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Redefining Inquiry in Science

Inquiry science occurs when students use reading, writing, and oral language to address questions about science content.

Susanna Hapgood and Annemarie Sullivan Palincsar

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Hands-on . . . activities may have overshadowed the importance of developing science content ideas.

Kathleen Roth and Helen Garnier

Like English and social studies, science curriculum is in need of significant revision, based on what I believe is an emerging consensus: that science, too, is best learned through an emphasis on content presented through intellectually engaging, age-old literacy practices. If we combine these with the right kind (and the proper amount) of hands-on labs and activities, then high-quality, effective, engaging science instruction will be within any teacher's reach.

The simple, essential ingredients for the majority of effective science curriculums are

- Close reading of selected portions of science textbooks;
- Regular reading and discussion of current science articles;
- Interactive lecture;
- Writing—from short, almost daily pieces to longer, more formal pieces; and

- A reasonable number of carefully designed science labs and experiments that reinforce the content being learned.

In this chapter we'll see—against the conventional wisdom—that an overemphasis on activities may be interfering with what matters most in science learning: opportunities for repeated reading, discussion, and writing about essential science content. These are finally being acknowledged as the core of authentic, *inquiry-based* science and are vital to critical thinking and reasoning in the sciences. And as with English and social studies, we'll see how science-related newspaper, magazine, and online sources could add an exciting element to science education.

Task, Text, and Talk in Science

As with language arts and social studies, effective science instruction consists of simple, effective combinations of purposeful reading, talking, and writing—of "task, text, and talk" (McConachie et al., 2006). To learn at advanced levels, students need frequent opportunities—every week—to carefully read science-related texts and to perform oral and written tasks within the framework of a coherent body of science content. They need these opportunities at every grade level.

This is why a growing number of prominent science educators are urging us to reevaluate our current priorities. They aren't telling us to abandon labs and experiments. But they *are* asking us to reexamine the assumption that we need *more* hands-on science labs or that such activities are the essence of science education.

The benefits of such a reversal would be considerable. Kathleen Roth and Helen Garnier are senior research scientists at the LessonLab Institute in California. They found that the highest-achieving countries had one crucial element in common: their "science lessons focused on content," on "engaging students with core science ideas." Not so in the United States, where content is pushed aside in favor of "engaging students in a *variety of activities*" (2006–2007, p. 16, my emphasis). Worse yet, the majority of these activities have little or no connection to essential science content.

Throughout these pages, we've heard from cognitive scientists that critical thinking and content knowledge are interdependent and are best learned simultaneously (Hirsch, 2008; Willingham, 2009b). Science educators concur. In "Characterizing Curriculum Coherence," Roseman, Linn, and Koppal stress that for students to make all-important connections between the life and physical sciences, they must acquire a coherent, "central core" of science content (2008, p. 17). Science professor and author James Trefil has no patience with those who believe we can scant science content and expect students to learn the science they need. "In the end," he writes,

> you cannot think critically about nothing—the concepts you manipulate have to be in your mental arsenal before you can begin manipulating them. . . . There is no point teaching students to think critically about global warming if they don't know the basics of planetary energy balance. (2008, pp. 176–177)

This doesn't mean we need to know everything about an issue before we can think critically about it; indeed, we learn content best by evaluating and analyzing its meaning *as we learn* (Silva, 2008; Willingham, 2009b). Even so, if we don't know the essential science concepts that inform an issue, then we are at the mercy, in any argument, of those who do.

But here, too, less is more; we must keep our focus on essential science concepts, learned deeply.

Less Is More: Fewer Science Standards

In the highest-achieving countries, the number of core concepts and standards taught in science is less than half that of the United States. The Australians and Japanese know that in-depth learning is impossible with a set of standards that foolishly "goes beyond" the essential ideas needed at each grade level to understand science (Roth & Garnier, 2006–2007, p. 24). Nonetheless, curriculum experts Rodger Bybee and Pamela Van Scotter observe that here in the United States, science curriculum routinely "suffers from a lack of focus; teachers are expected to cover too many topics" (2006–2007, p. 45). Gerald Wheeler, the executive director of the National Science Teachers Association, writes that our standards documents contain "far too many concepts to address" (Wheeler, 2006–2007, p. 31).

This is not news. But we have yet to fully, publicly own up to the disastrous effects of our overlong standards documents: "curricular chaos," which results when teachers realize they can't teach to all the standards, so each teaches to his or her personal favorites. Despite wide acknowledgment of this phenomenon, entirely different standards continue to be taught in the same course (Berliner, 1984; Marzano, 2003; Schmidt, 2008).

The higher-achieving countries make sure this doesn't happen. They focus less on activities, and more on *actually teaching* a much smaller set of essential content standards in sufficient depth to be meaningful and engaging for students. As we'll see, literacy is central to their success in both mastering science and learning to think critically about it.

What, then, about the role of hands-on science activities, labs, and experiments? These findings may surprise some of you.

The Trouble with Hands-On Science

As we saw earlier, U.S. science instruction is typically built around a variety of activities that often have little or no connection to essential science content (Roth & Garnier, 2006–2007).

My daughter took an advanced high school science course from a teacher who proudly proclaimed that no textbook would be used in the course—it would consist entirely of hands-on activities. Now

in college, she is grateful for the teacher who *did* have his students read liberal amounts of complex, content-rich textbook material. This prepared her to understand the challenging textbooks she now reads routinely in her university courses. Interestingly, my daughter continues to disparage the activities she has to complete in her college science labs, where students do lots of measuring, pouring, and filling in of blanks—but not much learning.

Is this unusual?

Science educators are confirming, in force, that much hands-on lab work often has very limited value. Somewhat perversely, these often supplant the mastery of essential content, which is learned largely through interaction with text, effective lectures, and discussion.

In his interviews with students and teachers, James Trefil found that most "labs" are carried out pro forma. Students typically "game" the activity by merely working backward from the correct results, learning nothing in the process. He believes there are "elements of faddishness in the current excitement" about labs and hands-on activities, which are usually "an unnecessary frill" (2008, pp. 188–189).

Bruce Alberts, the former president of the National Academy of Sciences, does not disagree. As a student, he found science content fascinating but loathed the typically "tedious cookbook . . . boring laboratory exercises." It was only when he was given the freedom to devote himself to reading and absorbing the content of the discipline that he "discovered the excitement of science" (2006–2007, p. 18).

More Literacy, Fewer Labs

Alberts's experience echoes what Timothy Shanahan and Cynthia Shanahan found in their two-year study on the value and use of textbooks. Scientists told the researchers that the true "essence" of the scientific disciplines was learned not as much from labs as from the slow, close reading of *science textbooks* (2008, p. 54).

The countries with the highest science achievement not only devote *less* time to hands-on activities, they also make sure that their labs connect directly to the content being taught. In the United States, however, science activities did not typically support a coherent body of essential science concepts. Most science activities in U.S. classrooms "contained no explicit science content at all" (Roth & Garnier, 2006–2007, p. 20)—and according to the National Research Council, most high school science labs were "poorly integrated into the rest of the curriculum" (Bybee & Van Scotter, 2006–2007, p. 44).

There you have it. Good science labs, richly connected to science content, are essential. But prominent science educators are calling us to put the brakes on the popular notion that science is optimally learned through activities. This is a myth. It is time to reevaluate the profusion of disconnected, ill-conceived, "cookbook laboratory exercises" (Wenglinsky & Silverstein, 2006–2007, p. 25). They add little value to science learning and emphasize only "procedures rather than learning goals" (Perkins-Gough, 2006–2007, p. 93).

These are the "brutal facts" of science education in the United States. Surely we can do better. We can arrange for all students to learn the same essential content, using the same procedures for selecting, organizing, and teaching that content described in Chapters 2 and 3.

Then, once the content is selected and organized, we must resist the knee-jerk imperatives of multiple-choice teaching and testing. The best way for students to learn is not by having them memorize disconnected facts. It is by providing frequent, focused opportunities for close critical reading, talking, and writing about science concepts.

Effective Science Inquiry—Through *Literacy*

As we've seen, there is a growing acknowledgment that reading (including textbook reading), writing, and talking are essential

features of a quality education in any discipline—including and notably in science. As Louis Gomez and Kimberly Gomez argue, we are in need of "an intensive reading in science infusion" (2007, p. 225). A recent report from the National Research Council supports these findings:

> Being science literate entails being able to read and understand a variety of science texts to form valid conclusions and participate in meaningful conversations [discussion] about science. (In Zmach et al., 2006–2007, p. 62)

One of the report's key recommendations was for teachers to ensure that they "engage students in extensive reading of content area texts" (in Zmach et al., 2006/2007, p. 63). We saw how the scientists in the Shanahan and Shanahan study noted that the very "essence" of science was learned from close, careful reading of science textbooks. Literacy is also the basis for "inquiry"—critical thinking—in science.

In "Where Literacy and Science Intersect," Susanna Hapgood and Annemarie Sullivan Palincsar make clear that true science *inquiry* occurs when students engage in "reading, writing and oral language to address questions about science content." This is precisely how students learn "to build their capacity to engage in scientific reasoning . . . how to generate claims [arguments] about a phenomena" (2006–2007, p. 56). Their article affirms the need to make the textbook central—and also to teach and model how to read, write, and discuss science content as we learn it.

One of the best science lessons I ever observed was an expressly Socratic discussion in a high school chemistry class. The day before, students had learned the molecular explanation for why water changes forms under different conditions. First, the teacher had students arrange their desks into a circle—so that the discussion would be face to face. (Try this; you'll be surprised at how much richer the interaction will be.) Then they were asked leading questions about such phenomena as condensation, fog, and evaporation ("What do you think happens if . . . ?"). As the students discussed, the teacher would occasionally nod or comment briefly to indicate that they were on or off the right track. Students listened to each other intently and worked hard to articulate their thoughts as they questioned and corrected each other, always building on or responding to each other's remarks—or the teacher's cues.

For a full hour, these students were expanding both their mastery of these concepts and their powers of listening, thought, and expression. They were doing this in the only way possible—through language, the medium of thought. Students clearly enjoyed the discussion. All students participated, and several kept discussing the topic after the bell rang (reinforcing, once again, Azzam's finding that 83 percent of students find discussion their *favorite way to learn* [2008]).

Now multiply this experience by about 50 (which is about how many such discussions occur in that chemistry class each year), then add writing, and what do you have? A phenomenal chemistry education—simply achieved.

Language, Not Labs

Language is the medium of thought and its refinement. Inquiry-based reading, writing, and discussion—not cookbook science labs—are the essence of true inquiry-based science. That means we must literally teach students, starting in the early grades, to read science texts as we "consistently model how to read critically and question ideas presented in the text," according to Hapgood and Palincsar. Moreover, they found that "students who used textbooks" and wrote purposefully about the content "learned the most content" (Hapgood & Palincsar, 2006–2007, pp. 57–58).

But we can't just assign textbook chapters. That won't work. We need to vigorously implement the same simple elements of

instruction we've been looking at. Courtney Zmach and her colleagues implore us to teach students *how* to read, talk, and write purposefully about science texts with lessons replete with "think-pair-share, paraphrasing[,] . . . modeling, guided practice and chances to apply the [reading] strategy independently"—the same "routine components" Marzano recommends for all lessons (Zmach et al., 2006–2007, p. 63). Strategic reading, talking, and writing (when will we learn this?) are perhaps the truest forms of "active learning."

And once again, *students will enjoy this*. Hapgood and Palincsar found that students are "eager to talk, read, and write" about what they learn in science. They love to "compare their thinking with others' thinking, actively communicate with one another and express their ideas through words and graphics" (2006–2007, p. 56).

Zmach and her colleagues made the same discovery: students were "eager and engaged" during their reading in science lessons. They found that the readings themselves "stimulate lively discussion." I always had great luck with reading, discussion, and writing activities when I actively taught these processes like I would any good lesson—with modeling, guided practice, checks for understanding, and adjustment.

What can we expect if we turn the ship of science instruction in this radically new direction toward literacy practices (and joined to the most basic and effective teaching practices)? Great things, indeed: "significantly higher" scores on both reading and science tests, more positive student attitudes toward science, and "more confidence in their capacity to learn science" (Hapgood & Palincsar, 2006–2007, p. 59).

Maybe that's why, in the high-achieving Netherlands, science teaching is grounded in literacy.

Science and Literacy in the Netherlands

In Dutch science classrooms, literacy is front and center. The textbook plays a central role. Consider the power in the following simple routine: In the Netherlands, specific textbook readings are assigned daily, then introduced by a seemingly dull daily regimen: a five-minute orientation to the text—precisely the kind of purpose-setting "anticipatory set" that ought to be a regular feature of instruction (but usually isn't). When we provide even brief, meaningful background information, we ensure that far more students will understand the text; far more will read with motivation and curiosity and will learn and retain more as a result (Marzano, Pickering, & Pollock, 2001, pp. 92–96). (The crafting of such "orientations" should be high on a team's list of priorities at professional learning community meetings—and during professional development).

After the brief orientation, the readings are interwoven with explanations by the teacher and opportunities to discuss questions related to the reading. Students read for a manageable 20 minutes or so, *as they write* in response to text-related questions. This is followed by a whole-class review of the questions, with the teacher then asking students to revisit and "elaborate" on their initial written responses (Roth & Garnier, 2006–2007, p. 20).

The whole-class review is a crucial step. I'm not sure the average teacher has discovered the magic in this straightforward step of having students review their writings and annotations (even a few minutes after writing, taking notes, or annotating). This invariably promotes deep thought—the ability to see patterns, to make new inferences and connections that they didn't, or couldn't, see before. It's a ripe, simple opportunity to clarify, extend, and refine our thought even further as we "think on paper." This is the "miraculous power" writing has to make us better thinkers (R. D. Walshe in Schmoker, 2006). This simple routine could be used several times per week, in any science course—just as it is in the Netherlands.

Strategic reading, writing, and talking have never been prominent features of U.S. science instruction. How does this affect prospects for scientific learning and careers?

Why We Fail: The Erosion of Literacy

The erosion of literacy is one of the most profound but insidious developments in modern schooling. Until we put literacy at the heart of science instruction, the goal of science learning for all will elude us.

Gomez and Gomez found that students' difficulties with reading textbook materials were among the chief reasons for low performance in science and social studies (2007). Though textbooks continue to line the shelves of most classrooms, actual textbook *reading* is "abandoned early" (2007, p. 225). With each passing year, students fall further behind in their ability to read challenging, content-rich text. No one sounds the alarm, even as teachers cease to even see the textbook as "an active, meaningful ingredient" in science instruction. The current rage for activities "conspires to keep understanding of text below the instructional radar" (2007, p. 228).

In their article on science education, Hapgood and Palincsar note similarly the "impoverished reading diets" on which we put students the moment school begins. Despite what we say, the actual taught curriculum suffers from a crushing "dearth of informational texts" (2006–2007, pp. 56–57). The consequences of this "diet" show up in the later grades.

Zmach and colleagues implore science instructors to make content-based literacy lessons the core of science instruction, right from the beginning. They recommend extensive reading, discussion, and note taking from science texts—with plenty of "modeling, guided practice," and independent practice (2006–2007, pp. 63–65). But we avoid such instruction, starting in the early years. As a result, middle school students have difficulty reading "demanding text . . . [in] their textbooks and content-area materials in science" (p. 62). Rather than redress this situation aggressively, both middle and high school collectively abdicate, as "students engage in *little reading of content texts in secondary classrooms*" (p. 63).

Thus does the American bias against text quietly diminish learning, aptitude, and interest in science, technical, and mathematics careers.

What Real-Life Scientists Say About Reading

Our aversion to demanding text ensures that students will continue to underperform in the content areas (Gomez & Gomez, 2007, p. 225). As we've been seeing, you cannot learn a discipline without being a habitual, close reader in that discipline (Alberts, 2006–2007; McConachie et al., 2006). Such reading—and note taking—is essential to understanding the essence of science (Shanahan & Shanahan, 2008).

Real scientists know this. Let's now listen to two of them—acquaintances of mine—as they share their perspective on the vital (if unfashionable) importance of science textbooks.

An Astronomer's Point of View

Jeff Hall is an astronomer working at Lowell Observatory in Flagstaff, Arizona. He speaks almost reverentially of the role of textbooks in his life as a student and successful scientist.

> Where I'm sitting, I can see the spines of some of my favorite textbooks. These books improved my grades greatly by helping me to understand material better. Some of these are real gems, immortal texts I can still learn from . . . they gave me a deep understanding of quantum mechanics, general relativity, thermodynamics, the interaction of light and matter. These are topics that underpin the modern field, and to understand them you have to do *a lot of reading*. (my emphasis)
>
> Scientist don't just "do" science; you can't do scientific work without being a regular reader of scientific articles. Reading textbooks prepares you to read scientific articles. In research, you need to have read enough textbook material to read scientific material with skill, to stay abreast of and maintain currency in the field. Your conversations with other scientists are important, but those conversations simply don't go into as much depth as you get from reading.

For Jeff, reading science textbooks literally "sets the stage for future success in scientific pursuits." This is precisely what it did for another renowned scientist and acquaintance.

An Evolutionary Biologist's Experience

Paul Keim is a popular, world-renowned scientist and a famous local resident, also in Flagstaff, Arizona. An eminent evolutionary biologist at Northern Arizona University, he was the lead researcher who helped crack the Washington, D.C., anthrax case of 2001.

Keim speaks of the complementary power of reading and lectures and of the value that textbook reading had for him when he was a student.

> I shape my lectures around the content in the textbooks, so that they reinforce and complement each other, so that the text supports and clarifies my lectures. For students, this approach is invaluable.

Keim doesn't have students read all of the textbook. He wants students to read deeply and slowly, the way he did as a student:

> There is too much material in most textbooks. I have them read about 25 percent of the text. The body of facts and concepts they will learn from lectures simply don't stand by themselves. They need to be put in the context of the discipline. How can we talk about the nucleus of a cell without understanding cytoplasm?

> *The textbook is one of the few places you can go to learn more and in more depth about these concepts; it gives you the total story* [my emphasis]. The big downside for those who don't read the textbook is that they don't get the critical supportive details. No matter how effective your lectures are, there is so much good auxiliary material students will miss if they don't read the text.

That vital "auxiliary material," read slowly, gave Keim a crucial advantage when he was a student.

"Slow Reading": An Equalizer

Ironically, textbooks can be either a barrier to learning or an opportunity to catch up or accelerate science learning. Textbooks can be, in Professor Keim's term, true "equalizers"—providing an opportunity for slower students (all students) to catch up if they get behind. As Keim explained,

> The information in the textbook provides students the chance to slow down or speed up, to get more details at their own pace. It gives them the chance to catch up if they aren't understanding everything in the lectures. The textbook can be an equalizer for slower students. . . . In college *I would often read only one page in my biochem book at a time.* I had to read and reread the most difficult material. That gave me an advantage, being able to reread parts of the text until I understood it. (my emphasis)

Clearly, it is time we made textbooks a central element of science teaching—starting in the early grades. And we need to teach students the simple strategies for how to read them. This can't be left to chance; we need to model how we would read science texts, several times per week, showing students how we would annotate, how we would reread or refer to graphics in the text to achieve understanding, form arguments, and make connections as we navigate the "lexical density" of science textbooks (Shanahan & Shanahan, 2008, p. 53).

These fairly straightforward activities would have great impact, as would another traditional, underestimated tool we've already discussed: lecture. Executed effectively, lecture complements textbook reading, as it does for Professor Keim. As Bybee and Van Scotter point out, "reading, lecture, and discussion" are among the essential elements for promoting reasoning and scientific literacy (2006–2007, pp. 44–45). For James Trefil (2008), lecture is one of the most powerful, efficient ways to impart a foundation of essential scientific knowledge.

Interactive Lecture

As we've seen, there are tremendous advantages to employing the right amount of lecture in any content area. Interactive lecture can be a "marvel of efficiency" (Silver et al., 2007, p. 26). But done wrong (as it often is), lecture is among the most boring and ineffective practices.

To be effective, interactive lecture has to contain the same routine components described in Chapter 3 and that recur throughout this book: modeling, guided practice, and formative assessment.

I encourage you to revisit the more detailed treatment of interactive lecture in Chapter 3, but here are its essential steps.

- Begin the lecture by providing essential or provocative background knowledge and an overarching unit question or some essential questions.
- Ensure that the lecture stays closely focused on the question.
- Ensure, through guided practice and formative assessment, that students are engaged and on task; do this by circulating, observing, and listening as students take notes and pair up to process each chunk of the lecture.

- Avoid talking for more than seven minutes without giving students an opportunity to connect learning to their essential question or task—to review their notes and pair up to compare their connections and perceptions with others.
- Ensure, in discussions, that all students respond multiple times during the lecture.
- Reteach or clarify whenever checks for understanding indicate that students have not mastered the material in the previous chunk of instruction—and only move on when you feel they are ready.

This model has a lot going for it, including the essential components that are the backbone of any effective lesson. Because it is both interactive and highly effective, it can be a regular staple of instruction—and would therefore have a disproportionately positive impact on learning.

We now know about the importance of content learned through literacy activities and effective interactive lecture. To clarify further, let's now look at how all this fits into the scheme of standards, pacing, and assessment.

Achieving Coherence with Science Standards

Once again, the aim here is not to prescribe or to show the one best way to select and apportion standards. I merely want to simplify and demystify this process that is so critical to achieving common, coherent curriculum. The general process is described in detail in Chapter 3 (which I encourage you to revisit).

Choosing Standards

In brief, start by having each member of your team choose only the most essential 50 percent or so of what is on the standards document. Then, record on a flipchart or whiteboard only those standards that all or most participants agreed on—a much shorter list. As

mentioned earlier, this can be a very rewarding moment as teachers see common patterns of agreement and as they realize, at a glance, that they can indeed cover this now-manageable amount of core content and can do it *in sufficient depth*. Fewer standards means there is time to incorporate the higher-order reading, discussion, and writing that we know is essential to content area learning.

Even so, these drastic reductions can make some participants nervous. It never hurts for the facilitator to remind participants that the countries with the highest achievement in science and math teach *fewer than half the number of standards* we have in our bloated documents.

Let's now look at how we might complete this process if we were mapping 6th grade science standards. The same basic approach/procedures would work for 2nd grade science or high school chemistry.

Establishing Pacing

The first thing we would notice is that there are nine pages of standards (in the science standards document I'm looking at). That's way too many. After an initial review, the team would probably agree there are redundancies, vague language, and too many unnecessary details in this highly rated standards document—which was, again, *never field-tested*. For starters, the first two pages contain an unwieldy abundance of terms and directives for "inquiry process" (their unfortunate word for labs and experiments; as we've seen, content area "inquiry" regularly occurs in the context of reading, talking, and writing). As we discuss and list our favorite standards, we would realize that the essential standards from these two pages could be boiled down to the following:

> Students will design and/or conduct X number of controlled investigations per unit/grading period. These will incorporate background reading and research; the use of hypotheses, observations, measurement, and record keeping; and communication

of results and conclusions in writing and with tables, graphs, and charts.

We then could add this: *all labs and experiments will directly support the science content we are teaching in the unit.*

We just eliminated about a page and a half of bloat from the state standards. We did it without sacrificing essence while *adding* clarity, concision, and connection to essential content, not to mention that the members of our 6th grade team are far more apt to actually teach such short, essential lists of standards and less apt to revert to the "self-selected jumble" (Rosenholtz, 1991) that results from foisting unrealistically long, untested lists of standards on practitioners (Marzano, 2003).

One strand down, six to go. One of them is "history and nature of science." It mentions numerous major scientists and important discoveries. We know we'll never get around to this many, so we decide to learn about *only half* of them and to teach only *two scientists and their allied discoveries* for each of the five remaining major content units (life science, environmental science, physical science, earth science, and space science).

We must now divide the five remaining strands by grading periods. Here, too, we decide to reduce the number of topics in each strand by about half—and by even more in physical science (which we thought had far too much material). We end up eliminating enough material from physical science to teach *both* physical science *and some* earth science during 3rd quarter. We will teach the remainder of earth science and the essential standards for the last strand—space science—during 4th quarter. So our general standards map looks something like this:

- First quarter: essential topics and content/units for life science.
- Second quarter: essential topics and content/units for environmental science.

- Third quarter: essential topics and content/units for physical science, with some earth science.
- Fourth quarter: essential topics and content/units for earth science and space science.

For all of the above two- to four-week units, we will provide only the most appropriate, well-integrated labs and experiments and two one- to two-day studies of important scientists or major scientific movements and discoveries (using online resources found by the team).

Simple. But such processes ensure that we'll make enormous strides toward guaranteed and viable curriculum. If we complete them with a review of 5th and 7th grade science curriculum—to fill in any important gaps and reduce redundancy—we're even better off. We'll increase the odds that a good, coherent curriculum is actually taught, with plenty of room for in-depth reading, writing, and discussion about essential concepts and topics.

But to ensure that these good things actually occur, we have to do one more thing: develop common assessments for each grading period and unit.

Creating Assessments

End-of-grading-period assessments may include a certain amount of multiple-choice items. But at least half of our assessments will consist of good essay-response questions that give students the opportunity to (once again) argue, explain, infer, draw their own conclusions, and synthesize the views found in conflicting source documents (Conley, 2007, p. 24). These assessment questions should be given *before the unit or grading period*—not at the end. They create the form and purpose for each unit while piquing curiosity and interest in the lectures, reading assignments, discussions, and lab activities.

There is no reason that such assessments could not be conducted over two or more days, with access to books, readings, outlines, and lecture notes—in an open-book format. This is because such assessments are not an interruption to learning; the reading, review, and writing are richly educational experiences in and of themselves. Much more of our assessment should be conducted in this fashion. (We'll discuss efficient grading practices in a moment.)

If we're smart, we will literally and repeatedly take students through the steps of how to prepare for truly "educative assessments" (Wiggins, 1998) by modeling and providing supervised practice exercises as we check their understanding and mastery of these moves so essential to success in college or careers.

These written assessments can also be the basis for the quarterly data review: The administrator or teacher leader can simply ask the team

1. How many students succeeded on each end-of-unit and/or end-of-grading-period assessment, and
2. For areas of weakness that need to be worked on in the subsequent grading period (see Schmoker, 2006, pp. 130–33).

To get a clearer look still, let's examine a few sample questions for one grading period and for the major units within the grading period.

Sample Unit Questions and Writing Assignments

Let's assume that during the first grading period, the first of the three units covered in life science will focus on cells—their structure and function, and the differences between plant and animal cells. *Up front,* students will be given the tasks they will need to complete both their end-of-unit and end-of-grading-period assessments. They will know that there will only be a limited number of multiple-choice items on the tests and that half or more of the exam questions will be composed of writing prompts like the following:

- Explain and illustrate cellular structures and functions based on reading and lecture notes, with original or personal observations, insights, and connections. (The teacher will clarify and model "observations, insights, and connections" *multiple times* during the unit.)
- Explain and illustrate essential similarities and differences between plant and animal cells.
- Read two opposing arguments on a past or present issue or problem related to cells/cell research (e.g., stem cells, pharmaceuticals) and annotate them. Take a position on this issue. Be sure to also refer to what you learned in this unit on cells.

Each of these writing activities quite naturally incorporates inferencing, drawing conclusions, supporting arguments with evidence, and reconciling conflicting source documents.

As an option, on each common assessment (per unit or grading period) we might require students to make arguments and connections with respect to previous units (e.g., linking life science and physical science, or earth and environmental science). To prepare for these assessments, we would be sure to give students ample opportunities to write from their readings and lecture notes. All of these processes would of course be taught with lessons that included modeling, guided practice, and formative assessment. To help students even further, we would take them carefully through exemplars of such written work from previous year's students (with names blacked out). This would be done all year, every year.

As we saw in social studies, we could have students complete one or two more extended essays each semester. This could be done by simply having students choose one end-of-unit question and expand it into a two- to five-page paper (depending on grade level), with the requirement for them to research and integrate a given number of other sources. In a moment, we'll see how current articles could be a part of this. *Even two such papers, each year,* in every science course, would be excellent preparation for the demands of college science or a science career.

Again, as we saw in social studies, we cannot expect science teachers to be English teachers. Most short writing assignments could be graded by walking around and checking off good-faith or satisfactory efforts; longer, more formal papers would be graded primarily for content, clarity, and logic—not the finer points of writing or perfect grammar and mechanics. (See discussion of this and a simplified rubric for social studies and science in Chapter 3.)

Once standards are mapped and assessments are developed, it is time for the next seemingly "boring, pedestrian" (Collins, 2001a, p. 142) step that is in fact enormously productive: selecting, as a team, the best pages from the textbook and from common supplemental readings to go along with each major unit.

Common Readings: Textbook Pages

The preceding elements provide the general infrastructure for good science instruction. Because they reduce and clarify science standards, they decrease anxiety and give teachers confidence that their students are enjoying a coherent, literacy-rich program of study. All can now move forward knowing that students will learn essential, common content, regardless of which teacher they have. But the next step is no less critical (though it is seldom taken seriously).

Choosing Pages

Teams of teachers must go through their textbooks, carefully selecting which pages students should read (not too much now; sometimes two or three pages will suffice). Then they should collect and assemble a core of supplemental texts and articles that support the major units and standards (more on this in a moment).

We would continue to do this in team meetings, as we build and align a strong, focused curriculum with plenty of content learning, reading, writing, and discussion, and the right amount of meaningful lab and hands-on activities.

And there we go. Even crude attempts to implement the above "infrastructure" of science instruction will pay enormous dividends and represent a vast improvement over business as usual.

But we should also institutionalize and enhance an exciting element already discussed in social studies: the inclusion of supplementary and current science readings. Once again: I am as excited about the general payoff this will have for stimulating interest and success in schooling as anything on the horizon. I believe it should make up as much as 20 percent of the curriculum (inclusive of discussion and writing). That's a hefty amount, I know. Let me make the argument for it now.

Choosing Supplementary Texts

Every week or two, I'd like to see students read and discuss articles about scientific discoveries and controversies. These would be collected from science journals and newsmagazines and from online sources. Ideally, they would connect to the science content students are studying. Some of these texts might have enduring value and become part of the formal curriculum, used for years.

I wouldn't insist that current articles would always have to connect to the unit being studied. After all, science and science articles in any sphere connect to the other sciences and scientific topics. And, as we'll see in a moment, almost any science article offers readers an opportunity to exercise modes of thinking common to all scientific work.

Finally, interesting current articles about late-breaking discoveries have the power of "now"; they often focus on timely, urgent issues of interest. I think that 10 to 20 percent of the curriculum should be focused on such readings, with discussion and writing. I can't imagine a better way to imbue scientific studies with excitement and relevance.

Don't worry that there isn't enough time for this. If we scrap the extraneous (versus essential) standards, along with the movies, worksheets, and the less-essential labs and activities, we will open up more than enough time to have students reading, talking, and writing about the content from their textbooks and the abundance of fascinating articles available about exciting new developments in science. As Hapgood and Palincsar found, students are indeed "eager to talk, read, and write" about science topics. They love to "compare their thinking with other's thinking"—if we set the stage for it (2006–2007, p. 56). This component could do more to promote interest in science and promote the goals of scientific and technical careers than anything done to date, and the materials for doing this are readily available.

Kelly Gallagher (2009) has made close, analytical reading of *Newsweek* a weekly staple of instruction in his high school English courses. His mission is to help students to become more informed, thoughtful, and articulate. This weekly exercise helps ensure that they will be.

Articles for Elementary School Students

Newsweek has real merits for secondary students, but there are several good sources more appropriate for the younger grades. In the social studies chapter, I described *TIME for Kids, Junior Scholastic,* and other excellent resources for younger students. *TIME for Kids* also contains many good science-related articles. As I previously noted, one recent article addressed the possible reasons for the depletion of tiger populations; another looked at earthquakes (in Haiti and Chile). These were written for 2nd and 3rd graders. Each article is written in clear, readable prose, packed with the kinds of interesting

facts and statistics upon which scientific thinking depends. *Kid Biz/ Achieve 3000* is another good resource that translates recent newspaper and magazine articles into language appropriate for different grade levels.

Again, a caution: *Please ignore the ever-present questions, activities, and worksheets that always accompany such materials—they are seldom worth your time. Instead, simply have students read carefully to argue, infer, and make their own connections and conclusions as they read, underline, and annotate.*

Of course, there are many other good resources. Two that I've mentioned previously and that I think are especially helpful are ProCon.org and *The Week*.

ProCon.org is an excellent, free source for any teacher, and certainly for the science teacher. In its science and technology section, you will find abundant materials arguing both sides of issues like the following:

- Alternative energy versus fossil fuels
- Are cell phones safe?
- Is nuclear power practical?

For many of the topics, you can click to related pages. For example, the alternative energy page contains links to many short, readable arguments for and against the use of biofuels and nuclear, solar, and hydrogen power. Each topic also has a "one-minute overview" that provides background for the issue in clear, easy-to-read language. With a click, you can review an "expanded background" for each topic. These would be perfect to construct anticipatory sets and pique student curiosity. Below this overview are 9 or 10 short, argumentative paragraphs in each of two columns—"pro" and "con." Each summarizes the important facts or conclusions from one article; citations for each article are listed below (if students want to look them up online). But by themselves, every one of these clear, well-written scientific argumentative paragraphs provides students with abundant opportunities to learn essential content, read closely to make inferences, synthesize competing claims, analyze arguments, and reach conclusions. The format itself is compelling: students have a chance to see the arguments in close juxtaposition, making comparison and synthesis easier. I highly recommend this resource.

Another source of good articles for science courses that I love to recommend is *The Week* (a relative newcomer in the weekly newsmagazine category). Once students reach the upper elementary grades (especially if they've done some regular nonfiction reading in the early grades), they are more than up to reading the high-interest science articles from *The Week*, which I discussed at length in the last chapter.

The Week contains excellent science and health articles one page or shorter in length. The "Health and Science" page typically contains about four short, readable pieces. They are consistently arresting and full of potential to spark an interest in science. Each piece stimulates scientific thinking and demystifies the essential patterns always found in scientific studies.

In one issue from May 1, 2009, I found interesting recent scientific discoveries about

- The myth of the multitasker,
- The academic benefits of chewing gum, and
- How Facebook use may adversely affect students' grades.

In all of these pieces—indeed in science articles from any source—we run into the same recurrent patterns and opportunities for discussion, analytic thought, and writing:

- Most of the pieces reflect the interesting and recurring issue of *cause vs. correlation*, which students will enjoy debating. (Is gum chewing the cause of higher grades, or do smart kids like to chew gum? Does Facebook use cause lower grades, or do underachieving students just spend more time on Facebook?)
- All of the brief articles admit (at least implicitly) that many late-breaking discoveries are inconclusive about root causes. (For example, in the gum-chewing piece, some scientists speculate that chewing gum stimulates mental activity because it promotes blood flow in the region of the brain . . . *but they have no proof.*)
- All three pieces exhibit another common pattern in science articles: they invite analysis and debate about *the way the studies were designed*. For example, multitaskers in the one study were identified as those who merely happen to use the most different kinds of technology; nothing is said about using them simultaneously. Taught to read carefully, many students will ask: Is this really the best way to identify "multitaskers"?
- All the articles invite us to think and discuss scientifically, to see connections among science disciplines. The gum-chewing article has implications for both chemistry and biology, and the Facebook article connects both behavioral and biological/neurological science.

These articles are based on serious, well-funded science work. But they exhibit the range and appeal of such studies in a way that is bound to promote interest in students' science courses and in scientific and technical careers.

Frequently, there are also well-written single-page articles in *The Week* on a major scientific issue. I am looking at one on nuclear energy. I will now use it to describe how to model and teach effective reading of such articles—or a textbook, for that matter. Any teacher could learn to do this effectively. And such instruction would demystify such intellectual work and the (quite straightforward) art of reading nonfiction closely and critically.

Close Reading: A Science Article

I would start every weekly lesson carefully reading the first paragraph or two out loud, stopping whenever I felt it beneficial to reread, and even dramatize as I stop to weigh a phrase or sentence. I would note, for instance, that this article tells me the United States has gone "30 years without building a new nuclear plant" but is now "preparing to build as many as 29 in the next several years." I would say to my class:

> This gets my attention. Does it get yours? Why did we wait so long to build more plants—and then decide to build so many so fast? I have always had mixed feelings about nuclear power. [I might briefly share my knowledge of the Three Mile Island and Chernobyl incidents, and use this as an opportunity to explain how previous knowledge helps us to evaluate current arguments and think critically about what we read.] I want to read on to see if the article addresses my concerns or adds anything new that might change my opinion.

In the next line, I read that nuclear plants "emit no greenhouse gases."

> None? Zero? I didn't know this. That's great, but that leaves the issue of nuclear waste, which is also very dangerous. I mean, that has to be why we haven't been building new plants all these years. So I will read the rest of this article—as should you—for the answer to this question: Is it safer to build such plants now than it used to be? Do we know new ways to get rid of harmful nuclear waste? With these questions in mind, I will read these arguments very carefully.

I might go on to read another portion of the article that tells us that thanks to nuclear power, the United States now releases 190 million fewer tons of carbon dioxide per year. I might say:

> Sounds great, but I'm wondering—relative to what? What is the total amount of carbon dioxide that enters the atmosphere each year? Is 190 million tons a drop in the global bucket or a sizeable proportion?

Here students are learning another core intellectual habit—that numbers are indispensable in many arguments but must always be looked at carefully. Because numbers have such persuasive power, we have to be somewhat on our guard: The worth of any number or statistic is almost always relative—important only with respect to other numbers or values.

Close Reading of the Textbook

We would do the same kind of close, careful reading if we were reading a science text. According to Shanahan and Shanahan, science textbooks and articles must be read closely and carefully. In science, even more than in most subjects, we need to recognize the close interdependence between words and graphics. To understand the concepts found in science textbooks, readers must do something simple but somewhat unnatural: we must often reread and alternate—many times if necessary—between the written text and any illustrations or statistical tables. In this way, as one scientist pointed out, students "learn the essence of science" (Shanahan & Shanahan, 2008, p. 54).

These are the simple but essential operations that mature adult readers perform automatically to master difficult, complex material. But students don't realize early enough that even adults pause, many times, to reread a sentence or paragraph or refer to an illustration several times—in order to understand it.

If we want *not some but all students* to learn science, we need to repeatedly model, encourage, remind, and reinforce these simple operations of thoughtful reading every year in *all* science classes. Then, as with any good lesson, we need to follow up such modeling with opportunities for guided practice. Let them read the next paragraph or two, annotate or scribble some notes or reflections, and then share those with each other in pairs. This prepares and gives them confidence for the next important step: to share their now much clearer, more refined thoughts in whole-class discussions—whether it is about molecular theory or the pros and cons of wind energy. (Again, I would encourage you to revisit and integrate the use of the two templates in Chapter 3, which pertain to virtually any lesson or learning target in a good curriculum.)

If we do such simple things, repeatedly, from the earliest grades, students *will learn* to read and think and articulate with increasing skill and sophistication. But they must also write, for writing takes students to even higher levels of clarity and precision in their powers of thought.

Writing in Science

As often as possible, every close reading or discussion should include or end with some opportunity—if even for just a few minutes—to summarize, argue, or respond to a question in writing. It is in writing that students have a chance to convert what they have learned from reading and talking into more coherent, logical, and precise thought and language. In writing, new thoughts are often born, thoughts that build on the insights already gleaned from reading and talking. Writing takes thinking to the next level (see Schmoker, 2006, Chapter 5).

Doug Reeves (2008) is a longtime champion of writing in the content areas. His Leadership and Learning Center conducted a research study showing that writing and note taking, consistently implemented, contribute tremendously to learning science content. In schools where writing and note taking were rarely implemented in science classes, approximately 25 percent of students scored proficient or higher on state assessments. But in schools where writing and note taking were consistently implemented by science teachers, 79 percent scored at the proficient level. Writing matters—hugely.

With this much at stake, students should regularly write short pieces, maybe one or two brief paragraphs. They might simply cite a few notes or annotations from the text to formulate an argument or two based on the understanding they have acquired from close reading and discussion.

It is also critical for science students to write at least two longer papers each year—their length increasing at each grade level. By high school, these should be three to five typewritten pages—mostly completed in class, where we can monitor, guide, and check for understanding to ensure success. As Conley (2005) found, liberal amounts of such writing could have more of an impact on college readiness than any single measure we could take.

Science teachers are not English teachers—and vice versa. In science, the emphasis should be on producing a sound, readable paper that will be evaluated primarily for clarity and content—for the student's ability to cite written sources to support a scientific argument or conclusion with evidence. The finer points of writing can be left to the language arts teacher.

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Again, the suggestions here are not intended to be exhaustive, but rather to bring us back to the surefire elements that should be the focus of the great majority of science instruction: close reading and discussion, interactive lecture, regular reading and discussion of current science articles, writing, and a reasonable number of science labs and experiments tied directly to the content being learned.

These simple elements should constitute the operative core of science instruction, on which our staff development and team meetings should consistently focus. If they do, we will make great strides toward ensuring a high-quality science education for all.

Let's now look at one of the critical underpinnings of scientific thought and exploration—mathematics.