Science Literacy Q & A

1. I do not teach English, and students in my classroom already know how to read and write (or they should). Why should I focus on these things when it is not my content area?

My response to this question comes from my early days of teaching. As a biology teacher, I wanted to engage my high school students in investigations and activities that would allow them to develop deep conceptual understandings of scientific ideas and of the process of inquiry. As part of that work, I wanted my students to read and write texts much as scientists would, as part of the regular process of investigation.

Scientists read the results of prior studies in order to generate hypotheses, replicate experiments, or improve on research designs. They also read the work of others as they progress through an investigation to help them make sense of their own findings. In addition, because investigations are generally complex and carried out over months, if not years, scientists must record data points, observations, and initial analyses in writing. Finally, scientists generally do their work to solve problems, and therefore want to communicate their findings with other people. They do so in day-to-day conversations with members of research teams, in formal oral presentations, and in formal written documents. In sum, although many of us who teach the natural sciences tend to think that literacy is not a part of our content, if you stop and think about the way that scientific study is done in the everyday world, it becomes clear that language—oral and written—is key to doing science and producing knowledge. And that's what I hoped to teach my students, not only the "facts" of science (which, of course, are ever-changing), but also the processes and practices that make science what it is. Imagine my dismay when I realized that my students couldn't read and write the way I thought they should for science.

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I was fortunate enough to have opportunities to observe my students in contexts other than my classroom, and I could see that the problem did not lie in their cognitive abilities, but rather, in my lack of instructional practices for supporting the development of students' scientific literacy skills. I emphasize *scientific literacy* here because the ways that scientists talk, read, and write are somewhat different from the ways we talk, read, and write in other domains (e.g., at home, at church, in English class, etc.). The texts scientists read are different from those students read in English class, the texts scientists write are different, and so on. Thus, as science teachers, we need to teach both oral and written language practices and skills in our classes because science as a domain of study is dependent on oral and written language and because no other teacher can teach them in the way we can. And the literacy skills they learned in elementary school, while necessary, do not equip them to deal with the texts of the upper level content areas. Our disciplinary expertise enables us to give specific guidance to students on how to read, write, and talk in scientific ways. Our knowledge of technical vocabulary allows us to introduce new words and concepts to students that they would not learn in other content areas and to distinguish between a word used one way in the everyday world and another way in science (e.g. *compound* or *structure*). Our knowledge of how scientists plan, carry out, and communicate the results of investigations allows us to model those processes and practices for our students in ways that the English teacher cannot.

2. How do I fit literacy instruction and the use of literacy strategies into my daily instruction when I do not have enough time, as it is, to cover my content?

Teaching scientific literacy is actually about teaching content. As we teach young people how to make sense of science texts (whether textbooks, newspaper articles, or an excerpt from a scientific report), we are also teaching them science information and, often, science concepts. An example might help here: I like to use newspaper articles to teach students both science concepts and processes. I recently read an article that I was eager to use in a classroom. The article reported a possible link between incidents of breast cancer and rates of taking antibiotics. Unfortunately, the article reported the finding in a way that suggested that taking antibiotics might cause breast cancer. But if one read the actual study, it was clear that the links were only correlational and could easily be explained in the reverse (i.e., that women with undiagnosed breast cancer may have compromised immune systems that make them susceptible to bacterial infections, thus requiring treatment with antibiotics).

What a great opportunity to study a variety of scientific concepts (e.g., cell and systems, communicable and non-communicable disease, health and medicine, etc.), as well as scientific processes, such as how causal relationships are studied, the difference between cause and correlation, and how investigations are designed and reported. Finally, the article, which was very brief, provides opportunities to engage in think-alouds, where the teacher and students read a text together, stopping to ask questions of the text, not to test students' comprehension, but to allow the teacher to model her/his thinking about those questions as the class reads. The text also provides the opportunity to teach scientific vocabulary, scientific writing and the translation of scientific vocabulary to everyday vocabulary, and how to read critically and ask questions of text while synthesizing information from other text sources and experiences to help make sense of a target text.

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3. In regards to reading, writing, and word learning in science, what kinds of texts should students read in my class?

Texts to Read

Students should read a wide variety of texts in science classes. These include (a) well-written expository text passages (similar to those found in textbooks or encyclopedia entries), (b) newspaper articles that report scientific phenomena or findings, (c) science books and magazines, (d) pamphlets, brochures, and materials produced by health or environmental advocacy groups, (e) excerpts of scientific journal articles, (f) materials found on the Internet, and (g) the work of other students and their teachers.

Some of these materials require special mediation. Some textbook or other expository passages are challenging to read because they condense or gloss over a great deal of information in an attempt to make short texts. Textbooks can also be challenging because the publishers try to reduce information into age-appropriate concepts and in doing so sometimes introduce misconceptions. In some cases, too, editors delete words or shorten sentences to make texts fit grade level readabilities. Unfortunately, shorter sentences do not necessarily support reading comprehension because meanings are lost or obfuscated as important transition or cueing words are removed from the text. Newspaper and magazine selections may need teacher mediation for reasons suggested previously: As journalists translate scientific findings to the general public, they may misrepresent findings because they have lost the scientific precision of language. These materials, however, make great fodder for the development of critical reading skills and they help connect the science of the classroom to the real world!

Internet materials require a special kind of teacher scaffolding. Internet materials are generally unedited, and the qualifications of authors to write about particular concepts may vary widely. We need to use these materials and teach our students how to search carefully, checking multiple sources, reading for author background, and comparing results or claims across many sites (and with materials that have benefited from editing). This kind of teaching fosters critical scientific digital literacy skill development.

Finally, reading even an excerpt of a scientific journal article can be daunting for most people and thus, such reading activities need to be heavily scaffolded. I have even used just the titles of scientific articles simply to demonstrate to students that the writing of scientists is vastly different from the representation of the same findings we eventually see reported in popular magazines, websites, and newspapers. In other words, I do not recommend simply handing articles from *Science* over to students to make their own way (even to A.P. biology students), but I do recommend the heavily scaffolded introduction of such materials. Another great source is popular science books written by scientists. A popular book (or essay) by Stephen Jay Gould, for example, can provide an introduction to careful scientific thinking without necessarily immersing students in the depths of scientific discourse.

In all cases, the texts used in classrooms should offer images, diagrams, charts, tables, and graphs that support students' understanding of print. And teachers should make a point to teach students how to read the print and the images or other graphics together for deep learning of concepts.

Texts to Write

Students should also write a wide variety of texts, but the three that I suggest should be an integral part of regular science classroom activity are (a) running investigation logs or notebooks (much like scientists would keep), (b) formal scientific explanations or reports, and (c) opinion or perspective journals.

Logs or notebooks are important written texts for science classrooms because they not only reflect the kind of writing that scientists do on a regular basis, but they also help to ensure that students can track the results of their investigations so they can reflect on results and draw conclusions over time. Logs are also a good place to practice recording in different ways, sometimes in tables, other times in charts, and sometimes in simple prose. Keeping them over time—rather than, for example, in an isolated lab report turned in every other Friday—replicates the careful notetaking and organization of scientists.

Formal scientific reports that include explanations of scientific concepts, hands-on investigations, or text-based research should also be a mainstay in science classrooms. That said, students need to be taught how to write such reports. Teaching such writing processes involves more than telling students the steps in writing reports or assigning deadlines. Students benefit from teacher modeling of how to ask good research questions, read relevant background material, formulate hypotheses, design investigations, record and analyze results, and then, ultimately communicate their findings in relation to their original hypotheses and to what others have reported (the others can be published science accounts or the results of others in their classroom community). In addition to modeling, students need opportunities for scaffolded practice, peer and teacher feedback, and display (written papers, presentations, poster sessions) and questioning. Rogers Hall and Susan Turow have experimented, with good results, in bringing practicing scientists into classrooms to serve as expert audience members for middle-school students as a way of helping students enter the discourse of science.

Finally, students should have the opportunity to write about their personal views of scientific phenomena and research. Often, we ask developing adolescents to leave their world views and emotions at the classroom door, especially when they enter science, math, and social studies classrooms. And yet, in research that my research team has done with youth, we find that one of their main reasons for writing outside of school is to express their emotions, fears, and frustrations. Giving students the opportunity to express their views about scientific issues is a way of ensuring that they have a voice in what they are learning, of bridging the gap between their everyday lives and interests and the science we ask them to learn in school, and of honing writing skills as they use scientific terms and concepts, but are able to write in the discourse of their own experiences and communities.

Words to Learn

I would suggest focusing on two types of words in most science classrooms. One type is the technical term. Terms such as *mitochondria*, *polymer*, or *quantum* need specialized instruction. They are not terms we encounter in the everyday world, and they have particular meanings that are absolutely critical to developing scientific understandings of the natural world. However, a number of other terms are equally important and we do use them every day, in ways that are often quite different from—and even sometimes at odds with—their uses in science.

The second type of term is the everyday word that is used in precise ways in science. Words such as *energy, volume, nucleus, variable, force, momentum*, or *hypothesis* have qualified meanings in the natural science domains. And yet, many people use these words in the course of general conversation. The difference between everyday and scientific meanings of terms and phrases (and even larger wordings of ideas) can be confusing for students if the differences are not clarified. Jay Lemke, in *Talking Science*, provide a useful data-based exemplar of the student confusion that resulted from the use of the word *create* rather than *convert* in a discussion of the transformation of light to heat energy. A student introduced the word *create* into a class discussion, and the teacher took it up without realizing it, leading to all sorts of confusion.

One additional note about words and scientific discourse should be offered for those who teach in classrooms with English language learners. Many scientific terms come from Latinate roots and, therefore, if you are working with native Spanish speakers, you can use Spanish or Latin root forms to support students' developing understandings (which offers the side benefit of bringing Spanish to the foreground and thus validating the usefulness of fluency in more than one language—so many English language learners are made to feel deficient in our classrooms when English is the only language validated). However, if working with English language learners it is important to recognize that due to the multiple linguistic influences on the English language, some English words may appear to share root with words in other languages, when in fact, those root, or cognate, meanings are quite different (what is referred to as "false cognates"). In addition, it is helpful to remember that phrasings can be very different across linguistic groups, so simply translating or defining word by word may not be as useful as getting larger ideas across to students (this is also true for native speakers). Finally, it is also good to know that scientific words in other languages sometimes translate differently than one might expect; i.e., as with everyday language, literal translations are not always accurate.

4. What literacy skills (or learning strategies related to literacy) are essential for students to learn in science classrooms?

I have highlighted many of the scientific literacy skills that are essential for deep science learning in my response to the first question. Some more generic reading skills include (a) the ability to scan a given title, heading, or image and make predictions about what one might expect, (b) set purposes for reading a particular text or set of texts, (c) ask questions before and throughout one's reading that help monitor one's own comprehension, (d) recognize challenges to or mistakes in comprehension and apply strategies for addressing them, (e) summarize, especially long texts, as one reads and at the conclusion of reading, (f) synthesize meanings made from one text with others one has read (and make "intertextual" connections) during and after the reading.

The above processes are quite different from those a reader would use when approaching her reading of, say, *Harry Potter and the Deathly Hallows*. For example, the literary reading process certainly involves prediction, but the work of predicting involves remembering qualities of characters read about in the past, what we know about human relationships, what we hope based on the characters we love, and other emotional, or aesthetic responses. These boundaries between scientific reading and literary reading are not neat, unitary, or immutable; there are, of course, times when scientific reading produces aesthetic or emotional responses and times when literary reading depends heavily on domain knowledge of historical contexts, persons, or issues. Still, there are some general differences in reading process skills that are essential for young people to develop if they are to succeed in academic content learning. These skills do not get modeled in the everyday world and at times are even misrepresented in popular cultural texts—think of the popular forensic science television series and how they gloss over the tedious and time-consuming work that scientists actually do. These skills also cannot be modeled in elementary school at the level students need them in middle or high school because the texts of elementary school do not make the same demands on young people. Consequently, these skills require modeling and scaffolding by secondary school science teachers.

In terms of writing, students need to learn how to record data systematically and in multiple forms (prose, drawings, tables, charts, graphs). They also need to learn how to make clear and complete claims, use data to support the claims, and provide their reasoning for these claims. In work with middle and high-school aged youth, my colleagues and I find that a particular skill challenge for youth lies in the ability to articulate their reasoning for claims. Many students do not understand that part of the process of science is making clear how one arrived at conclusions or interpretations. In written explanations, they often make a claim and then reel off numbers or other forms of data. They think of the explanation as self-evident. We can see that the data do actually provide the warrant they need, but their failure to explain their thinking makes their work incomplete. We have worked on explaining that scientists must have access to the thinking of other scientists if they are to build on one another's findings to produce new knowledge, but it seems clear that this essential skill of articulating an argument (even when the argument seems obvious) is one that young people need to learn.

5. Many of my students lack sufficient literacy skills to adequately complete the content area work in my content area; other students have very advanced skills. How do I differentiate instruction in my classroom when students have such a disparate range of literacy skills?

Differentiating instruction in a classroom that is broadly heterogeneous in terms of skill levels is extremely challenging. One way to address different students' needs is to offer many different types of "participant structures," ranging from teacher-led whole group activities to small-group to partner to individual work. Heterogeneous small groups are often used to support struggling students and, if well crafted, to challenge students with advanced skills. But such groups also need to be carefully monitored to ensure that all students have opportunities to engage with materials, to respond in oral and written forms, and to make contributions to the group.

A second way to address the different needs of students is through whole-class work. As ironic as it seems, whole-class reading and discussion can actually support students who are challenged by texts, while also challenging students who find the texts simple to access. This work should not follow the typical pattern, however, of round robin reading of a text, with a teacher posing comprehension questions. Instead, *think-aloud* and *reciprocal teaching* strategies work well to support students across a range of skill levels. Think-aloud activities are initially modeled by the teacher. The class reads a text together, stopping at points the teacher has predicted will be confusing, challenging, or especially interesting. At the various stopping points, the teacher asks and answers her own questions about the text, thinking aloud to give the students a window into how she figures out new words, ask questions of herself as she reads, summarizes ideas, makes inferences, or monitors her comprehension. Think-alouds are best done with short passages, and can be used to introduce a reading, turning over the remainder of the text to students to read silently, in pairs or small groups, or as homework.

Reciprocal teaching follows a similar process, but seeks to turn over text questioning to the students themselves, so that after some initial modeling, students take the lead in asking questions of the text, and after some practice, other students learn to address those questions. Annemarie Palincsar, who developed the reciprocal teaching strategy, found that students across a range of abilities improved their reading skills when they used this strategy regularly over time.

In any whole-group work it will be important to develop systems for response in whole-group sessions that allow for all students to complete work before discussions are started or before responses are given to questions (preventing "advanced" students from getting all the air time in discussions). A similar strategy is to always ask students to either jot their ideas before discussing whole-class or to "think-pair-share" with another student.

Another way to differentiate is to offer extension activities for each base activity. In other words, some work is done whole class and in small groups, but as students with advanced skills complete activities, they can be offered opportunities to extend their investigations. Science is ripe with possibilities for developing new questions based on the findings of investigations, for reading related news articles, for conducting web searches on related topics. Of course, some of the most interesting activities often end up being extension activities, and so one challenge is to avoid offering the exciting and "fun" options only to those who finish early. For one thing, such a move might encourage skilled students to rush through what they see as standard or mundane work in order to get to the "good stuff." And worse yet, the students who struggle with literacy and science skills may feel marginalized or penalized because they do not have opportunities to do the really exciting work. Being cognizant of this possibility is critical if one hopes to avoid rewarding those who are skilled and penalizing those who struggle.

Finally, some students may need the extra support provided through literacy coaches or supplemental programs. However, I discourage referrals that take students out of regular content classes (or electives) because content knowledge is just as critical to improving reading and writing skill as good reading and writing are to improving content learning. If students are routinely pulled out of subject-matter courses to practice generic literacy and learning skills, then are failing to receive a critical component necessary for improving those skills. Extra support should be offered through opportunities for extra classes or afterschool strategic literacy tutoring sessions, such as those developed by Mike Hock and colleagues at the Center for Learning at the University of Kansas.

6. I know word learning and vocabulary instruction are important in science. What words should I focus on to teach and support? What strategies work the best?

I would suggest focusing on two types of words in most science classrooms. One type is the technical term. Terms such as *mitochondria*, *polymer*, or *quantum* need specialized instruction. They are not terms we encounter in the everyday world, and they have particular meanings that are absolutely critical to developing scientific understandings of the natural world. However, a number of other terms are equally important and we do use them every day, in ways that are often quite different from—and even sometimes at odds with—their uses in science. Thus, the second type of term is the everyday word that is used in precise ways in science. Words such as *energy, volume, nucleus, variable, force, momentum,* or *hypothesis* have qualified meanings in the natural science domains. And yet, many people use these words in the course of general conversation. One additional note about words and scientific discourse should be offered for those who teach in classrooms with English language learners. Many scientific terms come from Latinate roots and, therefore, if you are working with native Spanish speakers, you can use Spanish or Latin root forms to support students' developing understandings (which offers the side benefit of bringing Spanish to the foreground and thus validating the usefulness of fluency in more than one language—so many English language learners are made to feel deficient in our classrooms when English is the only language validated).

Useful strategies include morphemic analysis, Vocabulary Concept Cards, Semantic Feature Analysis, Concept-of-Definition maps.

7. How often should I use literacy strategies? In other words, should I use a before, during, and after reading strategy in every single science lesson?

The decision about whether to use a literacy teaching strategy is based on the purpose of the lesson, the nature of the text demands, and what you know about your students. Before-During-After, however, is not really a "strategy." It is an instructional framework, or teaching practice, and a good teacher always elicits and extends knowledge and sets purpose before a lesson, guides students in meaning making (whether or not one is reading print) during a lesson, and extends and applies understandings after a lesson.

8. What kinds of questions should I ask students when I teach science concepts?

The best kinds of questions are "why" questions that probe students' thinking and encourage them to articulate their reasoning. Elaborate articulation of reasoning is a central practice in scientific communication, and it is a skill that students do not use routinely in everyday life (most of us do not because we are typically conversing with people whose background and experience are similar, thus negating the need for elaboration of thinking).

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9. Do I need to use different strategies for boys and girls?

No. It is useful to recognize that girls' and boys' interests in science may differ, but, if anything, we should consider those different interests as a rationale for exposing them to a wide variety of concepts and ways of knowing. For example, although it may be the case that young women tend to emphasize relationships in their reading, writing, and daily activities, that doesn't mean they cannot learn to see the world differently and nor does it mean that boys can't learn to see the world in terms of relationships.

10. How does the use of literacy strategies relate to learning styles? In other words, what strategies lend themselves well to different styles of learning?

The use of literacy teaching strategies in science depends on the goal of your lesson, the demands of the texts, and the needs of your students. Therefore, one could argue that "learning styles" of students *might* be something to take into account. The research, however, on learning styles has not made it clear whether differences in how people learn are the result of some sort of neurological, cognitive, or social differences. In other words, learning styles may simply be learning *preferences*, which means that students can be introduced to other ways of learning. Rather than trying to link literacy teaching strategies to learning styles or preferences, I suggest that you make sure you are using a variety of strategies that will meet the many different needs of learners and teach students new ways of learning, keeping in mind that the choice of strategy is always about your purpose and the demands of the task or text.

11. On average, how much time should students spend in the act of reading and writing in a typical class in my science classroom?

There is no average calculation of time that should be spent on reading and writing. The way to think about how often to engage students in reading and writing is to ask yourself what the learning goals and tasks of your lesson demand. If, for example, you want students to learn how to engage in inquiry, then they should be *doing* inquiry. However, inquiry can be conducted with and on texts, and all scientific investigations involve reading the work of others, recording data and keeping notes on investigations, and writing scientific explanations and conclusions. Reading and writing are integral to science, so you will probably find that if you are really teaching science, then you are probably asking students to read and write in the service of science quite often.

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12. Many strategies appear to support the needs of struggling readers and writers; what strategies work best for advanced students in science?

Even (or especially) advanced students will encounter texts that are difficult to read. They will also be expected to write in ways that are new to them (if you are asking them to write formal science reports). Any of the strategies that work for students who struggle with grade-level texts can also work for students with advanced skills when they encounter texts or tasks that are above their level. For example, organizational strategies such as concept mapping or graphic organizers can work well with especially dense texts. Synthesis journals work well when reading across several complex literary works or when reading pieces that represent many different points of view. Fishbowl discussion strategies are excellent for managing discussions about difficult issues and also for teaching students—advanced or otherwise—how to engage in constructive discussion.

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13. What strategies or practices work best to motivate and engage students in reading and writing in science?

The best way to motivate and engage students in reading and writing in science is not necessarily a reading/writing strategy, *per se*. Conducting actual investigations of real-world phenomena that have meaning in adolescents' lives is motivating and engaging. When reading and writing activities are embedded in real-world investigations as another form of inquiry and as a way of communicating one's findings, then students are typically more motivated to read and write.

In addition, it has been my experience that students are motivated and engaged in reading and writing when they are not feeling completely frustrated by the reading and writing tasks. Therefore, activities that support them in making sense of complex texts should help to decrease frustration, increase feelings of efficacy, and keep readers and writers engaged. In sum, provide meaningful reading and writing activities that challenge students' thinking, but support them in the process.

14. What are the best and easiest strategies for assessing literacy skills in science?

I recommend constructing Content Area Reading Inventories, or CARI, (Readence *et al.*, 1989) for your science textbook or texts you like to use with your students. To construct a content reading inventory, you choose a passage that students have not yet read, construct questions that tap into literal, inferential, and applied levels of reading, and you ask students to read the text and answer the questions. I like CARI because it can assess how your students comprehend and apply the texts you want or expect them to read. However, CARI can be difficult to construct well. Readence and colleagues provide examples, and I suggest that you pilot them with your students. If they answer in ways that you did not expect, then do not automatically assume that they can't comprehend texts. The fault could lie in your questions; good comprehension assessments are very difficult to write!

For writing, the best way to assess is by asking students to write explanations of the procedures and of the findings of their classroom science investigations. Don't simply read what they write to assign a grade, however. Read to look for patterns in their writing. Often, students can make claims, but they don't use evidence. Or they use evidence, but don't provide their reasoning. Or they leave steps out of procedures, which is not good science, as the procedures need to be carefully documented. Look for the patterns in their strengths (and don't teach those over again) and in the areas they need to develop (do re-teach in those areas).

15. What are the best strategies for helping students comprehend visual texts (e.g. charts, maps, graphs, etc.) in science?

The best strategy is less of a strategy and more of a practice. You should make it a routine to walk through the visuals, pointing out, for example, what columns in a table represent or what points on a graph mean. You should ask students what they notice in images, perhaps even translating what they see into words. And you should ask students to visualize images from print descriptions so that they get used to moving back and forth across print and visual. Make a point to show them the different images and graphics in texts you assign, and make a point to ask them questions about their interpretations of the graphics and images on a regular basis (not just on a test).

Another excellent practice was suggested by a teaching colleague of mine: She routinely put tables or graphs on the board for bell work (seat work to focus students at the start of a class period) and asked students to write what the chart said in words. The next day, she might have a word statement on the board, and would ask students to represent the statement in a graph. (The graphics were always related to the concepts being studied a that day.) This work represents an important form of scientific literacy in the ability to move back and forth across multiple forms of representation and to know when one form was more useful than another.

References

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