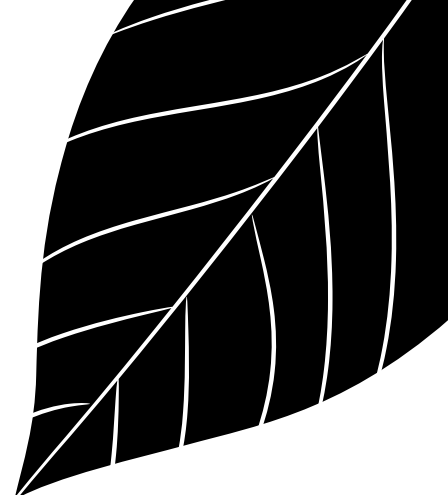
Problem	Page Number	Keywords and Concepts	Grade Band			
			Grades K–2	Grades 3–5	Grades 6–8	Grades 9–12
CHAPTER 5: ELEMENTARY LIFE CYCLES PROBLEMS						
1. Baby Hamster	68	Mammalian life cycle, needs of living things	•	•		
2. Wogs and Wasps	75	Insect and amphibian life cycles, needs of living things	•	•	•	
3. Humongous Fungus	83	Fungus life cycle, needs of living things		•	•	
4. Baby, Baby Pear	89	Plant life cycles, needs of living things	•	•		
CHAPTER 6: ECOLOGY PROBLEMS						
1. Where's Percho?	106	Competition, food webs		•	•	•
2. Lake Michigan—A Fragile Ecosystem	114	Competition, food webs, invasive species			•	•
3. Bottom Dwellers	121	Eutrophication, water quality indicators, water pollution, human impacts on the environment			•	•
4. Bogged Down	132	Ecological succession, plant dispersal, competition in plants			•	•
5. The Purple Menace	138	Competition, invasive species		•	•	•
CHAPTER 7: GENETICS PROBLEMS						
1. Pale Cats	154	Genotype to phenotype, inheritance of traits			•	•
2. Black and White and Spots All Over	162	Codominance, inheritance of traits			•	•
3. Calico Cats	169	Sex-linked and multigenic traits			•	•
4. Cat Puzzles	176	Patterns of inheritance, genotype to phenotype, codominance, sex-linked and multigenic traits			•	•

NATIONAL SCIENCE TEACHERS ASSOCIATION

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Theron Blakeslee
Martha Couretas

ABOUT THE AUTHORS

Tom J. McConnell is an associate professor of science education in the Department of Biology at Ball State University, Muncie, Indiana. He teaches science teaching methods courses for elementary and secondary education majors and graduate students, as well as a biology content course for elementary teachers. His research focuses on the influence of professional development on teacher learning and student achievement, and it focuses on curriculum development for teacher education programs. He is also an active member of the Hoosier Association of Science Teachers and the National Association of Research in Science Teaching.

Joyce Parker is an assistant professor in the Department of Geological Sciences at Michigan State University. She teaches a capstone course for prospective secondary science teachers. Her research focuses on student understanding of environmental issues. She is an active member of the National Association of Research Science Teaching and the Michigan Science Teachers Association.

Janet Eberhardt is an emeritus teacher educator and former assistant director of the Division of Science and Mathematics Education at Michigan State University. She has served as a consultant with the Great Lakes Stewardship Initiative and the Michigan Virtual University. Her work has focused on designing effective and meaningful teacher professional development in the areas of science and mathematics.

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 than 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 student. Students need to take risks in sharing ideas 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 they 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 create a culture of open discussion in your classroom. Throughout the vignette in this chapter, we have tried to indicate when 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 invasive plants in her "Ecology" unit, and today's activity follows some readings about ecosystems and food webs and a video about marsh ecosystems.

Ms. Sampson: Class, today we're going to start learning about a type of plant we can find in this area. As we work, you will take the role of a committee that manages the natural area at Rose Lake. We are going to use PBL 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

> **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.

record students' statements, questions, and hypotheses on the board or projected on the screen so all students can see the lists (see Figure 3.1).

You can create areas on the whiteboard 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.

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.

Figure 3.1. Recording Learners' Ideas in the PBL Framework

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 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 one, 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 what this process looks like in the classroom setting.

Ms. Sampson's Science Classroom: The Launch

Ms. Sampson: OK, class, today's PBL is called The Purple Menace. Here is Page 1. Please read this story quietly. I'll give you about 2 minutes.

She hands out Page 1 of The Purple Menace problem. (See Chapter 6, p. 140, 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 2 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 that the students look like they are thinking.

Andrea: Purple loosestrife has increased from 1 to 50 plants in 10 years.

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

Jamal: There are cattails in the marsh too.

Marcus: And it says they are found by the boat access. I think they mean the boat ramp.

Mai: What is purple loosestrife? I've never heard of it.

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

David: This says the loosestrife is successful, but I'm not sure what that means.

Carmela: I think they mean that they are increasing in number. They've gone from 1 to 50.

Ms. Sampson: OK, we can put that under "What do we know?" but the question goes under "What do we need to know?"

Carmela: Yeah, I think we need to look that up.

Moves to Make: "Unpacking Ideas"

During a discussion in the three-column framework described, 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 (see SEP 4, p. 13). Students also use this stage to define the problem (see SEP 1, p. 13).

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

Marcus: And it says they are found by the boat access. I think they mean the boat ramp.

Mai: What is purple loosestrife? I've never heard of it.

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

Until the discussion begins, the teacher may be uncertain what students know about the scenario described in the story. Knowing what this plant looks like and where it lives is certainly important to the problem! 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 their local ecosystems. 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 purple loosestrife later in the lesson, but another useful strategy would be to "unpack" the concept of *purple loosestrife* 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 unpacking the concept.

Let's compare the teacher-as-expert approach with the 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 understanding, students should be able to synthesize information by connecting ideas in the context

Table 3.1. Teacher-as-Expert Approach Versus Teacher-as-Facilitator Approach

TEACHER AS EXPERT	TEACHER AS FACILITATOR
Mai: What is purple loosestrife? I've never heard of it.	**Mai:** What is purple loosestrife? I've never heard of it.
Ms. Sampson: Mai, I can add that to the "What do we need to know?" page. Good question! Purple loosestrife is a plant found in wetlands across the Midwest. It grows about 6 feet tall, and spreads quickly when it gets in the marsh.	**Ms. Sampson:** Mai, I can add that to the "What do we need to know?" page. Good question! OK, does anyone know what purple loosestrife is?
Denise: So why does that matter?	**Devin:** I'm not sure, but I'm guessing it's a plant. They're talking about cattails, and those plants are really common here.
Ms. Sampson: Well this plant is not originally from this area. And some people are worried about what it will do to the plants normally found here.	**Denise:** Is it OK if I do a search for *purple loosestrife* on the web?"
Mai: Oh! So they might kill other species off. I think I get it.	**Ms. Sampson:** Sure! We'll come back to your answer in a few minutes.
Ms. Sampson: OK! Here's a picture of it so you'll know what we're talking about.	**Marcus:** My dad takes us fishing there all the time. I think I've seen those plants. They're kind of tall, and they have purple flowers at the top. Is that the right plant?
	Ms. Sampson: I think they're the ones we're talking about.
	Denise: Here it is! There are some pictures here. It says purple loosestrife is a Eurasian plant that lives in wetlands and was introduced to the United States in the 1800s.
	Mai: OK, that helps. Maybe we can move the purple loosestrife into the "What do we know?" section.

of a real problem, instead of repeating bits of disconnected facts. In the expert example, Ms. Sampson is hinting toward the concept of competition, but we only see evidence in the facilitator example that Mai and Marcus have started making a connection between the concept and the problem.

Generating Hypotheses

As students work through the analysis 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, we've figured out what loosestrife is. Do you have any other things we need to learn about or ideas about this problem we should add?

Angie: I have a "need to know" thing. Does it matter that there are cattails there? I'm guessing the cattails are important, because the thing Denise found online said that loosestrife spreads really fast. I bet the cattails are going to be hurt by this.

Ms. Sampson: Good question, Angie. You're thinking about the marsh as a system now [CC 4: Systems and System Models]. But I think I hear a hypothesis in that statement. You're asking if there's an interaction between loosestrife and cattail, 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 cattails and loosestrife will … " Is that the way to state it?

Carlos: Shouldn't we use the same kind 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?

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

> **Ms. Sampson:** Yes, that's right, Allysa! So, Angie, use that as a start. "I think that … "
>
> **Angie:** OK. "I think that loosestrife will take over the marsh and cattails will die off."
>
> **Joseph:** It needs a "because" statement.
>
> **Ms. Sampson:** Yeah, what would be the *because* part?
>
> **Angie:** "Because plants introduced from other places usually outgrow native plants."
>
> **Ms. Sampson:** Good! That's our first hypothesis.
>
> **Jason:** Wait! Can we really say they do that? We don't know for sure!
>
> **Mrs. Sampson:** That's right, Jason, but this is a hypothesis. We'll try to check to see if this really happens, and if not, we can reject a hypothesis.
>
> **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 think different animals eat loosestrife, so the animals will change, but the area around the boat ramp will still be pretty much the same.
>
> **Ms. Sampson:** You need to put it in hypothesis form, too!
>
> **Carlos:** How about this? "I think the loosestrife will attract new animals, but the marsh will be unchanged otherwise, because having more kinds of plants just means you can have more kinds of animals."

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 analysis 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 the cattails will die off because the loosestrife takes over," 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 of 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 fine 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 classes. 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 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 analysis 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 to 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 analysis 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 in Page 2. You may find that "What do we need to know?" items on your chart 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 chart. 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: OK, so we've mentioned pretty much everything in the story, but I still don't understand why having loosestrife in the area is a problem.

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

Jason: Yeah, I think so.

Ms. Sampson: Okay, got it. What else can we add to our lists? (long pause) 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: Cattail is a keystone species.

Rose: Yeah, but what does THAT mean?

Marcus: Yeah, I want to know too! We need to put *keystone species* under "need to know."

David: It says cattails support a diverse … what is it? "A very diverse wetland community."

Marcus: Yeah, but is that connected to this keystone thing?

Ms. Sampson: OK, it's under "need to know."

Tricia: We know the lake was made by a glacier.

Jason: There's something about rhizomes. I don't know that word.

Ms. Sampson: Alright, another "need to know!"

Denise: That last part of the story says again that the loosestrife is from Eurasia, and it says it has caused problems in other areas.

Andrea: But it doesn't say what kind of problems. I think we need to know more about that.

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

Denise: This thing about rhizomes … it says cattails are going to eliminate the ecosystem. Does that mean the lake will go away?

Vince: Cattails can't make a lake go away.

David: But they spread by the wind. Have you ever seen those fluffy things blowing away?

Jordan: Yeah, and milkweed does that, too! [CC 6: Structure and Function]

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.

Allysa: Hey! Maybe loosestrife has those fluffy seeds, too. It spreads fast and the wind could do that. I bet cattails spread the same way. [CC 1: Patterns]

Mai: Never mind that! The story asks about how to reduce the spread of loosestrife. I think we need to look that up. I think they should spray the loosestrife to get rid of it.

Ms. Sampson: OK, Mai, let's talk about that last part of Page 2. We need to think about how to control loosestrife. If you think it's important, do you want to make that a hypothesis? Vince, we can add your idea as a hypothesis too.

Mai: Yeah! I think spraying loosestrife with weed killer will keep it from spreading because it will die off.

Sarah: I don't think that will work. Wouldn't that kill the cattails, too? I think you have to dig them up and get rid of them, because using chemicals might hurt other things.

Ms. Sampson: Let's put both of those under "Hypotheses."

Carmela: Yeah, those are good ideas, but we still need to know more about cattails and loosestrife. And if there have been problems in other places, we might be able to look that up.

Ms. Sampson: We could, and you'll get a chance to do that soon.

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 the cattail seeds, 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, Sarah helped the process by introducing a new hypothesis to compete with Mai's. 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 type 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 info 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 pages, 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 in 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 Chapter 6, "Ecology Problems," the Bottom Dwellers problem is an ideal situation in which to use water sampling from a local stream or lake. By measuring dissolved oxygen using a simple test kit, students can learn more about how we test bodies of water to determine what might be causing a decline in some species of animals. This allows students to experience a real-world phenomenon and use data as one type of evidence they can use in constructing their final solutions.

You may also have inquiry-based investigations your students can conduct to learn or reinforce specific concepts. Cellular metabolism problems such as Mysterious Mass may include a lab investigation to burn a twig. An elementary life cycles problem like Wogs and Wasps may be supported by observing mealworms or tadpoles in the classroom over a period of a few weeks.

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 consider include the use of sharp objects, the safe use and disposal of chemicals, and the presence of fire hazards. Teachers are responsible for taking 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

Other 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, many text-based tools are certainly appropriate. You can decide which tools 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 Vignette: Beginning the Information Search

Ms. Sampson: OK, 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 look up cattails and what they mean by keystone species. Can we look for that?

Ms. Sampson puts Jamal's name next to cattails.

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

Denise: We'll look for stuff about loosestrife, like what eats it.

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

Jason: What about the problems loosestrife caused in other places? Can we look that up?

Ms. Sampson: Sure! Do you three want to look that up?

Jason: Yeah, we'll take that topic.

Rose: There's a hypothesis about how to keep it from spreading. Someone needs to look that up.

Ms. Sampson: Good idea! If you'll volunteer, you can do that. David, how about if your group helps Rose's by looking up the weed killer topic. It's related to Rose's group.

David: OK, we can do that.

Ms. Sampson: 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 keep a record of what sources you find, and bring it 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 a different group. 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, 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 and Designing Solutions; Engaging in Argument From Evidence; and Obtaining, Evaluating, and Communicating Information.

The class sharing session should still focus on the three pages of analysis they created during the discussion of Page 1 and Page 2, especially the "What do we need to know?" and "Hypotheses" pages. The information search should address specific "need to know" items, and their findings should help in the evaluation of some of the hypotheses as they apply what they have learned to the challenge presented in the story. Post the three pages 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. While 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 similar to the following: "Which solution do you think is the most useful? Explain why you chose this solution over the others."

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

Ms. Sampson: Today, we're going to share the information you found about The Purple Menace 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 cattails. We found a lot of pages with stuff about cattails. There's a PDF file that we liked from a good source that had a lot of information, but there were a bunch of other pages with a lot of the same stuff. It says they like shallow water and that they like to have what they called "wet feet." And they grow 3–10 feet tall. Some other pages talked about cattails being a big food source for a lot of animals. Birds, muskrat, insects, and some other animals eat them, but many other animals use them for nesting and shelter. They mention a lot of kinds of birds, muskrats, ducks and geese, rabbits, and even deer. The roots are in the water, so fish and insects hide in them, too.

None of these talked about keystone species so we looked that up, too. A keystone species is one that is really important for an ecosystem because so many other species depend on it. So we think that means the cattail is a keystone species because a lot of animals use it for food and shelter. We think the cattail is really important for the marsh or the edge of the lake.

Ms. Sampson: OK, that's a good start! It helps us understand how cattails are part of a system [CC 4: Systems and System Models]. We need to think about the role of the cattail as we learn about purple loosestrife.

Angie: Well then, I think our group should go next. We looked up loosestrife.

Angie, Denise, and Mai share information they found about loosestrife, including their origins in Eurasia, their ability to grow in shallow water, the way they spread their seeds by dropping them in water, and the fact that in North America, they are spreading fast because there are no animals that eat it. They found websites describing how marshes are being taken over by loosestrife, leading to the loss of species that depended on native marsh plants.

Ms. Sampson: Good information, girls! Let's think about what that means. How does loosestrife compare to cattails? We need to see if there are any patterns that might be important in this problem [CC 1: Patterns].

Jason: They live in the same kind of places—shallow water.

Carlos: Yeah, but nothing eats the loosestrife. Just about everything eats the cattail or lives in it.

Ms. Sampson: So what does that mean if they both end up in the same place?

Andrea: That must be why the loosestrife takes over the marshes.

Carmela: That's bad for the animals that need the cattail, isn't it?

Ms. Sampson: Good question! What do you all think?

David: I thought the loosestrife kills off the cattails.

Tricia: How can one plant kill another? I don't think that's what's going on here. Ms. Sampson, can you explain this?

Ms. Sampson: Well, let's look at what we already know! I don't think anyone is suggesting that loosestrife kills the cattail, but let's think about competition. Are the two kinds of plants using the same resources?

Jason: They live in the same part of the lake. They both like shallow water.

Rose: And they're both close to the same height.

Andrea: So what? They don't eat, so they're not fighting over food! How can they compete for food?

Ms. Sampson: Think about it. How do plants get food?

Marcus: Photosynthesis. They use sunlight.

Ms. Sampson: Right! Remember, we talked about the flow of energy through the ecosystem a couple of weeks ago [CC 5: Energy and Matter: Flows, Cycles, and Conservation]. Do you think they compete for sunlight?

Mai: Compete for sunlight? Why? There's plenty of it, right?

Ms. Sampson: But what if one shades out the other?

Angie: And our website said the roots of the loosestrife are so tightly woven that other plants can't grow there. I think the plants are competing for space.

Carlos: Oh, I think I get it! Since the loosestrife doesn't have anything eating it, it has an advantage, and it crowds out the cattails. But does that mean this would take a long time before the cattails are gone?

Ms. Sampson: Maybe! According to the story, how long ago did the loosestrife appear?

Carmela: It was from 1996 to 2006. That's 10 years, and there are only 50 plants. It's going to take a long time.

The class agrees that this helps them understand why loosestrife is a problem. Jason's group reports that they found a description of similar ideas on some websites from Minnesota and Wisconsin. Those states have passed laws banning the sale and distribution of purple loosestrife. They also share reports that a single loosestrife can produce thousands of seeds each year, and that once one plant grows in a marsh, the marsh might be all loosestrife within 8–10 years.

Ms. Sampson: Alright, we understand the problem. Now let's talk about controlling loosestrife.

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 an important learning goal.

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 like "Are there any of the 'what do we know' statements that contradict this solution?" In the vignette, Ms. Sampson asked students to review the facts they know about what resources each of the two plants needs as a way to get them to think about competition. 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* (NRC 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 on the screen, or introduce some type of activity to help guide the learning. A good example of this is illustrated in the vignette when Ms. Sampson brought up the topic of competition. Competition is a key concept in understanding how invasive species influence an ecosystem, but none of her students had searched for information about competition. Direct teaching has its place in the classroom, and your content expertise is important. Ms. Sampson could use this opportunity to present a short lecture about competition for natural resources, or maybe use the time to do a short computer simulation as a supporting activity.

Assessing Learning

When implementing a PBL lesson, the teacher or facilitator needs to 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 planning 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 analysis 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, knowing that tadpoles change shape as they develop into frogs is important, but students need to recognize that all living things have their own patterns of development. 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 more about the role of these assessments 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 can ask one of several different kinds of questions, including "What's one thing you've learned?" "What about today's topic still confuses you?" or "What's one question you have about today's lesson?" (Cornelius 2013) Each student then writes a short response and turns it into 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 vignette section that follows 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 Purple Menace 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 how loosestrife got into the area at Rose Lake. 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 the following:

Ms. Sampson: Your exit tickets tell me that there may be some questions about the beetles that Denise's group found. Before we go on, let's talk about that idea and how the beetles help control the loosestrife.

She explains that biologists would test the beetles in a controlled lab space and then in a larger test plot before releasing them in the wild. She also reports that the beetles don't kill all of the loosestrife, but they control the population enough that cattails survive in the marsh, allowing the animals who depend on cattails to also survive.

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. The groups were scheduled to share their ideas on the third day. In these summaries, Ms. Sampson noticed an issue that needed to be explained. Her students thought that purple loosestrife had the ability to "kill off" the cattails. Because this is a common misconception about invasive species, Ms. Sampson decided to address this in class.

Ms. Sampson: Alright, kids, I saw in your solutions that many of you used phrases like "kill" or "kill off" to describe what the loosestrife does to the cattails. I think we need to explain that a little bit more, so we're going to do a computer lab. The computers at your lab stations have a program called Pond Ecology, and we need to do the "Competition Activity" listed in the main menu. When everyone is done, we need to discuss your results.

The students worked in groups on the computer simulation that lets them introduce two species of fish that eat the same type of food and a predator that eats only one of the fish. They recorded data about population growth in their lab journals and then discussed the data in a large-group discussion.

Ms. Sampson: So what did you find out about the effect of competition in the pond?

Sarah: We noticed that both species of fish have bigger populations if the other is not around. Since they both eat the same food, they only have enough to keep a certain population alive. If someone else is eating the same thing, both have problems getting enough, and the populations go down.

Carlos: We saw the same thing. It makes a lot of sense. But the cool part was when we added a predator that ate just one of the fish, that fish's population went way down, and the population of the other fish went way up.

Ms. Sampson: Did the fish that went down disappear completely?

Carlos: No, not completely. There were still some fish, but not many.

Ms. Sampson: OK, that's good. Now let's think about how this relates to the loosestrife and cattail. What do they compete for?

Jason: Light. We talked about that earlier.

Mai: And space. Remember what we found out about the roots of the loosestrife crowding out other plants.

Angie: Ohhh … I think I get it! They both have lower populations because they compete, but because there's nothing that eats the loosestrife, it had a big advantage in the competition!

Ms. Sampson: That's a great connection! Now, let's go back to the computers and see what happens with both fish with the predator that eats just the first fish, and then add a predator that eats the second fish. That should help us see what the weevils and beetles do to help control purple loosestrife.

Summary

Facilitating PBL requires a slightly different set of skills than 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 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 than 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. Do's 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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K–12

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