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Summary

CHAPTER 3 DECIDING HOW TO TEACH IT

Introduction

The previous chapter may have helped you decide *what* to teach, but will your students *learn* what you teach? Is there a best way to teach science so children *get* what you want them to get? How do you plan meaningful instruction so they will get what you want them to get?

The short answer to the "best way" question is *no, there is not a best way to teach science, there are multiple ways depending upon the learning goals and needs of the students.* One thing research over the past quarter century has borne out is that no single method defines exemplary science instruction. In its study*, How People Learn* (Bansford, 1999), the National Research Council (NRC) Committee on Developments in the Science of Learning concluded that four categories of the learning environment are particularly connected to how well students learn, how they transfer that learning, and perform competently:

1. **Learner-centered environments.** Effective instruction begins with what learners bring to the setting; this includes cultural practices and beliefs, as well as knowledge of academic content. A focus on the degree to which environments are learner centered is consistent with the evidence showing that learners use their current knowledge to construct new knowledge and that what they know and believe at the moment affects how they interpret new information. Sometimes learners' current knowledge supports new learning; sometimes it hampers learning.

2. **Knowledge-centered environments**. The ability to think and solve problems requires knowledge that is accessible and applied appropriately. An emphasis on knowledge-centered instruction raises a number of questions, such as the degree to which instruction focuses on ways to help students use their current knowledge and skills. New knowledge about early learning suggests that young students are capable of grasping more complex concepts than was believed previously. However, these concepts must be presented in ways that are developmentally appropriate by linking learning to their current understanding. A knowledge-centered perspective on learning environments highlights the importance of thinking about designs for curricula. To what extent do they help students learn with understanding versus promote the

acquisition of disconnected sets of facts and skills? Curricula that are a "mile wide and an inch deep" run the risk of developing disconnected rather than connected knowledge.

3. **Assessment to support learning**. Issues of assessment also represent an important perspective for viewing the design of learning environments. Feedback is fundamental to learning, but feedback opportunities are often scarce in classrooms. Students may receive grades on tests and essays, but these are summative assessments that occur at the end of projects. What are needed are formative assessments, which provide students with opportunities to revise and improve the quality of their thinking and understanding. Assessments must reflect the learning goals that define various environments. If the goal is to enhance understanding and applicability of knowledge, it is not sufficient to provide assessments that focus primarily on memory for facts and formulas.

4. **Community-centered environments**. The fourth, important perspective on learning environments is the degree to which they promote a sense of community. Students, teachers, and other interested participants share norms that value learning and high standards. Norms such as these increase people's opportunities and motivation to interact, receive feedback, and learn. The importance of connected communities becomes clear when one examines the relatively small amount of time spent in school compared to other settings. Activities in homes, community centers, and after-school clubs can have important effects on students' academic achievement.

In keeping with these findings, our goal is to provide instruction that is *learner-centered*, *knowledge-centered*, *supported by assessment*, and *community-centered*. This will be accomplished through ***inquiry-based instruction***.

Inquiry-based Instruction

Remember the five essential features of classroom inquiry identified in Chapter 2? This section asks, how do you make it happen? Or, in the words of the National Science Education Teaching Standard B (NSES, 1996), how do you:

- focus and support inquiries while interacting with students?
- orchestrate discourse among students about scientific ideas?
- challenge students to accept and share responsibility for their own learning?
- recognize and respond to student diversity and encourage all students to participate fully in science learning?

- encourage and model the skills of scientific inquiry, as well as the curiosity, openness to new ideas and data, and skepticism that characterize science?

Here, in table format, are those five essential features. Also included is an adaptation of inquiry variations from *Inquiry and the National Science Education Standard* (National Academy of Science, 2000). These variations are based on levels of student self-direction. Recall from Chapter 2 that the overarching goals for your classroom inquiry instruction will focus on Structured Inquiry or Guided Inquiry. As far as Open Inquiry goes, "…students rarely have the ability to begin here. They first have to learn to ask and evaluate questions that can be investigated, what the difference is between evidence and opinion, how to develop a defensible explanation, and so on. A more structured type of teaching develops students' abilities to inquire…. Experiences that vary in 'openness' are needed to develop inquiry abilities. Students should have opportunities to participate in all types of inquiries in the course of their science learning (NSES, 1996, pp 29-30)."

Table 3.1 Essential Features of Student Inquiry and Levels of Student Self Direction

	Levels of Inquiry based on Student Self-Direction		
Essential Features of Classroom inquiry	**Open Inquiry**	**Guided Inquiry**	**Structured Inquiry**
1. Students begin with questions that can be answered in a scientific way.	Learners pose scientific questions for themselves.	Learners clarify and select from among questions suggested by the teacher.	Learners use questions provided by the teacher or other source.
2. ***Students give priority to evidence in attempting to answer the questions.***	Learners carry out investigations and information searches on their own.	Learners are guided by the teacher in carrying out investigations and searches.	Learners perform investigations and search sources following directions provided.
3. Students develop descriptions, explanations and predictions based on the evidence collected.	Learners formulate descriptions, explanations, and predictions from their collected evidence.	Learners are guided by the teacher in formulating appropriate descriptions, explanations, and predictions.	Learners draw from descriptions, explanations, and predictions presented by the teacher.
4. Students connect their	Learners take the	Learners are guided	Learners are shown

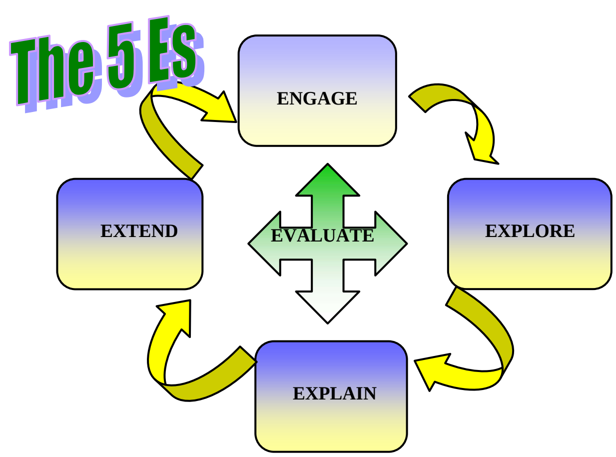
evidence and explanations leading to scientific knowledge.	lead in connecting evidence and explanations to their developing knowledge.	by the teacher in connecting evidence and explanations to scientific knowledge.	how evidence and explanations link to scientific knowledge.
5. Students communicate and justify their procedures, evidence and explanations.	Learners take the lead in presenting, discussing, and challenging questions, evidence, and explanations.	Learners are guided in communicating procedures, evidence, and explanations.	Learners follow procedures for communication given to them by the teacher.
	Less Teacher Direction	←→	More Teacher Direction

Source: *Inquiry and the National Science Education Standards: A Guide for Teaching and Learning* (2000) by the National Academy of Science, National Academies Press, Washington, DC.

The 5 Es

Numerous models of inquiry instruction have been introduced over the years with varying degrees of success, but perhaps none as applicable as the *5 Es*, originally developed by Biological Sciences Curriculum Study (BSCS) in 1989. As you will see, the *5 Es* answer the Teaching Standard B questions posed above and provide the mechanism for you to plan inquiry instruction that captures the five essential features of classroom instruction. The 5 *Es* can be defined as: *An inquiry process of* ***e****ngaging students in the big ideas,* ***e****xploring the big ideas further,* ***e****xplaining why things happened,* ***e****xtending understanding through new applications, and continually* ***e****valuating understanding through a variety of techniques.* The first E, *engage,* is about *piquing* your students' curiosity, *hooking* them, and *focusing* their attention on the topic. Once students are sufficiently engaged they are ready to *explore* the content in more depth, therefore you as the teacher should consider what learning experiences will encourage students to gather evidence, try out hunches, and pursue answers to questions. The third E, *explain*, helps to equip students with the information they need to demonstrate their understanding. The key is to build on your students' experiences to help them grasp scientific explanations. Look for examples of how you could help students *make sense* of their observations and questions, *describe* what they see, and give *explanations* for why things happened certain ways. Students then *extend* their experiences by digging deeper, applying new understandings to new situations, presenting and defending their own understandings and explanations, and working through misconceptions. *Evaluate* is unique in that it almost continuously applied since information about how students are doing and understanding the science is needed on an ongoing basis. As a teacher you should plan both formal and informal means of assessment that will reveal what students understand and are able to do.

As the *5Es* diagram below suggests, one "*E*" flows into the next in an organic, non-linear fashion. While initially the process usually starts with *engage* and proceeds through *extend*, with *evaluate* applied throughout, it doesn't stop there because the very action of going through these Es invites more engagement, exploration, explanation and extension.



Here's a suggestion. Work through the *guiding prompts* before reading about each *E* in more depth. You will understand the *5Es* best by actually applying them – the prompts are designed to help you do that. You could do this alone in a written response format or in a small-group brainstorming session. Either way, the benefits will be obvious. To answer the prompts you need some kind of teaching context to apply it to. Perhaps you're already planning instruction for the classroom. If so, use these prompts to guide that planning. If not, peruse the units in Part 2 of this textbook, find one that's intriguing, then use the prompts to guide your inquiry planning for that unit.

Engage

Guiding Prompts

1. How could you probe students' conceptions and misconceptions about the *big ideas* of this unit?
2. In what ways could you use students' prior knowledge to create interest and generate curiosity about the topic?
3. Come up with some strategies to elicit responses to uncover what the students know or think about the concepts addressed in this topic.
4. How could you *pique* your students' curiosity?
5. How could you *hook* them?
6. How can you *focus* their attention on the topic?

Prior Knowledge

The way students organize, interpret and understand new information is significantly determined by what knowledge, skills, beliefs, conceptions and misconceptions they bring to the classroom. Their memory, reasoning, problem-solving and acquisition of new knowledge are all influenced by prior-knowledge. They don't come into your classroom with blank slates, so it behooves you as a teacher to probe, pre-assess, and elicit responses to figure out what is on those slates. This is the stuff you need to figure out how to *engage* them in whatever topic you're going to introduce. It also provides valuable *evaluation* evidence against which you can compare later evidence as you travel through *explore, explain* and *extend*.

Discrepant Event

Prior-knowledge is only part of the *engage* equation. You still need to find the means to *hook* them, to *pique* their interest. It's called the *discrepant event*, and it is one of the more powerful tools you can use to introduce a topic, unit, or lesson. A *discrepant event* occurs when a *discrepancy* exists between what the learner *thinks* is going to happen, and what actually happens. In Piagetian terms (Piaget, 1978), the learner experiences disequilibrium and in order to return to equilibrium seeks a solution. This increases curiosity and a strong motivation to know, to figure out. Naturally, the discrepant event has to be intriguing enough for the learner to care about its solution. How excited will you be in a class that begins with: "Today, we're going to learn about air pressure"

Now imagine an egg on the mouth of a bottle. "Can anybody tell me how do get this egg inside the bottle without destroying the egg?" You light some crumpled paper, drop it in the bottle, replace the egg on top of the bottle, and *pffffff-plop*, the egg is in the bottle. Whole.

Try it and see if any of your students say, "So?"

A good discrepant event should create a strong feeling within your students to know more. "How did it do that?" "It's a trick." "What's the fire got to do with it?" "Is it because of the smoke?"

You have *engaged* the students. Time to move on.

Wait a minute, you weren't thinking of giving them the answers, were you? And ruin this great start to *inquiry*? Resist the temptation to give answers too soon. Instead, look for opportunities to build on the student questions. Remember that the first essential feature of classroom inquiry is: *Students begin with questions that can be answered in a scientific way*. If your *engage* phase sets the stage for this to happen, consider it a success.

A discrepant event doesn't necessarily have to be a physical demonstration – anything that grabs your students' attention and goes against what they expect, stimulates curiosity and interest, and generates open-ended questions – will work. Generally speaking, however, whenever you can use physical demonstrations, they are powerful. Most of the unit-opening activities in Part 2 qualify as discrepant events, and they are predominantly physical activities.

<u>Setting up the Discrepant Event</u>

You should not expect to use discrepant events for every activity or lesson. First, their impact would be diminished by overuse; but second, there simply are not discrepant events for every kind of teaching you are going to do. As a general rule of thumb anticipate introducing new topics or units with a discrepant event, and perhaps some key lessons within the unit. The following general guidelines should help.

1. Set up. Try the activity yourself beforehand, then make sure you have the necessary materials for demonstration. Use some variation of the question: *What do you think will happen?*
2. What happened? Let the students ask questions and pose explanations. Anything goes. No need to squelch excitement with a "that's not a testable question" reply. Still, as the conversation ensues you can provide guidance in how their questions might be explored. For example, you

could assist them in effective use of the process skills (e.g., observations, recording data, classifying, predicting, controlled experiments).

3. Next steps. There is no reason to immediately "solve" your discrepant event. Instead, use it to set up what's next. It may be that the discrepant event is simply a unit-opener, or perhaps the questions generated become inquiry questions for the whole unit. Whatever the purpose, letting the solution hang for a while replicates real science and is sound pedagogy. From a structured or guided inquiry perspective, the discrepant event can pave the way for teacher provided questions and investigations.

Explore

<u>Guiding Prompts</u>

1. How could experiences be structured to encourage students to gather evidence, try out hunches, and pursue answers to provocative questions?
2. How could you scaffold learning experiences to allow the students to explore as much as possible on their own?
3. Come up with some probing questions you could use to redirect students' investigations when necessary.
4. What activities will allow students to *handle and manipulate* materials?
5. How could you help students *make discoveries*?
6. How can you get students to *talk about* their discoveries?

Scaffolding

Building on the egg-in-the-bottle example, you may have had one or more big ideas in mind—the effect of heat on air pressure, higher pressure-lower pressure – and now you want your students to manipulate materials and gather evidence to come up with some explanations. So you set up a handful of investigations related to heat and air pressure and provide maximum opportunities for students to *explore* and refine their questions and investigations. The second essential feature of classroom inquiry comes in here: *Students give priority to evidence in attempting to answer the questions.* Your role is to largely assist students in their explorations, which involves *scaffolding* to get them closer to answering questions with evidence.

Scaffolding, the "role of teachers and others in supporting the learner's development and providing support structures to get to that next stage or level" (Raymond, 2000, p. 176). is a powerful instructional tool originating from Lev Vygotsky's concept of the *zone of proximal development* (ZPD*)*. "The zone of proximal development is the distance between what children can do by themselves and the next learning that they can be helped to achieve with competent assistance" (Raymond, 2000, p.176).

You may need to provide a lot of scaffolding early on, but as your students' understandings and abilities increase, back off and allow them more autonomy. The goal "… is for the student to become an independent and self-regulating learner and problem solver" (Hartman, 2002). The notion of removing scaffolds is important because, as Vygotsky postulated, "…the system of knowledge itself becomes part of the scaffold or social support for the new learning" (Raymond, 2000, p. 176).

In *Scaffolding for Success*, Jamie McKenzie (1999) describes six qualities of scaffolding instruction:

1. Provides clear direction and reduces students' confusion – Educators anticipate problems that students might encounter and then develop step by step instructions, which explain what a student must do to meet expectations.

2. Clarifies purpose – Scaffolding helps students understand why they are doing the work and why it is important.

3. Keeps students on task – By providing structure, the scaffolded lesson or research project, provides pathways for the learners. The student can make decisions about which path to choose or what things to explore along the path but they cannot wander off of the path, which is the designated task.

4. Clarifies expectations and incorporates assessment and feedback – Expectations are clear from the beginning of the activity since examples of exemplary work, rubrics, and standards of excellence are shown to the students.

5. Points students to worthy sources – Educators provide sources to reduce confusion, frustration, and time. The students may then decide which of these sources to use.

Science Process Skills

In the *engage* phase the process skills may or may not have been introduced, but in this phase it is time to help students learn how and where to use applicable process skills. The science process skills are those skills typically employed by scientists to solve problems. Traditionally the process skills were taught as separate functions, often out of context which left students disconnected from how the skills actually work in scientific inquiry. Under the current paradigm of science inquiry they are integrated and in context. Students learn to use them as scientists do – as tools to help them move their inquiries forward. Still, the skills need to be developed to progress beyond the novice stage. In *How People Learn*, one of the key research findings of expert versus novice is: “Experts notice features and meaningful patterns of information that are not noticed by novices (Bransford, 1999).” Though we are not trying to turn all our students into experts, we are trying to help fine-tune their inquiry skills and experience successful learning. Briefly, here are the dominant science processes:

Observing: Using any or all of the senses to acquire data (characteristics, properties, differences, similarities, changes) about objects and events. Instruments may also be used to extend the senses.

Measuring: Using instruments to quantify variables or compare an unknown quantity with a known (e.g., metric units, time, or other frames of reference).

Classifying: The process of grouping or ordering objects or events into categories based on one or more common characteristics.

Inferring: Using prior knowledge, observation data and understandings of that data to draw tentative conclusions. Note that *inferring* makes assertions about what *happened,* while *predicting* makes assertions about what *will happen*.

Predicting: Using prior knowledge, observation data and understandings of that data to forecast potential outcomes of an experiment or investigation. Note that *predicting* makes assertions about what *will happen,* while *inferring* makes assertions about what *happened.* Also note that a prediction *is not* a hypothesis, which is more formal and controlled. The terms have often been treated interchangeably, but this creates confusion down the road when careful manipulation of variables in a controlled experiment are required.

Investigating and Controlling Variables: This is the process of setting up an experiment that intentionally manipulates just one variable at a time and holds all other variables constant. The effect of the manipulated variable on one or more responding variables is then observed, measured and/or classified, leading to possible inferences, predictions, hypotheses or other explanations. Note that this "single" process skill is really the integration of "several" processes.

Hypothesizing: A more formal and controlled prediction. Forming a hypothesis implies possible relationships that might occur through an investigation. Therefore, to have a hypothesis you need to know something about what data your are going to look at or manipulate or control.

Using Number Relationships. Applying numbers and mathematical principles or calculations to understand scientific questions.

Two other process skills, *explaining* and *communicating* are also important, but since they fit more under the *explain* phase we'll consider them then.

As you can see, the *engage* phase might take considerable time. That's alright. One of the tendencies we need to break in classroom science is beginning and ending lessons in one class period. A lesson might extend over a number of class periods, an investigation could conceivably begin with the start of a unit and still not be done by the conclusion. You have to keep reminding yourself what your goals are, which should be less getting-the-right-answer oriented and more focused on activities that explore science questions and use evidence to improve understanding.

When you come to the point that your scaffolding has brought your students to the next level, or when it is evident that they need more information to move forward with their inquiries, it is time to transition from *explore* to *explain*.

Explain

Guiding Prompts

1. How could you introduce new concepts to guide students to link the concepts back to the experiences they had during exploration phase?
2. How would you assist students to use the new concepts along with evidence from investigations to build descriptions and scientific explanations?

3. What ways could you get students to justify and clarify their explanations of concepts and definitions?

4. How could you help students *make sense* of their observations and questions?

5. How could you help students *describe* what they see?

6. How can you help students with *explanations* for why things happened certain ways?

Classroom Discourse

An error teachers often make at the *explain* phase is telling “the right answers.” The thinking is that students have had their fun exploring and coming up with their own explanations, but now its time to get it right. This is a sure way to kill the spirit of inquiry and engender student distrust. Research on student attitudes about school science bears out that by the time students get to high school one of their biggest complaints is that lab science is boring because the answers are pre-determined. “Why not just tell us the answers,” the complaint goes, “if you already know what the answers to the experiments are anyway?” As teachers we tow a fine line here. After all, the truth of the matter is that we *do* want them to get to the right answers, so when do we intervene in their learning? “Ultimately, teachers do need to help shape students’ views of science, and to do that, they must intervene at key moments in students' learning, even in inquiry-based learning. Opportunities for figuring out scientific ideas must be contrived, organized in such a way that learning is likely to occur” (Hinrichsen & Jarrett, 1999—NW lab lit review).

This is the phase in which you will use scientific vocabulary and introduce science concepts and related information to help students make sense of their (and your) questions, but it needs to be done with the awareness that they need opportunities to describe their observations and provide their own interpretations and explanations of events. Think of it as the next scaffold: connecting your students' observations, interpretations and explanations to new knowledge through meaningful discourse. But beware: "What we describe as 'discussion' in the classroom is often in reality a question-and-answer session – with the teacher doing most of the questioning. Such exchanges lack the richness of genuine dialogue, where there is a much more equal sharing of the questioning and the answering. The value of real dialogue lies in learners hearing others' ideas and in having to express their own" (Harlan, 2001).

According to the National Science Education Standards, "An important stage of inquiry and of student science learning is the oral and written discourse that focuses the attention of students on how they know what they know and how their knowledge connects to larger ideas, other domains, and the world beyond the classroom" (NSES, 1996). You support and guide this discourse in two ways:

1. Require students to record their work – teaching the necessary skills as appropriate; and
2. Promote many different forms of communications (for example, spoken, written, pictorial, graphic, mathematical, and electronic).

Two additional science process skills also become important in this phase:

Explaining: Logically connecting evidence and existing scientific knowledge to clarify discrepant or confusing events. Explaining may sound like inferring, but the difference lies in the many pieces of the puzzle that a typical explanation requires. It may need to draw on several inferences as well as the results of controlled investigations and existing theories.

Communicating: Formally, communicating is about recording the steps of an investigation, then conveying the results to an audience. Realistically, it may involve conveying smaller facets, say the steps taken for a particular science process or even the observation results of a single event. Communication can and should occur in multiple formats, such as posters, graphs, demonstrations, drawings, diagrams, tables, oral reports, PowerPoint presentations, or any number of creative approaches.

Questions

One of the most important strategies to encourage discourse is *questions*. Teachers use questions for instructional purposes all the time, of course, but there are different kinds of questions, so what kinds will best serve our purpose to encourage student discourse in the inquiry process? Questions to encourage student learning, according to Jos Elsteest (2001), are either "productive" or "unproductive." The unproductive ones are the "why, how and what" questions – closed questions used to test whether or not students know the "right answer." Productive questions are the ones that make students think and ponder in particular ways. Let's look at some of his examples, adapted from "The Right Question at the Right Time," in *Primary Science: Taking the Plunge*, Edited by Wynne Harlen. London: Heinemann Educational Books, 2nd Edition. 2001. (Taken from Institute for Inquiry, Exploratorium)

1. Attention-focusing questions -- To help students focus on observations and other details and make connections:
    - "Have you seen...?"
    - "Do you notice...?"
    - "What is it?"
    - "What does it do?"
    - "What do you see? Feel? Hear?"
2. Measuring and counting questions – To help students develop confidence because the questions can be answered directly from the experiences of the activity:

- "How many...?"
- "How long...?"
- "How often...?"

3. Comparison questions – To help students focus their observations and to classify, categorize and/or order objects or results.

   - "In how many ways are _____alike?"
   - "How do they differ?"
   - "Can you describe an order or pattern to ______?"
   - "In what ways can you classify/categorize ______?"

4. Action questions – Help students explore new materials, properties, forces, and/or events. Can be answered through simple investigations.

   - "What happens if ___?"
   - "What happens if you don't___?"

5. Problem-posing questions – Engage students in realistic problem-solving situations, encourage experimentation and promote critical thinking.

   - "Can you find a way to ___?"
   - "Can you do it another way?"

6. Reasoning Questions – Stimulate students reasoning and help them to draw conclusions and generalizations, leading to expanding or changing their ideas. These questions should not be asked until students have sufficient experience to reason from evidence.

   - "What do you think about ____?"
   - "Why do you think ___?"

7. Metacognitive Questions – These questions help students think about their own thinking processes (adapted from "Developing a Community of Scientists," by Jeanne Reardon in S*cience Workshop,* Wendy Saul et.al.,. Heinemann Educational Books, 1985.)

   - What have you discovered?
   - How do you know?

- What do you wonder?
- What will you do next? How do you decided what to do next?
- How do you decide what to record?
- What helps you do science?
- How do you know when to stop, that you are finished?
- Do you ever give up (abandon) your idea/question/explanation? When? Why?
- What makes you reverse your explanation?

You should notice a few distinctions about these questions:

1. They are, by and large, open ended, or divergent – encouraging diverse responses.
2. They help to sharpen the science process skills.
3. They are reflective and open the door to critical thinking and creative problem solving.

Effective questioning doesn't happen without preparation, so here are some guidelines:

- Prepare specific questions for each of the seven types. It's easier to adapt than it is to come up with new questions on the spot.
- Have a purpose for your questions. Are you trying to stimulate the science process skills? Which ones? Do you want students to confront their misperceptions? Do you want to encourage problem solving? Gain insight into their interests? Help them set realistic expectations? Encourage reflection and communication skills?

- Some convergent questions (yes-no) may be necessary, but emphasize divergent (open) questions
- Be simple, concise and direct.
- Less telling, more asking.
- Use questions to connect student questions and thoughts
- Help your students improve their own questions. Do this first by modeling good questioning yourself, "teaching" good questioning, and encourage questions in an atmosphere of trust.
- Repeat and paraphrase what they have said in uncritical tone.
- WAIT! The typical teacher waits less than one second for a response, but research shows that if you increase "wait-time" to three to five seconds you will increase active participation, stimulate longer and enriched discussions, and encourage more constructive reasoning and problem-solving.
- Pay attention to both kinds of wait-times. *Wait-Time 1* is the initial wait-time the teacher waits for the *first* response before continuing (The 3 to 5 second *wait*). *Wait-Time 2* is the *total* time the teacher waits after receiving the answer before continuing. The difference is that *Wait-Time 2* could conceivably take minutes or, in the case of a full-blown inquiry, days.

One of the side benefits of the *explain* phase is that it provides the forum for *misconception* to surface. This gives you the opportunity to identify which misconceptions are particularly stubborn and what to do about it. You should expect to deal with misconceptions in any and all of the *5E* phases, but the next phase, *extend*, is particularly suited to address them, so let's move on.

Extend

<u>Guiding Prompts</u>

1. How could you help students dig deeper into the concepts and skills acquired?
2. What are some possible new situations in which students could apply or extend the concepts and skills they learned?
3. Identify possible student misconceptions and how you could help students work through them.
4. How will students *apply* newly learned concepts and skills to *new situations*?
5. How could you help them to *present and defend* their understandings and explanations?
6. What are possible student *misconceptions* and how would help students work through them?

Concept Application

This phase is the crowning feature of the *5E* process because it is about acquiring understanding through concept application and conceptual change. It is an often neglected phase by teachers, no doubt because applying new concepts and confronting old ones is challenging – albeit rewarding, if you have the right tools.

Your first tools are the inquiry activities themselves. Your students have already conducted inquiry activities from the start, of course, but the distinction here is that they now conduct activities with a wealth of new knowledge. Consider what they have gone through since that initial discrepant event. Students began with questions, gathered evidence in an attempt to answer those questions, and developed descriptions, explanations and predictions based on that evidence. In other words, the first three of the five essential features of classroom inquiry have already been met, and even the remaining two (*Students connect their evidence and explanations leading to scientific knowledge*, and *Students communicate and justify their procedures, evidence and explanations*) are well on their way.

There are many tricks to helping students apply their new knowledge but none so powerful as applying that knowledge to real world applications. Let's get back to our egg in the bottle discrepant event. The "ahas" were great and they generated a lot of intriguing questions, followed by various activities to gather evidence that helped clarify the concept of air pressure. Students learned that the air pressure inside the bottle increased because it was heated, and when the egg was placed on the opening the air inside cooled, causing the air pressure to decrease. Because the air pressure in the room became greater than the air pressure in the bottle, the greater pressure exerted enough pressure on the egg to push it into the bottle.

Neat stuff – maybe – but how do you extend this into real world applications? Are your students into basketball? If so, they could apply the concepts they have acquired to how well a basketball bounces based on the inside air pressure. Basketball doesn't quite do the trick? How about rockets? Or airplanes. Having learned the role air pressure plays in the flight concepts of lift, drag and thrust, and how these work in conjunction with the force of gravity. They can end up designing a better airplane based on these concepts.

The unit activities in Part 2 provide suggested concept applications, but in reality nobody knows better than you and your students what is important in their world. Find something in their world that they care about, find novel ways to apply the concepts they have acquired to that "something", and you will have successful concept applications.

Conceptual Change

We learned in Chapter 2 how stubborn misconceptions can be. Even after students have gone through all five Es and the evidence against their conceptions is overwhelming, there will still be resistance. Conceptual change is about repairing those misconceptions (Chi and Roscoe, 2002), but since there will be barriers, let's look at some of them:

1. The first and perhaps strongest barrier is stubbornness. Children can tenaciously refuse to admit that their preconception is wrong, and will find ways to bend their beliefs before assimilating new one.

2. "Hard-core ideas" hold sway. Lakatos (19__), suggests that students will protect their hard-core beliefs, even if they have to change their positions on concepts that are less important. Recall the example from Chapter 2 of students changing their concepts of light and dark to protect their hard-core beliefs that eventually the eye would see even in a pitch black room. Not even the hard evidence of a first hand experiences could sway them.

3. "It's magic" is a frequent response when children cannot cite scientific knowledge to explain evidence that contradicts their misconception.

4. Language. Each language, each region has its own vernacular, everyday use of certain vocabulary words. When science uses those terms the meaning may be entirely different. But not to the student. "Hot" and "cold", for example, have deeply embedded meaning for many children, so the scientific concept of heat as a measurable quantity of energy that all objects (even cold ones) contain.

5. The senses can deceive us into believing something that isn't true. I see the sun rising over the horizon each morning, thus the sun rises, I don't care what you tell me. The full moon is much larger at the horizon, don't tell me it's an optical illusion. Place one hand in ice water and one in hot water for five seconds, then place both in lukewarm water. The lukewarm water feels warm to the ice water hand, cool to the hot water hand.

6. Science itself poses barriers, as discussed by David Hawkins (19__). Understanding size, volume, weight, and heat, for example, are concepts

scientists themselves have struggled with for centuries. Children are unlikely to grasp such concepts in a matter of days or even weeks.

What can we do about these barriers to bring about conceptual change? Piaget's concept of assimilation indicates that when confronted with a new experience, children first fit this experience into existing mental schemes, but when the existing mental scheme doesn't fit, they must change their mental schemes – accommodation. This is a reasonable cognitive concept, but how do we get them from assimilation to accommodation? Posner and Strike et.al (1982) proposed the "conceptual change" learning model to answer this question. The theory states that four conditions foster the accommodation process. Students need to:

1. be dissatisfied with their existing belief,
2. see that the new concept appears to be somewhat plausible,
3. grasp that the new concept is more attractive to them, and
4. recognize that the new concept has explanatory and predictive powers.

Conceptual change requires confronting one's misconceptions through a variety of avenues. Thus, what follows is a variety of tactics. To increase the likelihood that all four conditions of the conceptual change model are met, use several tactics.

Tactic 1, building on Vygotsky's zone of proximal development (ZPD), recognize that children need your help because the capacity to accommodate new schemes on their own is hindered by too many factors. The reason ZPD remains vibrant decades after Vygotsky introduced it is because experience bears out that scaffolding guides students through the developmental factors that inhibit growth without such guidance. Improvements in memory, skills acquisition and reasoning ability, to name just a few developmental factors cited by Vygotsky, are all enhanced when effective scaffolding is used.

Tactic 2, you must start with the unique world view that each child brings to the table determined by their own personal observations and experiences that got them there. You help them link that world view with the generally accept scientific concepts by allowing them to discuss their understanding with others (Driver, et al., 1994a, 1994b; Vygotsky, 1962, 1978). Pay attention to the many avenues available through the process skills of explaining and communicating. For example, using a white board to illustrate and demonstrate their understanding of how a phenomenon works can provide students the necessary vehicle to use examples from personal experiences to give a picture of their conceptual view.

Tactic 3, use observation techniques to draw attention to characteristics or behaviors of a phenomenon. You can have student draw things that behave in similar ways to the thing being observed, or write about distinctive characteristics and infer or predict changes in behavior if some variable were changed. Thus, you start with observed phenomena but through creative teaching strategies extend the thinking into inferences, predictions, or new questions that make explicit connections (Saul & Reardon, 1996).

Tactic 4, encourage more experimentation. The nature of experimentation requires predicting or hypothesizing which has far reaching consequences for conceptual change. To hypothesize you need to link new information with what you already know; the active process of doing this makes students more willing to accept the new information and change their thinking accordingly.

Tactic 5, stress relevance. As already noted under *concept application,* if children can relate the new concepts to their everyday lives they're going to accept them. In addition to your own repertoire of "relevant" applications, ask the students to come up with examples of the new information in their lives. Once they own the new idea they are more apt to accept it and replace misconceived ideas.

Tactic 6, use reflective thinking. Journal writing is a perfect example. Have your students write what they think about the phenomena observed, inference made, experiments conducted, and evidence gathered. And have them write about how the new information relates to their pre-existing ideas. This "reflective abstraction" – thinking about one's own thinking (Piaget, 19__), facilitates the developmental processes of assimilation and accommodation.

Tactic 7, stress consistency in the logical thinking process. If, for example, the child maintains that heat has nothing to do with air pressure after having already surmised that the heated bottle caused the egg to plop inside and the balloon placed over the opening to be drawn inward, tactfully challenge this inconsistency by posing additional investigations, citing additional examples, or simply asking the child to consider how two contradictory positions could both be true.

Tactic 8, whatever misconcepts are replaced need plausible explanations if children are going to accept them. Be ready with such explanations, or work with your students to come up with the new explanations. This new explanation should be tested so the students can see that it is a sound replacement for the former explanation that did not stand up to scrutiny.

Tactic 9, introduce concepts or new information with examples and nonexamples. So when you are teaching the concept that heat reduces air pressure by heating a bottle and placing an egg over the top, doing it also with a deflated balloon over the mouth of the bottle, and a water balloon, and a few other "examples" that students themselves come up with. And don't just use a heated bottle. Come up with other examples. The unit on air pressure in Part 2 provides several hands-on activities that could be used as examples. Non examples would include placing the same materials over a cold bottle and observing what happens (or doesn't happen).

Evaluate

Guiding Prompts

1. Describe different ways (formal or informal) you can monitor progress so you can give students feedback on the adequacy of their ideas and inquiry procedures?
2. What kinds of assessments will provide you with the evidence that students understand the big ideas or concepts and have changed their thinking or behaviors?
3. What are some strategies you could use to help students self-assess their own learning and make adjustments to their tasks?
4. What assessment tasks can you select that will also be good learning experiences?
5. What creative expressions of understanding can you integrate into your ongoing evaluation?
6. What performance tasks can you integrate into the inquiry process?

Ongoing Evaluation

It used to be that assessment was something tacked on at the end of a learning experience to "test" how well students retained the information. We now know that ongoing assessment is paramount to successful learning. The NSES science teacher standards state that "… information about students' understanding of science is needed almost continuously. Assessment tasks are not afterthoughts to instructional planning but are built into the design of the teaching" (NSES, 1996, p. 38).

For purposes of the *5Es* what you should be looking for are ways to evaluate that will support the inquiry process. As your students maneuver through the *Engage-Explore-Explain-Extend* phases you are looking for evidence to indicate what they are "getting" or "not getting." Based on this evidence you can adjust instruction as needed and ultimately make a determination about whether or not your students have met expected outcomes. There are many ways to do this. Sometimes it is informally observing and listening to your students as they work, other times through interviewing them, or in a number of other ways such as "performance tasks, investigative reports, written reports, pictorial work, models, inventions, and other creative expressions of understanding" (NSES, 1996, p. 38).

The process used during instruction to indicate how well students are grasping the big ideas and desired outcomes, and where more guidance is needed, is often referred to as <u>formative evaluation</u>, which simply means we assess understanding as the activities are forming, or occurring. The focus is on the process, which is why formative evaluation is such a critical part of inquiry.The four primary purposes of formative evaluation are:

1. To monitor student progress on an ongoing basis throughout the unit.

Informal checks for understanding are all you often need for much of your formative assessment. A daily journal entry, an open-ended question, some misconception checks – these or number of other variations come a long way in telling you what you need to know. *Traditional assessments* might be used if your unit is long enough. A weekly quiz, for example, can help you determine how on-track things are. *Essays* or *prompts* also have their place. You might have students write about the practical application of a concept they have been exploring, or illustrate how it works. Not only will this help inform you where they are at, it will help your students solidify their understandings.

2. *To inform the teacher about what is working, what isn't and what adjustments to the plan are needed.*

The assessments used to monitor your students' progress will in all likelihood be the same assessments to inform you about what is working (and not working), so the additional step here is making adjustments based on that information. No instructional plan should be so rigidly set that you cannot change it to better meet your goals. Sometimes this means scrapping a planned lesson altogether, more often if means adjusting some aspect of the lesson. Say students did not grasp the concept that the phases of the moon have to do with where it is in relation to the sun. You really thought they would get it in one lesson but your formative evaluation says otherwise. It's time to make some adjustment. Maybe a bodily-kinesthetic activity will help students grasp the concept, but whatever it is, a good formative assessment will help you make the determination.

3. *To identify struggling students who need direct interventions.*

Even instruction that goes well is bound to leave some students behind. You need formative assessments to identify who these students are and what they are struggling with. Once again, any of the four assessment types have the potential to help you do this, so the question you need to ask is: *Once I have administered the formative assessment,* *how can I use the information to assist struggling students.* If you are trying to identify students struggling with the moon phase concept and you give them a *true-false* questionnaire, you have to ask whether the results are really going to help you identify and help those who don't understand. The 50-50 chance of getting any answer right means some clueless students are going to slip through the cracks; a more reliable assessment would probably be a performance assessment where the students must demonstrate and explain their understanding, or if you really want to use a traditional assessment, then something like a completion or short answer quiz.

4. To provide timely feedback to students with opportunities to improve.

Remember that formative evaluation is occurring alongside instruction. In fact, much of the instruction *is* the formative evaluation, and you don't want to disrupt the flow with too many quizzes or writing prompts or journaling if they are add-ons to the learning activities. So think *quick feedback.* What information do the students need so they can look at what they're doing or thinking and make adjustments to keep the process moving? *Informal checks for understanding* work well here because some are as simple as a quick thumbs up/thumbs down or a few well placed questions. Daily journal entries – say the last ten minutes of the lesson – can also be effective. Some questions will emerge during the journal writing itself, others will be evident when you read the journal entries, which you can then address before the next lesson proceeds. Of course, there are many other possibilities as well, so look through the assessment types and choose which ones will serve the purpose of providing feedback for ongoing improvement.

Summary

- This chapter opened with an answer to "the best way to teach science" question as instruction that is learner-centered, knowledge-centered, supported by assessment, and community-centered. It proceeds to address how to do that by laying out the groundwork for inquiry-based instruction.
- Inquiry-based instruction ranges on a continuum from student-directed, open inquiry to teacher-directed, structured inquiry. Whether open, guided or structured inquiry, teachers should assure that these five essential features of classroom inquiry are incorporated: 1) Students begin with questions that can be answered in a scientific way; 2) Students give priority to evidence in attempting to answer the questions; 3) Students develop descriptions, explanations and predictions based on the evidence collected; 4) Students connect their evidence and explanations leading to scientific knowledge; and 5) Students communicate and justify their procedures, evidence and explanations.
- The mechanism to help guide teachers in the planning and teaching of inquiry instruction is the *5Es*, defined as *an inquiry process of **e**ngaging students in the big ideas, **e**xploring the big ideas further, **e**xplaining why things happened, **e**xtending understanding through new applications, and continually **e**valuating understanding through a variety of techniques.* The process is initiated with *engage* and proceeds through *extend* and *evaluate*, then cycles back through the *5Es* again, representing the non-linear, organic process of inquiry.
- *Engage* consists of probing student's conceptions and misconceptions, using prior knowledge to create interest and generate curiosity, hooking the students, and focusing their attention.

- The *discrepant event* is one of the more powerful tools to hook students and pique their interest. A *discrepant event* occurs when a *discrepancy* exists between what the learner *thinks* is going to happen, and what actually happens.
- *Explore* consists of structuring experiences to encourage students to pursue answer to provocative questions, *scaffolding* learning experiences, gathering evidence and making discoveries. This is also the phase where the *science process skills* are widely used.
- *Scaffolding* is a teaching technique that supports students through the inquiry process. The technique originated with Vygotsky's *zone of proximal development (*ZPD), defined as "the distance between what children can do by themselves and the next learning that they can be helped to achieve with competent assistance."
- The *science process skills* are those skills typically employed by scientists to solve problems. They are integrated into the science inquiry process and consist of: observing, classifying, inferring, predicting, investigating and controlling variables, hypothesizing, using number relationships, explaining, and communicating.
- *Explain* consists of introducing new concepts, building and justifying descriptions and scientific explanations, and making sense of observations and questions. Two key strategies to support this process are *classroom discourse* and *questions.*
- *Classroom discourse* involves orchestrating classroom discussions, conversations, interpretations, and explanations in such a way that the spirit of inquiry stays alive and learning occurs. It goes beyond the traditional question-and-answer session to rich, genuine dialogue where students hear each others' ideas and express their own.
- *Questions* represent a primary strategy to encourage discourse and sharpen the science process skills. They are predominantly open ended and encourage critical thinking and creative problem solving. They can be categorized as attention-

focusing, measuring and counting, comparison, action, problem-posing, reasoning, and metacognitive questions.

- *Extend* consists of helping students dig deeper by applying or transferring the concepts learned to other situations, present and defend their understanding and explanations, and confronting their misconceptions. Two key strategies within this phase are *concept application* and *conceptual change.*
- *Concept application* is a strategy that deepens conceptual understanding by applying concepts to real world applications. The bottom line is to find something in your students world that they care about and find novel ways to apply the concepts they have acquired to that "something."
- *Conceptual change* is a process to help students confront their misconceptions and replace them with more accurate conceptualizations. It is outlined in a four step process that states students need to: be dissatisfied with their existing belief, see that the new concept appears to be somewhat plausible, grasp that the new concept is more attractive to them, and recognize that the new concept has explanatory and predictive powers. This chapter provides nine tactics to increase the chances that confronting misconceptions and making it through all four steps will occur.
- *Evaluate* is an ongoing process of monitoring student progress, giving feedback, and using assessment evidence to guide instruction. It may be formal or informal and consists of multiple methods. A useful approach to planning assessment is according to the categories of diagnostic, formative and summative. *Diagnostic* measures existing knowledge and skills, helps reveal students' misperceptions, serve as a diagnostic tool for planning instruction, and provide "pre-assessment" data. *Formative* monitors student progress on an ongoing basis, inform the teacher about what is working or not working, identifies struggling students, and provides feedback

to students. *Summative* serves as an end-of-unit measurement of learning and provides “post-assessment” data to be compared to “pre-assessment” data.