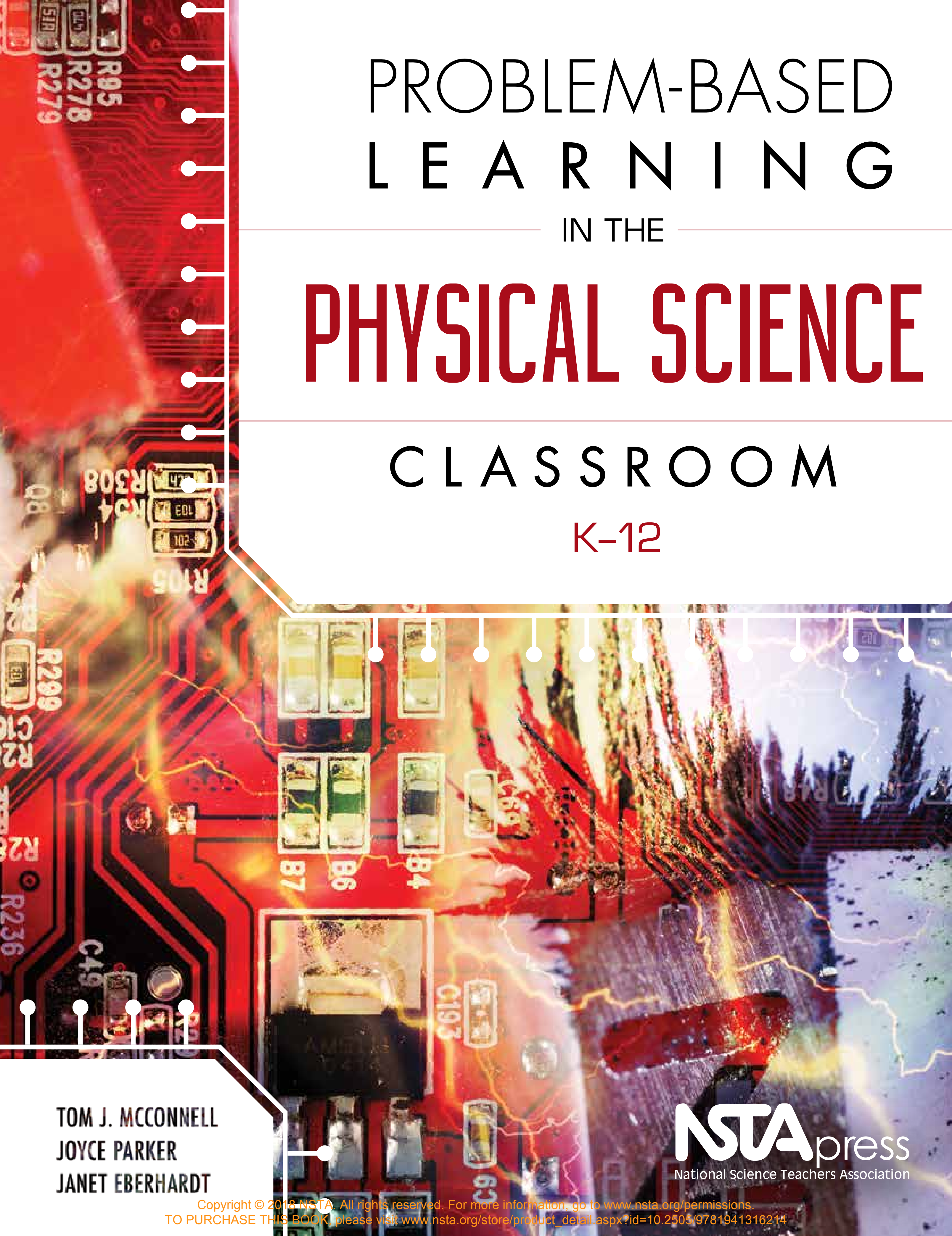

# PROBLEM-BASED LEARNING IN THE PHYSICAL SCIENCE CLASSROOM

K–12

TOM J. MCCONNELL
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21 20 19 18 4 3 2 1

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Cataloging-in-Publication Data for this book and the e-book are available from the Library of Congress.
ISBN: 978-1-941316-21-4
e-ISBN: 978-1-941316-70-2

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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 strength 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 challenge 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. 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 (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 forces 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 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 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 disciplinary core ideas. 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 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 (describing motion, forces and motion, engineering energy transformations, or engineering electricity and magnetism), 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, some problems in this book, such as Rescue Force (Chapter 6) and Rube Goldberg Machine (Chapter 7), use materials that may not be available or procedures that may not be possible in some classroom settings. A teacher with a different set of available materials should modify the problems and activity guides to match the context of his or her classroom. 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.

This book is the third volume in a series. The first volume presented life science problems, and the second volume offered problems specifically written for teaching Earth and space science. This volume features physical science problems. The 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 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 Teacher 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.

## References

Barrows, H. S. 1986. A taxonomy of problem-based learning methods. *Medical Education* 20 (6): 481–486.

Bybee, R. W., J. C. Powell, and L. W. Trowbridge. 2008. *Teaching secondary school science: Strategies for developing scientific literacy*. Upper Saddle River, NJ: Prentice Hall.

Delisle, R. 1997. *How to use problem-based learning in the classroom*. Alexandria, VA: Association for Supervision and Curriculum Development.

Gijbels, D., F. Dochy, P. Van den Bossche, and M. Segers. 2005. Effects of problem-based learning: A meta-analysis from the angle of assessment. *Review of Educational Research* 75 (1): 27–61.

McConnell, T. J., J. Eberhardt, J. M. Parker, J. C. Stanaway, M. A. Lundeberg, M. J. Koehler, M. Urban-Lurain, and PBL Project staff. 2008. The PBL Project for Teachers: Using problem-based learning to guide K–12 science teachers' professional learning. *MSTA Journal* 53 (1): 16–21.

McConnell, T. J., J. M. Parker, and J. Eberhardt. 2013. Problem-based learning as an effective strategy for science teacher professional development. *The Clearing House* 86 (6): 216–223.

Meyer, D. 2010. TED: Math class needs a makeover [video]. *www.ted.com/talks/dan_meyer_math_curriculum_makeover?language=en.*

NGSS Lead States. 2013. *Next Generation Science Standards: For states, by states.* Washington, DC: National Academies Press. *www.nextgenscience.org/next-generation-science-standards.*

Savery, J. R., and T. M. Duffy. 1995. Problem based learning: An instructional model and its constructivist framework. *Educational Technology* 35 (5): 31–38.

Schmidt, H. G. 1983. Problem-based learning: Rationale and description. *Medical Education* 17 (1): 11–16.

Torp, L., and S. Sage. 2002. *Problem as possibilities: Problem-based learning for K–16 education.* 2nd ed. Alexandria, VA: Association for Supervision and Curriculum Development.

# 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: GET MOVING** | | | | | | |
| 1. Get Me Out of Here | 70 | Distance, direction, motion | • | • | • | |
| 2A. Fastest Beetle | 82 | Distance, position, speed | | • | | |
| 2B. Fastest Human | 91 | Distance, position, instantaneous and average speed or velocity | | | • | • |
| 3. Constantly Moving | 101 | Distance, position, time, speed, velocity | | • | • | • |
| 4. Good Driver | 109 | Distance, position, time, speed, velocity, acceleration | | • | • | • |
| **CHAPTER 6: FORCES AND MOTION** | | | | | | |
| 1. Asteroid Field | 130 | Force, acceleration, direction, speed, velocity, Newton's first and second laws of motion | • | • | • | |
| 2. Cartoon Cliff Escape | 141 | Force, acceleration, velocity, speed, direction, gravity, vertical motion | | • | • | |
| 3. Rescue Force | 149 | Force, acceleration, direction, mass | | • | • | |
| **CHAPTER 7: ENGINEERING ENERGY TRANSFORMATIONS** | | | | | | |
| 1. An Energetic Ride | 164 | Conservation of energy, kinetic energy, potential energy, energy transfers and transformations | | • | • | |
| 2. Rube Goldberg Machine | 176 | Energy conservation, kinetic energy, potential energy | | • | • | • |
| 3. Keep It Warm, Keep It Chill | 189 | Thermal energy, energy transfer, insulation, conduction | | | • | • |
| **CHAPTER 8: ENGINEERING ELECTRICITY AND MAGNETISM** | | | | | | |
| 1. A Light in the Dark | 205 | Electrical circuits, batteries, light bulbs, electricity | | • | • | • |
| 2. Wiring a Cabin | 218 | Electrical circuits, electricity, batteries, light bulbs, fuses, switches | | • | • | • |
| 3. Cool It | 229 | Electricity, magnetism, electric current, electric magnet, electric motor, polarity | | • | • | • |

# ACKNOWLEDGMENTS

We wish to thank the following individuals who helped design, revise, and facilitate the problem-based learning (PBL) lessons presented in this book. Their expertise and insight were instrumental in the development of the problems and tips on facilitating PBL learning.

## Michigan State University

Merle Heidemann
Susan Jackson
Edwin Loh
Christopher Reznich
Mary Jane Rice

## Lansing Community College

Alex Azima
Christel Marschall
Dennis McGroarty
Teresa Schultz
Jeannine Stanaway

## Mott Community College

Judith Ruddock

## DeWitt High School

Mark Servis

## Retired Faculty

Roberta Jacobowitz (Otto Middle School)
Barbara Neureither (Holt High School)
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# 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 supply 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 and evaluating their own ideas.

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!

Still, there may be times when you need to share your knowledge of the concept. This may mean giving some examples of phenomena that demonstrate a process or explaining how certain ideas are connected. You 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 following 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 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.

## 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.

## 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 gravitational forces in her "Forces and Motion" unit, and today's activity follows some lab activities about velocity and the effects of forces on a toy car rolling across the table, as well as a reading from the textbook about gravity.

**Ms. Sampson:** Class, today we're going to begin a project in which each team will try to understand the motion of falling objects. This will be a chance to make a plan and test what affects how objects fall. 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.

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 be able 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 you, as the facilitator, about your 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 a "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 his or her own ideas when the student is busy writing others' ideas on the board, and your students probably will not be 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?" and "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 whatever way works best for you, such as divided into small groups, seated on the floor in a circle, or seated at desks.

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.

**Figure 3.1. Recording Learners' Ideas in the PBL Framework**

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. Some 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 that students 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 Cartoon Cliff Escape. Here is Page 1. Please read this story quietly. I'll give you about two minutes.

She hands out Page 1 of the Cartoon Cliff Escape problem. (See Chapter 6, p. 142, 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 as though they are thinking.

**Andrea:** We are supposed to figure out the way to fall into the water at the slowest speed and the highest speed.

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

**Ms. Sampson:** OK, good. What else do we know?

**Jamal:** In the cartoon, three characters went off the cliff. One just ran off the edge, one jumped up, and the other pushed down off the cliff. But I think we have to know how high they were before we answer this problem.

**Ms. Sampson:** OK, "How high is the cliff?" goes under "What do we need to know?"

**Marcus:** The last part of story said something about jumping up counteracts gravity.

**Mai:** Yeah, but do we really know that? I'm not sure jumping up really does that. I think we need to find out more about that.

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

**David:** Will gravity act on them the same way if they jump up? That doesn't sound like a very good idea to me. But I'm not sure how to describe how gravity works in this case.

**Ms. Sampson:** David, should I add something about gravity to the "What do we need to know?" page? Good question!

**David:** Yeah, I think we need to find out how gravity works.

**Carmela:** The challenge says we need to test our answers. That goes under "What we know."

**Ms. Sampson:** I can put that under "What we 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 the discussion by suggesting experiments they want to conduct.

## Moves to Make: "Unpacking Ideas"

During a discussion in the three-column framework described earlier, students are 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. David brings up an idea to include in the "What do we know?" column:

> **David:** Will gravity act on them the same way if they jump up? That doesn't sound like a very good idea to me. But I'm not sure how to describe how gravity works in this case.
>
> **Ms. Sampson:** David, should I add something about gravity to the "What do we need to know?" page? Good question!

The concept of gravity is certainly important to the problem about falling from the cliff. But it is likely that not all the students in the class are familiar with it or know how it will influence this challenge. 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 gravity 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 experts or problem solvers who recognize 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.

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

| TEACHER AS EXPERT | TEACHER AS FACILITATOR |
|---|---|
| **David:** Will gravity act on them the same way if they jump up? That doesn't sound like a very good idea to me. But I'm not sure how to describe how gravity works in this case.<br><br>**Ms. Sampson:** Gravity is important here. There will be no measurable difference in the way that gravity acts on the characters. The force of gravity will still accelerate the characters at 9.8 $m/s^2$ no matter what height they come from.<br><br>**Denise:** But if the one that jumps falls from higher up, will he be moving faster by the time he hits? He is accelerating for a longer time.<br><br>**Ms. Sampson:** Yes, he will, because he is accelerating for a longer time.<br><br>**Mai:** What about Rambles? He runs off the cliff horizontally. Won't that slow down his fall?<br><br>**Ms. Sampson:** That would add another direction to his motion, but gravity will still pull Rambles down at the same rate. | **David:** Will gravity act on them the same way if they jump up? That doesn't sound like a very good idea to me. But I'm not sure how to describe how gravity works in this case.<br><br>**Ms. Sampson:** David, should I add something about gravity to the "What do we need to know?" page? Good question! Does anyone else have more information about that?<br><br>**Andrea:** Well, that section we read in the book yesterday said that gravity on Earth is always the same amount. Let me find that number. … Here it is! 9.8 $m/s^2$.<br><br>**Denise:** That $m/s^2$ thing is confusing. Is that how fast something falls?<br><br>**Ms. Sampson:** OK, does anyone remember what that number describes?<br><br>**Steven:** That's the acceleration. A falling object speeds up at that rate as it falls.<br><br>**Marcus:** Yeah, so I think that means if Randy jumps up, he will be higher up and will accelerate a little longer. He should move faster. Maybe he will reach the ground faster … I think.<br><br>**Denise:** That doesn't make sense to me. If he jumps up, he has to travel up for a while. That would make it take longer, wouldn't it?<br><br>**Mai:** I think we should try it out. Can we do an experiment before we answer this?<br><br>**Ms. Sampson:** That's a great idea. You can certainly do an experiment.<br><br>**Rosa:** Yeah, it even says we are supposed to test it. I want to see what happens to the one that runs off horizontally. I think that will make it fall more slowly. |

In the facilitator example, the students get much of the same information, but they have either reasoned 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 of a real problem instead of repeating disconnected facts. In the expert example, Ms. Sampson is explaining how gravity affects the cartoon characters, but we cannot tell whether 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 covered a lot of ideas, 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. I want to know if the one that pushes down off the cliff is in the air for a shorter time. If he is, I think he will be going slower when he hits the water, but I'm not sure.

**Ms. Sampson:** Good question, Angie, but I think I hear a hypothesis in that statement. You're asking if an object that is thrown down hits the water sooner, but can we reword your question to make it 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 all right! 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 think that if we throw a ball down …" Is that the way to start 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 you learned to use when we're going to change a variable and see what the result is, Carlos. Since we are changing a variable, that makes sense.

**Angie:** OK, I think it should be "If we throw a ball down instead of dropping it, it won't be going as fast when it hits the ground."

**Joseph:** It needs a "because" statement.

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

**Angie:** "Because … because it got to the water quicker and gravity had less time to pull on it."

**Ms. Sampson:** Good! That's our first hypothesis. Can anyone tell me more about what's going on with the forces in this example?

**Jason:** Wait a minute. Why are you talking about a ball? This is about a cartoon, isn't it? Where did the ball come from?

**Angie:** We have to test this, so I thought throwing a ball would be a way to set up an experiment.

**Andrea:** OK, so if you throw the ball down, gravity won't affect the ball as much?

**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 the ball thrown down will still hit the ground going faster than the one we drop.

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

**Carlos:** How about this? "I believe the ball that's thrown down will be going faster when it hits the ground, because throwing gets it going downward."

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 Denise said, "I want to know if a ball you throw upward falls slower, because a golf ball you hit seems to hang in the air and looks like it falls slowly," 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 about 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 is meant 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, you will need 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 they 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:** OK, I see that gravity is one of the forces, but when we drop the ball in different ways, we have to figure that in. We need to know what those forces are doing.

**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:** Don't we need to know how far the animals fall?

**Jamal:** We already have something about how high the cliff is under Need to Know.

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

(long pause)

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

**Multiple students:** Yeah! We need more information.

**Ms. Sampson:** All right 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 then Devin reads Page 2 aloud.

**Ms. Sampson:** OK, good. Let's take a look at these videos.

The classes watches the videos, and then the teacher continues the discussion.

**Ms. Sampson:** 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:** In the videos, you can kind of see the balls speed up as they are dropped.

**Rose:** Yeah, but we need a way to measure how fast they are going or the time it takes. We have to be able to compare the different balls. They don't all drop from the same height. And how do we know how heavy each ball is?

**Marcus:** We don't know that for sure. I think that should go under "What do we need to know?" Put "How heavy are the balls in the videos?"

**Rose:** We can't find that out, can we? What if we just put "Does the weight of a ball matter?" Then we can test it ourselves and know what the balls weigh.

**Ms. Sampson:** Testing it sounds like a good idea! Let's put that under "What do we need to know?"

**Vince:** Yeah, and we can try different heights. And maybe try different types of balls. Some of the balls in the videos were tennis balls. But the ones we have in gym class are old and don't bounce very well.

**David:** Yeah, they're pretty bad! Have you ever seen those pumps you can use to restore a tennis ball? My dad has one, and it really works. Maybe we need to test to see if that changes how bouncy other balls are.

Ms. Sampson struggles to let the conversation work its course—the students are getting off track and starting to talk about issues that are not important to the problem. But she adds Vince's hypothesis about different types of balls to the list.

**Alyssa:** But wait, we don't care what kind of ball we use. We're looking at how the ball is dropped or tossed. As long as we keep the type of ball the same, it doesn't matter. You're talking about testing a different variable now.

**Anthony:** But we need to keep the ideas for now and figure out which ones to test later.

**Mai:** I agree with Alyssa. Let's think about the main question, but I think we need to start experimenting right now. I think we need to test some hypotheses. I still want to test the downward throw. Maybe it will fall the same, but I think it will be moving slower when it hits, and that's what the challenge asks about.

**Ms. Sampson:** That's an interesting idea, Mai. If you think it's important, do you want to make that a hypothesis?

**Mai:** Well … I think the hypothesis should have something about gravity always acting the same and how long the ball is in the air, so it hits slower.

**Ms. Sampson:** Do you think your hypothesis is like Angie's?

**Mai:** Umm … I guess it is!

**David:** And I want to add a hypothesis, too. I think if we throw the balls down, they will fall at a higher speed because they started at a higher speed when gravity pulled on them. … Oh, I think that's the same as what we already have.

**Ms. Sampson:** I'll put your wording up too, David.

**Devin:** Does that mean we cross out that old hypothesis?

**Ms. Sampson:** Well, have we found evidence to rule any of these out?

**Angie:** No, not yet. But can we start doing some experiments to test them now?

## 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 tennis balls. 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 understanding. So you need to let students explore those ideas, even when your instincts tell you to steer them in a new direction. Teachers likely will 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 this above. She included Vince's hypothesis about testing different kinds of balls on the list. You should avoid eliminating hypotheses for your class. Let students decide when the evidence means an idea should be rejected. That's a difficult thing for teachers to do, and it may take some practice, but it is important! When students get off track or propose hypotheses you know are not correct, be assured that these things are normal in the PBL process. Each of the authors has experienced this, and we have felt the same internal conflict between providing content knowledge and 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.

In the previous case, when class discussion started to drift, Mai and David helped keep the process on track by introducing a new way to word a hypothesis. Including the different wordings will allow students to focus on the ideas instead of a particular wording when they compare hypotheses with evidence and information they collect. Eventually, the students will have all the tools they need to decide which hypothesis is most viable. If Mai and David had not pulled the conversation back to the main point, Ms. Sampson could have done this by asking students how their present discussion topic related to the challenge.

There are also other 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," that 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 each of 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 as new information becomes available. 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, you are faced with some choices that will determine what the next part of the lesson will include. Would an inquiry-based lab or hands-on investigation 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 you 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 "Engineering Energy Transformations" chapter (Chapter 7), the Keep It Warm, Keep It Chill problem is an ideal situation in which to do tests with various containers to test their insulating qualities with both hot and cold materials. 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 your students conduct inquiry-based investigations to learn or reinforce specific concepts. Motion problems such as the Constantly Moving problem (see Chapter 5, p. 101) may give you the opportunity to insert your favorite demonstration, model, or simulation of a skateboard or ball rolling on a surface. Problems from Chapter 8, "Engineering Electricity and Magnetism," provide a context for doing a project with different types of circuits and maybe even different types of energy sources.

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 analyze hazards, assess risks, and take actions to minimize risks. Safety issues to be considered include the use of sharp objects, the use and disposal of chemicals, and the presence of fire hazards. You are responsible for precautions such as having students wear safety goggles or glasses, providing disposal containers for sharps and chemicals, and ensuring that students know where fire extinguishers, eye washes, 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, 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 analyze 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: Finding Information and Experimenting

**Ms. Sampson:** All right, class, you've created a good list of ideas, hypotheses, and things we "need to know." Now we need to plan some experiments. We know we will be dropping balls in sand and measuring crater size. 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 compare how hard the ball hits the floor if you throw the ball down versus if you toss the ball up. But I think we need to look up some numbers about the force of gravity. Can we do that?

Ms. Sampson puts Jamal's name next to "Toss Down vs. Toss Up." You got it, Jamal! Your group can get started. When you find the information about the force of gravity, please write it on the whiteboard. We all should see that information.

**Mai:** And we want to test the dropping the ball from different heights.

**Ms. Sampson:** OK, your group can do that experiment.

**Denise:** I'm not sure how to measure the speed of the ball when it hits. Can we look up some experiments for measuring the time it takes other things to drop? We want to see how others have done that.

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

**Rose:** We want to try the motion sensors we have in the cabinet. Maybe we can figure out a way to test how fast the balls are moving when they hit the ground, like Jason said.

**Ms. Sampson:** Good idea! If you'll volunteer, you can do that. All right then, folks! You need to get started. In the time we have left today, you should plan your experimental procedures, 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 it with you tomorrow. Remember, when we're done, each group is responsible for describing its experimental design. Be organized!

### Teacher-Selected Sources

For some classes, "searching" for information may require more assistance from the teacher. In these cases, you 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 resources such as the videos on Page 2 of the problem. 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 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 it needs to solve the problem or build a complete solution to the challenge. But if students 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 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 students' findings should help in the evaluation and adjustment 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. 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 he or she 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 the students in 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. You 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 it explored, what evidence it collected through research or experimentation, and how the evidence leads to a solution. The group then presents its 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 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 students to vote on which one they prefer, or ask each student to write a short response or exit ticket with a prompt such as 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 "Responding 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 Cartoon Cliff Escape problem we've been working on. As you present, remember that you need to describe how you got the data you used, any sources you found, and the results you want to share with the class. 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 it found. Jamal, I'd like your group to start, if you don't mind.

**Jamal:** OK. We looked up the force of gravity, and it's 9.8 $m/s^2$, just like we talked about on the first day. We read that a ball tossed up should hit the ground at the same speed as the ball that's tossed down. That didn't make sense to us. Then we did our experiment—and the data were kind of weird. First, we had a lot of trouble figuring out if we were tossing the balls up the same way we were tossing down. We each took turns holding the ball and swatting it up or down. The balls we batted up always took a little longer to hit the floor than the ones we batted down. But when we used the motion detector to measure the velocity near the floor, there was a fair amount of variation, but it looked like each person's tossed-up and tossed-down balls had about the same speed.

**Rose:** We had trouble with the motion sensors because they have to be aimed just right. But we found another way to find the velocities. There's an app we used on the tablets that lets us take a video and find the times by analyzing the video. Then we figured out the ball's speed in the video over the last meter.

**Anthony:** What? That's totally cool! Did it work better than the motion sensor?

**Rose:** Definitely! Our numbers were really consistent. It's kind of like what they do on Myth Busters.

**Ms. Sampson:** It's the same idea, Rose. But what did you find out when you tested the dropped and the tossed balls? Didn't I see your group doing the same tests as Jamal's group?

**Rose:** Yeah, we did. And we found the same weird thing. The balls are going about the same speed whether we toss them up or down.

**Mai:** Whoa, that's not what I expected! Our results were kind of unexpected, too. We found that the ball took the same time to drop if it was dropped or if it was pushed sideways. We decided that since, either way, the ball had to fall the same distance from the table to the floor, and they both took the same amount of time, both had the same speed. Here is our data table.

Mai put the data on the document camera to show the class.

**Ms. Sampson:** OK, let's put both sets of data on the board. Did anyone else get data about this?

**Jason:** Yeah, we tested dropping, horizontally tossing, and tossing upward. Our numbers for the dropped and horizontally tossed balls are almost as close as Mai's, but we tested with stopwatches. We thought the horizontal toss would take longer, but those trials were almost the same as for the dropped ball. It didn't make sense at first, so we did some research. There are some physics demonstrations that show that a bullet fired horizontally drops at the same rate as an object dropped straight down. It just travels horizontally at the same time it is falling. One website we saw said that gravity works in one direction, while the force of shooting the bullet acts in a different direction. We're pretty sure the same is happening with the balls. The trials when we tossed the balls up took longer than the others, but you could tell from size of the crater the ball makes in the sand that the balls are hitting the floor harder. We don't understand why, though.

**Ms. Sampson:** OK, that's a pretty strong pattern then. And your data match some sources you found online. Do you want me to add this to the board?

**Andrea:** Yeah, but then we want to share some other data. We tested the force when the ball hit the floor. I think we have some ideas to share.

**Ms. Sampson:** Sure, use the document camera.

**Andrea:** OK, we found a couple of ways to measure the force. One of them uses a "force table." That's a sensor that measures the force. We wanted to try that, but we don't have one. So we used the crater size method. The more force, the bigger the hole.

**David:** Wait a second. That doesn't sound like it would work. Wouldn't the sand just move back into the hole? And how can you measure that?

**Andrea:** Well, there's a website that suggests how to do it. Debbie, can you put that site on Ms. Sampson's computer so we can show how we did it?

Debbie found the website on the teacher's computer.

**Andrea:** See. You leave the ball in the sand, and it really seems to work!

**Ms. Sampson:** OK, that's one way we have learned to design experiments—borrow ideas from other sources. So, what did you find out?

**Andrea:** Well, first, we found that if you toss the ball up, it hits with more force. We thought that made sense. It's falling from higher, and if it's accelerating all the way down, it should be moving faster. We found a site that gave a formula that the change in velocity is equal to $a \times t$.

**Ms. Sampson:** Good! Take a look at this formula, class. It's telling us that the change in velocity will be more if the acceleration, $a$, is more or the time, $t$, is more. In this case, $a$ is always the same. It's the acceleration due to gravity. But as you found, the balls are falling over a longer period of time, so they end up going faster.

**Andrea:** It was a lot harder to test the horizontal throw, though. It's really hard to hit the box of sand every time. We only hit the sand twice, and since the ball is moving horizontally, it kind of splatters sand all over. It's hard to tell where to measure the depth.

**Rose:** Hmmm … I wonder if there's a better way to test that?

**Ms. Sampson:** If we have time, maybe we can test that again.

**Marcus:** Yeah, I have some ideas. But we need to work out our design first.

**Ms. Sampson:** OK, I understand that. Hey, Denise and Steven, did you do some tests, too?

**Denise:** Yeah, we did. Hey, guys, come up and help me show the trials we tested, then we can show our data.

Each group showed the results of its experiments and discussed its methods. Once all the groups were done, Ms. Sampson redirected the discussion to the original problem.

**Ms. Sampson:** OK, I think we've gone over these data pretty thoroughly. Now, it's time for your teams to start thinking about how your evidence relates to the Cartoon Cliff Escape problem. You have the rest of the class to talk about it, and you can share ideas outside of class. By tomorrow, I want each group to write its solution to the problem.

## 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 you have identified as an important learning goal. Resources such as Keeley and Harrington's (2010, 2014) publications can help teachers anticipate the types of inaccurate or incomplete understandings that may emerge during the PBL analysis process.

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. In the problem described in the vignettes, many students intuitively believed that the ball tossed horizontally would take longer to reach the ground. When skillfully used, asking questions can help students notice the problems with their claims. One of the most effective approaches is to have students compare a problematic claim with information they have listed under the "What do we know?" column of the analysis charts.

One strategy that can be effective is to ask questions such as "Do any of the 'what we know' statements contradict these findings?" In the vignette, Jason's group couldn't explain its results. Andrea's group had found the answer, but if the whole class had been stuck, having students examine the "what we know" list would have been helpful. Because the students had done research on gravity, they had a "What do we know?" item about gravity acting on an object in the same way regardless of horizontal movement, which may force the students to question their claims and conclusions. By asking students to use information from the sources they found, you can help them develop connections between evidence and concepts and among concepts (SEP 8: Obtaining, Evaluating, and Communicating Information). This is a critical practice in our world of abundant information. Students will be exposed throughout their lives 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 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 source of information. As in the strategy above, this places students in the role of evaluators and requires comparison of evidence and conclusions of their classmates. 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. Thus, you need 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' thinking processes, you may have to step in and present information that students need. If necessary, 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 acceleration time and the change in velocity. The formula was beyond what her students needed to know, but it applied directly to their questions, so she used her expertise to make it accessible to the students. There are many other ways to explain concepts using models, examples, and diagrams (Keeley and Harrington 2010, 2014; Schwarz, Passmore and Reiser 2017).

## Assessing Learning

When implementing a PBL lesson, you should respond to the learning needs of your students as they emerge. Flexibility is key, but to be flexible, you need 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 it provides for continuous assessment. The process of analysis using the PBL framework allows you 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, you see 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 helpful to implement informal assessment strategies such as exit tickets. These are 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 a ball falls at the same rate whether dropped or thrown horizontally, but we also want them to understand how gravity acts on other moving objects such as airplanes and rockets. 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 accompany specific problems, but they can also inform the choices you make about the next activities to include in a unit. Application questions are also offered as examples of summative assessments for the 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

Exit tickets (Cornelius 2013) are a simple and quick way to collect information about your students' understanding and issues that need to be resolved. An exit ticket 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 you at the end of class. The next step is for you 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 "What's one question you have about the Cartoon Cliff Escape 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 want to know if air resistance will change the time it takes objects to drop or their impact speed, depending on their size. 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 forces working on the ball you threw horizontally. Let's talk more about that.

She explained that any moving object may be influenced by forces acting in different directions. She set up a demonstration on a lab table using a table tennis ball. She had one student blow on it gently with a straw to show its motion. The force of blowing on it pushed the ball in a straight line. In a second trial, the first student blew on the ball, then a second student blew on it from a 90-degree angle. The ball changed direction but was still moving toward the far end of the table. Ms. Sampson explained that each force was independent and had pushed in a straight line. To make the ball stop moving toward the end of the table, a force would have to push back in the opposite direction from the first force.

### Group Summaries

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

In this assessment, students in each group are 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, 8). In the process of discussing and writing this summary, group members are able to solidify their understanding. 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

After the students thought about the Cartoon Cliff Escape problem and their experimental results, Ms. Sampson asked each group to write and turn in a summary of the plan they had developed with an explanation of how the plan worked. In these summaries, she noticed an issue that needed to be explained. Some of her students wrote that the ball that was tossed up had more velocity because a stronger force was acting on that ball.

**Ms. Sampson:** All right, I saw in your solutions that many of you wrote that the ball tossed upward has more force acting on it, so it is moving faster when it hits the ground. So I have a question for you. Which spaceship would move faster in outer space: one when you give a one-second burst of thrust with the rocket or one with same amount of force but the thruster firing for a four-second burst?

The students looked confused at first, so she asked them to view an online computer simulation that let them experiment with the movement of a spaceship in which they could control the thruster and see the velocity. She gave groups time to try out several scenarios and take some notes.

**Ms. Sampson:** So what did you find out about the movement of the spaceships?

**Sarah:** Our ship keeps accelerating if you leave the thruster on for a longer time.

**Carlos:** Yeah, and a short burst pushes the rocket, and it keeps going the same speed after that. If you keep firing the thruster, the velocity graph keeps going up.

**Mai:** We got the same thing, but I'm not sure I see what this has to do with the balls.

**Ms. Sampson:** OK, those are some good observations. So let's talk about the forces on the balls.

**Jason:** Well, gravity is pulling on the balls. It's that 9.8 $m/s^2$ thing. That's the rate of acceleration.

**Angie:** Oh, I think I get it now. When you toss the ball up, gravity is pulling it down for a longer time. It's like a thruster left on a little longer. So it will end up moving faster. It's not the force that's bigger. It's the amount of time the force is pulling it down.

**Ms. Sampson:** That's a great comparison! Keep in mind that the force of gravity is the same for all the balls—the force is constant. Now let's see how that might change your answers a bit.

## Summary

Facilitating PBL requires a slightly different set of skills than direct teaching does, 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 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 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.

## References

Bandura, A. 1986. *Social foundations of thought and action: A social cognitive theory*. Upper Saddle River, NJ: Prentice-Hall.

Cornelius, K. E. 2013. Formative assessment made easy: Templates for collecting daily data in inclusive classrooms. *Teaching Exceptional Children* 45 (5): 14–21.

Dinsmore, D. L., P. A. Alexander, and S. M. Loughlin. 2008. Focusing the conceptual lens on metacognition, self-regulation, and self-regulated learning. *Educational Psychology Review* 20 (4): 391–409.

Keeley, P., and R. Harrington. 2010. *Uncovering student ideas in physical science, Volume 1*. Arlington, VA: NSTA Press.

Keeley, P., and R. Harrington. 2014. *Uncovering student ideas in physical science, Volume 2*. Arlington, VA: NSTA Press.

Lambros, A. 2002. *Problem-based learning in K–8 classrooms: A teacher's guide to implementation*. Thousand Oaks, CA: Corwin Press.

National Research Council. 1996. *National Science Education Standards.* Washington, DC: National Academies Press.

National Research Council. 2000. *Inquiry and the National Science Education Standards.* Washington, DC: National Academies Press.

NGSS Lead States. 2013. *Next Generation Science Standards: For states, by states.* Washington, DC: National Academies Press. *www.nextgenscience.org/next-generation-science-standards.*

Schwartz, D. L., C. C. Chase, and J. D. Bransford. 2012. Resisting overzealous transfer: Coordinating previously successful routines with needs for new learning. *Educational Psychologist* 47 (3): 204–214.

Schwarz, C. V., C. Passmore, and B. J. Reiser. 2017. *Helping students make sense of the world using next generation science and engineering practices.* Arlington, VA: NSTA Press.

Zhang, M., M. Lundeberg, T. J. McConnell, M. J. Koehler, and J. Eberhardt. 2010. Using questioning to facilitate discussion of science teaching problems in teacher professional development. *Interdisciplinary Journal of Problem-Based Learning* 4 (1): 57–82.

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ISBN: 978-1-941316-21-4

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