The Role of Practices in Scientific Literacy

Beth A. Covitt, Jenny M. Dauer, and Charles W. Anderson, January 2015

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Introduction

Scientists and engineers account for only about 5% of the U.S. workforce (Mather & Lavery, 2012). Thus, the vast majority of students in K-12 science classrooms are not learning science in preparation for science and engineering careers. Given that that's the case, why is there so much emphasis on scientific practices in the *Next Generation Science Standards* (Achieve, 2013)? In other words, why do the majority of U.S. students who aren't going to *be* scientists still need to learn how to *practice* science?

There are multiple reasons why becoming proficient in both the content and practice of science is important. Several oft-cited reasons for teaching science to all students, including the majority who will not pursue a science or engineering career, include fostering a sense of wonder about and appreciation for the material world and developing a citizenry that is capable of using science to inform personal and societal decisions about issues for which science is relevant (that is, for socioscientific issues). In this chapter, we focus on the second reason – discussing how individuals who are scientifically literate can use science as a tool for understanding and for making informed decisions about socioscientific issues they will encounter in their lives.

While science educators frequently talk about scientific literacy as a goal for students, succinctly defining this term has proved to be an elusive task (DeBoer, 2000; Feinstein, 2013). Without presuming to offer a comprehensive definition, we suggest that a person who is scientifically literate is able to understand, judge and use science in productive and scientifically aligned ways in their life. Leveraging this idea of scientific literacy, we use this chapter as an opportunity to discuss the role of scientific practices in a context based on a traditional meaning of "literacy" – namely, making sense of scientific information encountered in print and other media sources. All citizens need to be able to make sense of information in the media about myriad personal and societal issues such as food, medicine, climate, technology, and the list goes on…

This definition has important implications for K-12 science teaching. Let's begin the discussion of these implications by considering *when* and *how* the students in school today are going to need to be scientifically literate.

When: preparation for future learning. Bransford and Schwartz (2001) suggest that "preparation for future learning" is a key goal for education. This phrase captures an important characteristic of scientific literacy. Something educators have to do for students is *prepare* them for their lives after school, when they will need to learn new scientific knowledge to inform their decisions about socioscientific issues (Zeidler & Kahn, 2014; Zeidler, Sadler, Applebaum & Callahan, 2009). All of the scientific knowledge that students will need in their future lives cannot be taught while they are in school both because of curricular time limitations and because the boundaries of scientific knowledge will continue to change and expand after students graduate.

How: dealing with varied and sometimes unreliable sources of information. In K-12 science classrooms, teachers generally control the sources of information available to students, and try to make sure that the texts students read are accurate, informative, and written at an appropriate level for their understanding. Outside of the classroom, though, people encounter scientific information in a wide variety of media sources. Some of these sources compromise scientific accuracy because they are designed to persuade or entertain. Other sources oversimplify complex data or models. The most carefully verified texts (i.e., peer-reviewed scientific articles) are often written for specialized audiences and can be difficult to understand. Thus the sources of information that citizens are likely to encounter in their daily lives present challenges that K-12 students rarely have opportunities to grapple with in science classrooms.

Defining the work of scientific literacy. To continue the theme developed in Chapter 1, scientific literacy may be thought of as *preparation for future sense-making*, and this requires the capacity to engage in science and engineering practices. These practices involve both physical and intellectual work. In this chapter we focus on the careful intellectual work that non-scientists need to do to make sense of information in the media about socioscientific issues – including information that may be oversimplified, intended to persuade, or even intentionally deceptive in nature.

Scientifically literate people can use scientific practices and knowledge to make sense of and make informed decisions about socioscientific issues. In the first section of this chapter we examine how research on human thinking and on the relationships between scientific knowledge and practice shed light on what it means to be scientifically literate, and importantly, why it's so challenging to teach for scientific literacy. In the second section we develop two examples – diet and climate change – to illustrate some ways in which the use of scientific practices can enable people to make sense of and consequently to make better decisions about issues and questions they encounter in their lives.

Why and How Scientifically Literate People Use Scientific Practices

So how can science education prepare students for future scientific sense-making in places and contexts that cannot be predicted today? In this section we use research on learning and on the relationships between scientific knowledge and practice to discuss challenges involved in teaching for scientific literacy:

- Why do people need scientific practices? First, we discuss and contrast two ways that people have evolved for thinking and making decisions – fast, intuitive thinking versus slow, effortful thinking (Kahneman, 2011). While fast, intuitive thinking makes day-to-day life feasible, it is slow and effortful thinking that can help people use science to evaluate sources of information they encounter. Humans need scientific practices to counteract some of the problems and limitations associated with the fast and intuitive way we often perceive and make sense of the world.
- How can people use scientific practices? Second, we discuss how people can use scientific practices to understand the world, and in particular, complex socioscientific issues that they need to make decisions about. People can use scientific practices and knowledge to further build their scientific knowledge and to help them design solutions.

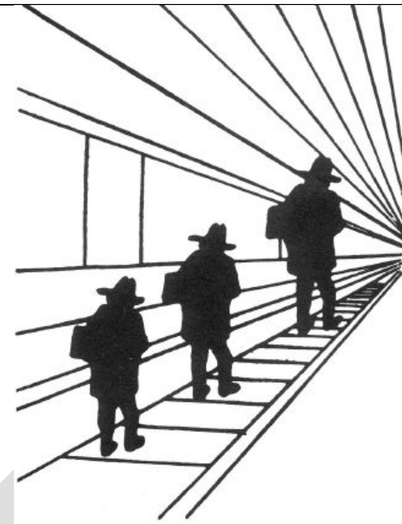
Why Do People Need Scientific Practices?

Why can't scientific literacy just be quick and easy? Couldn't people just find sources of scientific information that are accurate and easy to understand and rely on those? Aside from the difficulty of finding those sources, there are reasons embedded in the nature of human perception and learning that make engagement in slow and intellectually demanding practices a necessary part of scientific sense-making.

One reason for this has to do with how humans, over millions of years, have evolved to think and make decisions (Evans, 2008; Mithen, 2002). Humans can't be deliberative about every decision we make, so we have developed abilities to perceive the world and to make most decisions very rapidly. People rely on quick, intuitive thinking for most of our day-to-day decisions, and in general that's a good thing. Fast thinking enables us to take quick and decisive action using incomplete information, and there are many times when quick action is better than slow or no action.

However, there are problems inherent in quick and intuitive thinking. Fortunately, humans have also evolved a parallel way of thinking that is slow and requires conscious effort. Figure 1 (from Kahneman, 2011) provides an interesting example of the contrast between fast, intuitive and slow, effortful thinking. First, we perceive immediately that the woman on the left is angry, and we can be glad our fast intuitive thinking alerts us to this possibility quickly. But we also perceive immediately that the three silhouettes on the right are different sizes. Except, they aren't.

You need fast, intuitive thinking to be ready when this woman speaks…..



….but you need slow, effortful thinking to figure out that the three silhouettes are actually the same size.

Figure 1: Uses of fast and slow thinking

How can we tell that the three silhouettes are actually the same size? Well, we can't tell by just looking at the picture. No matter how long we stare, the right-hand silhouette still looks bigger. To confirm that this is an illusion, we need a different, slower strategy, such as getting out a ruler and measuring the three silhouettes. And as soon as we measure the silhouettes, we are engaging in scientific practices. We are generating data to interpret and analyze, and we are using mathematics and computational thinking.

Some other characteristics of the measurement strategy are also worth noting. In addition to being slower than our initial perceptions, it is also a product of conscious decision-making and effort. We have to decide to measure rather than just "seeing the picture." And we have to do work to arrive at our conclusions. And we can remember and consciously keep track of the steps of our process. In contrast, the automatic processing done by our eyes and brains to produce visual perceptions happens immediately, without conscious thought or effort.

It would be nice to say that the reward for the effort we put into slow and effortful thinking is that we discover the "real truth" about the world. Unfortunately the real truth is still elusive even after engaging in scientific practices. We still can't be *sure* that the silhouettes are the same size because we might have made a mistake measuring, or a more accurate ruler might show that the silhouettes really *are* a little bit different. The best we can do is to recognize and manage the multiple sources of uncertainty in our lives. While it falls short of knowing the real truth, managing sources of uncertainty by using slow and effortful thinking is still a very important aspect of scientific literacy. Table 1 summarizes and generalizes this discussion about fast, intuitive and slow, effortful thinking.

Table 1. Features of Fast and Slow Thinking (adapted from Haidt, 2001)

Fast intuitive Thinking	**Slow Effortful Thinking**
Unintentional, runs automatically	Intentional and controllable
Process is inaccessible, we're only aware of results	Process is consciously accessible
Does not demand attentional resources	Demands attentional resources, which are limited
Perceives stories and visual patterns	Analyzes patterns in data
Perceptions feel certain	Analyses acknowledge uncertainty

So how are these features of fast and slow thinking connected to scientific and engineering practices? In many ways, as it turns out. Scientific practices are valuable for a lot of reasons, but one key reason is that they help people *slow down*— i.e., to recognize when and how we need to question our perceptions and intuitions and analyze them more carefully.

As Table 2 shows, the practices are inherently strategies for slowing down thinking. Perceptions and informal ways of thinking provide people with quick and easy answers that are often wrong. It is possible to use scientific practices to slow down, verify data, check sources, and consider alternatives. Table 2 contrasts characteristics of fast perception with scientific practices from the *Framework for K-12 Science Education* (NRC, 2012) and the *NGSS.*

These contrasts are not just coincidence. Scientific communities have spent many generations developing practices that help their members avoid the pitfalls of too-hasty thinking and develop well-reasoned alternatives. These practices are an important cultural legacy—a gift from generations of scientists to our children today, a gift that they can use to employ slow thinking when they need it. We show how this gift can work in the real world in our diet and climate change examples below.

Table 2: Comparing Fast Thinking Practices with Scientific Practices

Issue	**Fast, Intuitive Thinking Practices (from Kahneman, 2011)**	**Slow, Scientific Thinking Practices (from NRC Framework, 2012)**
Answering Questions	*Substituting an easier question:* When confronted with a complex, difficult question, fast thinking supplies an answer to an easier, related question.	*1. Asking questions (for science) and defining problems (for engineering):* Scientific practice defines specific questions that are answerable with arguments from evidence.
Validating models and patterns in data	*Confirmation bias:* Fast thinking gives greater credence to sources, information and arguments that agree with our personal perceptions and narratives.	*2. Developing and using models:* Scientific practice searches out ways to falsify or test models.
Sources of evidence	*Seeing is believing:* Fast thinking makes use of information at hand to construct perceptions and stories, without asking whether critical information might be flawed or missing.	*4. Analyzing and interpreting data*: Scientific practice accepts only replicable data and constantly seeks out new data.
Patterns in data	*Stories, not statistics:* Fast thinking fits patterns we see around us into storylines that make sense, but may not account systematically for all the data.	*5. Using mathematics and computational thinking:* Scientific practice involves using statistical methods to find and verify patterns in data.
Explaining events	*Simple cause and effect:* Fast thinking finds single, simple causes for events	*6. Constructing explanations and designing solutions.* Scientific explanations use models and recognize complex causes.
Recognizing uncertainty	*False certainty:* Fast thinking produces instant conclusions that seem wholly true based on available information without evaluating the quality of the information.	*7. Engaging in argument from evidence:* Scientific practice relies on careful use of evidence and reasoning to reduce, but not eliminate or ignore, uncertainty.
Communicating results	*Source amnesia:* Fast thinking makes use of available information without questioning whether the source it came from is reliable, and quickly forgets the source entirely.	*8. Obtaining, evaluating, and communicating information:* Scientific practice documents and verifies sources of knowledge claims.

How Can People Use Scientific Practices?

Sometimes people need scientific practices to help them make sense of information they find in various media sources, but *how* should they go about using the practices? What does this work of scientific sense-making actually entail? Current views suggest that scientific practices need to be both learned and used in concert with scientific knowledge (Millar & Driver, 1987; National Research Council, 2007, Ch. 2). Thus, the *Framework* (NRC, 2012) and the *NGSS* forward a notion of "intertwined knowledge and practice" (see Figure 2 and chapters 1 and 2 in this book).

But how can people use scientific knowledge and practice together to make sense of socioscientific issues? Key relationships among scientific knowledge and practices are depicted in Figure 3. Some kinds of scientific knowledge are represented by the segments of the triangle including:

- **Data:** Scientific data are observations, but observations that are carefully made and selected to be precise, accurate, and replicable.
- **Patterns in Evidence:** Analysis of data can lead to the identification of patterns in evidence that extend across space and time. Patterns in evidence are verified and validated using statistical approaches.
- **Models:** Models are conceived to explain patterns in evidence and tested through predictions they make about future observations. The small top of the triangle in Figure 3 indicates that the power of scientific models lies in their parsimony—a few models can explain many different patterns, each of which is based on thousands of observations that extend across space and time.

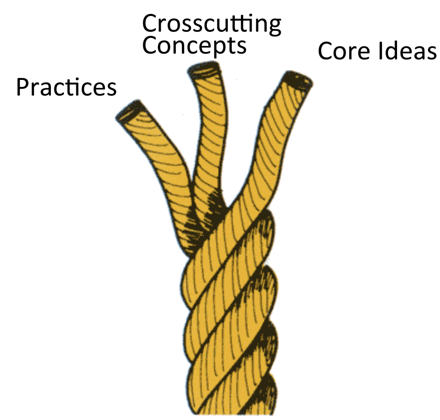


Figure 2: Strands of scientific literacy

The arrows around the triangle describe actions people take to develop and use scientific knowledge. Thus, the three arrows represent the practices of scientific sense-making as a cycle of developing and using knowledge. The arrows are important because they connect scientific knowledge and practice together. *Data* alone is not useful as *evidence* unless one can find and verify *patterns* in the data and explain those patterns using scientific *models*.

Developing Scientific Knowledge

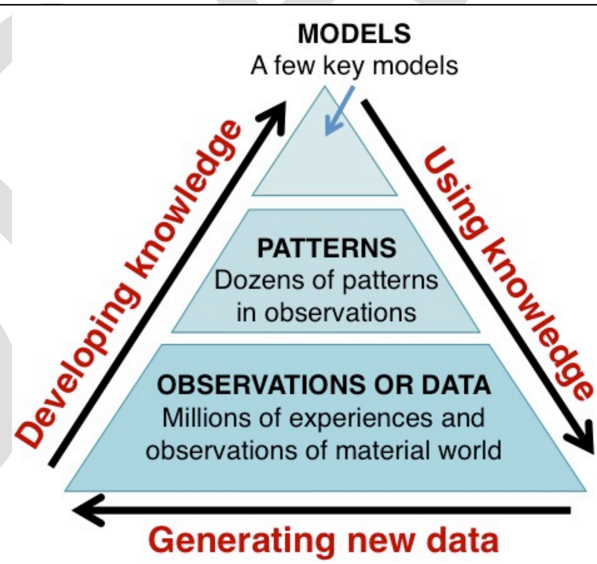
1. Asking questions (for science) and defining problems (for engineering)

2a. Developing **models**

3. Planning and carrying out investigations

4. Analyzing and interpreting **data**

7. Engaging in argument from **evidence**



Using Scientific Knowledge

2b. Using **models**

6. Constructing **explanations** (for science) and designing solutions (for engineering)

General Practices Associated with the Three Arrows

5. Using mathematics and computational thinking

8. Obtaining, evaluating, and communicating information

Figure 3: Connecting NRC Framework scientific practices with scientific knowledge

Thus scientific sense-making involves using sources of information to build and use scientific knowledge. Scientifically literate people engage in practices to *evaluate and connect data, patterns, and models.* This enables them both to be critical users—evaluating the quality of data, patterns, and models in the sources they encounter—and to know what they are looking for—finding sources that they can use to "fill in gaps" in their own understanding.

What Does This Mean for Science Education?

Clearly, the challenge of helping students become scientifically literate is daunting. Science education has to prepare students to learn about new scientific findings that can't be anticipated and to make decisions about socioscientific issues that will be different from the issues of today. In their future lives, students will often have to rely on media sources that are designed to entertain, persuade, or over simplify, rather than to educate, or they will have to search for more reliable sources that can be difficult to obtain and understand. What can be done in science classrooms to prepare today's students for these future challenges?

In this section we have argued that research about how people learn and about the nature of scientific understanding suggests two important ways that educators can prepare students to use scientific practices:

1. First, educators can prepare students to use scientific practices to *slow down and critically evaluate the sources of information* they encounter. Human minds reach some kinds of conclusions quickly and effortlessly, and writers who develop media to persuade and entertain know this; they provide instantly believable stories that ignore conflicting data and alternative interpretations. Scientific practices provide well-established ways to be critical of the stories that media tell and consider the alternatives.
2. Second, educators can prepare students to *build scientific understanding* by connecting verified data, robust patterns (often statistical) that extend across time and space, and validated scientific models. Scientifically literate individuals can identify the gaps in the information sources they encounter and in their own understanding, then pose questions and seek out additional sources that enable them to develop more complete and robust scientific accounts.

In combination, these practices can help prepare students to *design solutions to problems* that simultaneously consider and respect their personal goals and values and use scientific sense-making to better understand the nature of the problems and the possible consequences of their actions.

Examples of Science Practices and Scientific Literacy

We now turn to two examples of how these ideas apply to citizenship and day-to-day life. Our examples focus on issues that affect everyone: diet and climate change. There is important science related to these issues that can be taught now, but the science is still evolving. Thus, it's not possible to teach today everything that students will need to know in the future. For each issue, we discuss how scientific practices can help people live healthier lives and be more responsible citizens.

Example 1: Diet

Figure 4. Popular media messages about diet and weight loss

As Figure 4 shows, people are routinely inundated with claims about diet and its relationship to health and weight. These claims reflect the importance of diet and weight to all kinds of people. More than two-thirds of U.S. adults are overweight or obese, and obesity continues to be a leading public health problem in the U.S. (Ogden et al., 2014). Let's consider how science education can prepare students to use scientific practices as they learn and make decisions about diet in their own lives.

How can scientific practices help? Fast thinking provides humans with guidance about diet in the form of tastes and appetites, and this guidance, like the first image in Figure 1, worked pretty well for our ancestors. Taste helps people identify safer and more nutritious foods; hunger motivates people to search for food; and satiety tells people when to stop eating. Overall, fast thinking worked pretty well in times when food was scarce and hunger was the main dietary threat to well being.

But times have changed in countries like the United States, where for many people food is always as close as the nearest refrigerator or fast-food restaurant. Now, as in the second image of Figure 1, perceptions can lead one astray. Food and restaurant advertising is designed to appeal to fast thinking, providing tempting images of tasty food that spur people to eat without stopping to think about alternatives or consequences. Humans don't necessarily benefit from our appetites for sweet and fatty foods or from our bodies' ability to store fat in case there is a future famine. Today, people need slow thinking to reason about and regulate our diets and body weight (see, for example, Diamond, 2012, Ch. 11; Pollan, 2006, Ch. 1).

Many of us care about our own weight and health, or worry about our children's nutrition, or have to teach about diet and health to students. So what should we do when confronted with thousands of media messages about food and diet, the majority of which likely purvey information of dubious scientific value? How can we decide which claims and whose advice are worthy of our attention? As with other issues involving scientific literacy, this isn't just a scientific question. People legitimately use personal feelings, cultural traditions, and past experience to make judgments about what and how to eat. But in addition, people can use scientific practices to recognize when and how science may be relevant to choices and actions. In particular using scientific practices can help people (a) slow down and critically evaluate sources of information, and (b) build scientific knowledge to design solutions.

Slowing down and critically evaluating sources of information

Figure 4 immediately makes one problem clear. There's lots of useful information available that can help in designing an appropriate diet, but there's lots of junk out there too. As of 2001, the Federal Trade Commission (2002) found that more than half of all weight-loss ads contain one or more deceptive claims. How can people tell the difference? Scientific practices are not the only way to judge claims; it is also important to consider journalistic standards of publications and legal restrictions on advertising claims. However, scientific practices including engaging in argument from evidence (Practice 7) and using models (Practice 2) are still fundamentally important for making informed judgments.

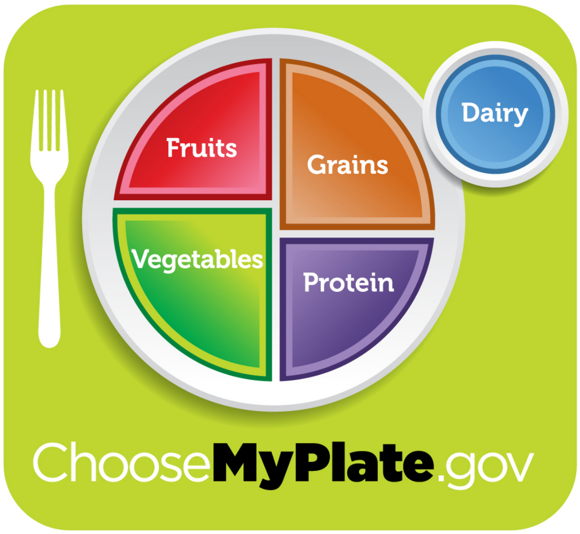
Let's consider one claim from Figure 4 above: "The Vitamin D discovery that SHRINKS FEMALE FAT CELLS and boosts weight loss up to 70%." (http://www.vitaminddiet.com/vitaminddiet/index?keycode=213879&cm_mmc=whcom-_-edit-_-VitaminDDiet). We know from our research about how students understand metabolism (Jin & Anderson, 2012; Mohan, Chen, & Anderson, 2009) that many students will find this claim believable. Students often think of weight gain and weight loss as actions that our bodies take—with the help of enablers such as food for weight gain and exercise for weight loss. So if exercise enables bodies to shrink fat cells, why couldn't there be a pill that does the same thing?

Evaluating this claim using scientific practices requires a more thorough analysis and consideration of relevant evidence and models. Let's start with models: bodies basically have one way to get rid of excess fat – using it as an energy source for cellular respiration. Exercise increases a body's energy use, and it makes sense that exercise could change fat cells. The claim that Vitamin D shrinks fat cells suggests a mechanism (supplements shrinking fat cells without bodies expending energy) that contradicts current scientific models. At best, the Vitamin D advertisement glosses over an important detail about energy use; at worst, it deceptively implies that weight loss can be easily achieved simply by taking a dietary supplement.

What about evidence? Well, some evidence in recent scientific literature has suggested that Vitamin D supports mitochondrial function, thus decreasing fatigue and supporting exercise (Sinha, et al., 2013). But how does this evidence cohere with both scientific models and the claims made in the advertisement? A careful read of the fine print in the advertisement says that weight loss did not require exercise. This suggests a claim about Vitamin D that does not align with scientific evidence or models of metabolism. Thus, using scientific practices to carefully examine evidence and models can help people be productively skeptical about the many potentially dubious media messages they will encounter in their lives.

Building scientific knowledge to design solutions

Fortunately, there is also plenty of valid scientific information about nutrition available. For example, the U.S. government has long been aware that nutrition is important, both because healthier people have higher quality of life and because healthier people are more productive citizens. Given its interest in public health, the government has sought to provide guidance to people who want to make good nutritional choices. Scientifically literate people can use this information to plan and to change diets.



Nutrition Facts

Serving Size 172 g

Amount Per Serving	
Calories 200	Calories from Fat 8
	% Daily Value*
Total Fat 1g	1%
Saturated Fat 0g	1%
Trans Fat	
Cholesterol 0mg	0%
Sodium 7mg	0%
Total Carbohydrate 36g	12%
Dietary Fiber 11g	45%
Sugars 6g	
Protein 13g	
Vitamin A 1% • Vitamin C	1%
Calcium 4% • Iron	24%

*Percent Daily Values are based on a 2,000 calorie diet. Your daily values may be higher or lower depending on your calorie needs.

NutritionData.com

Nutrition label for black-eyed peas

Figure 5: Approaches to communicating about nutrition

Planning diets. Figure 5 shows two different approaches to designing solutions (Practice 6) by planning a diet that meets nutritional needs. The Choose My Plate approach begins with an image that appeals to fast thinking—i.e., an image of a balanced meal that probably provides sufficient guidance for many healthy people. It does leave important questions unanswered though:

- Just how big are the servings supposed to be?
- What about foods that mix ingredients from different food groups?
- What about the diversity of foods within each group? Are they actually equivalent from a health and diet perspective?

The nutrition label, in contrast, can be used as the basis for a slower approach to designing a diet that makes use of scientific practices—the equivalent of getting out a ruler to measure the silhouettes in Figure 1. Nutrition labels provide opportunities for slow thinking that use both scientific knowledge and practices to plan a diet. A scientifically literate person can use the information on nutrition labels as evidence, look at patterns across different food types, and rely on a scientific model that explains how eating protein versus sugars or fats can affect body function.

Thus designing a diet using nutrition labels involves scientific practices including:

- Asking questions. Reference to a nutrition label allows one to pose and consider the more difficult question of, "what's the chemical composition of this food," rather than the easier but potentially superficial question, "what kind of food is this?"
- Engaging in arguments from evidence. Nutrition labels offer valid and pertinent evidence that readers can use to recognize tradeoffs associated with different foods.
- Using models. Food labels connect ingredients with theoretical models of metabolism and nutrition. People can trace how different molecules in food are used in the body.
- Using mathematics: Food labels allow readers to reason quantitatively about the nutrition they are getting from the food they eat.

So nutrition labels provide an opportunity for scientifically literate citizens to develop deeper knowledge about food and investigate the possible consequences of dietary decisions. Taking advantage of this opportunity requires some slow thinking that is inherent in the use of scientific practice and knowledge. Unfortunately though, the average consumer often has difficulty understanding which types of molecules are in the foods they eat, and how consuming different types of molecules can impact weight and health (Cowburn & Stockley, 2005). Many consumers also have difficulty engaging in computational practices like interpreting serving size information and converting from numbers on the labels to conclusions about the servings they actually eat (Cowburn & Stockley, 2005). Thus, science education has an important role to play in helping students develop facility with practices needed to make better choices about diet.

Changing diets. Scientifically literate people also *interpret and analyze data* to monitor health and modify diets**.** No matter how carefully we plan our diets, there are still lots of uncertainties involved. Studies reveal new information every day about how people process food differently, and about subtle effects of dietary choices on health and fitness. It is impossible to predict in advance exactly how any individual will respond to a diet—or how well our actual eating habits will reflect our conscious dietary choices. We all know that fast thinking can take over when we are hungry and the food is tempting!

So wise people will monitor the effects of diet solutions they have designed and interpret the data they collect (Practice 4). Some information about the effects of our diets is instantly available through fast thinking—how energetic we feel, how hungry we feel, how fat or thin we look in the mirror. We can also get out our "rulers" and measure the results of our diets using slow thinking – e.g., by measuring our weight, blood pressure, blood sugar, cholesterol level, endurance, etc. There may also be new data that come from studies about other people—evidence about how people with different personal histories or body types respond to diet and exercise; evidence about risks associated with particular foods or dietary supplements; evidence about how sleep, exercise, and other activities affect health and fitness.

So the practice of interpreting and analyzing data plays an essential role for scientifically literate people who want to plan their diets and maintain their health. And this practice is connected in turn with other practices, such as constructing and analyzing arguments from evidence (Practice 7) and designing new solutions (Practice 6) based on those arguments. Scientific practices cannot tell people the right thing to do, but they can help people evaluate claims, plan solutions, and respond to new evidence as it becomes available.

Example 2: Climate change

The first example in this chapter focused on how using scientific and engineering practices can help people make *personal* decisions about diet and health. The second example shifts to the large-scale *public* issue of climate change. We first discuss how scientific and engineering practices can help people learn about the issue. We then focus on how specific practices can help people evaluate the merits of claims, design solutions, and interpret and analyze data to inform decisions about policies and actions.

How can scientific practices help? Unlike diet, where fast thinking in the form of taste and appetite provide people with hard-wired evolutionary guidance, human understanding of climate change comes solely as the product of scientific data collection and analysis. Knowledge of climate change relies on the slow thinking efforts of scientists working early as 1827, when Fourier calculated that the Earth would be colder without an atmosphere (Jones & Henderson-Sellers, 1990).

Humans' fast-thinking perceptions, experiences, and impressions of the material world are limited in scope, and thus not sufficient for observing something as large in magnitude and as slowly changing as climate. People must engage in slow, scientific thinking to scrutinize evidence and explanations for climate change; climate change is best understood through consideration of patterns in data across time and space (i.e., long-term atmospheric data collected in locations around the world) and through reference to complex scientific models of Earth's systems.

However, given the human proclivity for fast, intuitive thinking, it is weather, rather than climate, that tends to be more persuasive to many Americans. For example, the number of Americans who believe that global warming is real dropped between September 2012 and April 2013, likely influenced by a relatively cold winter of 2012-2013 compared to the prior year (Leiserowitz et al., 2013). Being persuaded about climate change by short-term weather or extreme events is an intuitive thinking way of both substituting an easier question (e.g., "what's happening with the weather this year?" rather than "what do climate data reveal?") and relying on confirmation bias (i.e., thinking that a warm winter provides persuasive evidence supporting a climate change denier argument). A key challenge, therefore, is to prepare fast-thinking minds to comprehend a slow-developing process.

We next discuss how scientific practices can help people use scientific knowledge, develop new knowledge, and make decisions about global climate change. As in our discussion of nutrition and diet, we discuss how people can use practices to (a) slow down and critically evaluate sources of information, and (b) build scientific knowledge to design solutions.

Slowing down and critically evaluating sources of information

These days, Americans encounter many conflicting messages about climate change (e.g., see Figure 5). Mixed messages may be presented by journalists who give undeserving weight to deniers' arguments in an attempt to sound balanced and present both sides of the issue (Antilla, 2010; Moser, 2010). And climate change deniers use media to describe non-existent controversies within the scientific community and to promote discredited evidence, patterns, or models (Moser, 2010). Sometimes environmental advocates who think more should be done to mitigate future climate change also use arguments that are not adequately supported by current evidence (e.g., blaming all kinds of extreme weather events on climate change). The result is that climate change is a confusing, if not confounding, topic to make sense of.

CNN, Sept 28, 2013 | *Fox News*, Aug 20, 2013

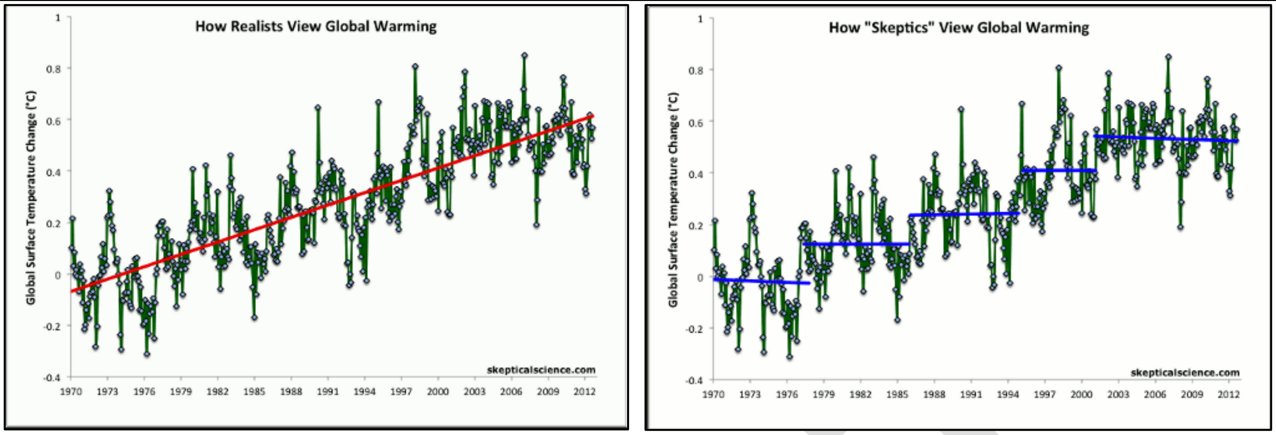
Figure 5. News articles about climate change

Many Americans aren't sure what to believe about climate change. A gap in science literacy is illustrated by how many fewer Americans (63%) believe that anthropogenic climate change is occurring compared with the consensus among scientists (97-99%) (Anderegg, et al., 2010; Leiserowitz et al., 2013). Recently the Intergovernmental Panel on Climate Change (IPCC, 2013) reported that it is "extremely likely" that human activities are driving warming. This high level of confidence, however, is not always emphasized in media reports (see Figure 5). A brief glance at news articles like these poses a challenging dissonance. How should a person make sense of claims about how Earth's climate is (or isn't) changing?

Scientific practices can play a useful role. To use scientific knowledge to evaluate a claim, a scientifically literate person will pay attention to different kinds of knowledge including data, patterns and models (segments of the triangle in Figure 3). All three components of the triangle are important. The data must be relevant and connect to the claim. The patterns must be robust and hold up to statistical testing. Also, there needs to be a principled reason (i.e., a model) that explains patterns in the data.

Let's use scientific knowledge and practices to evaluate the claim in the Fox News headline above: global warming has experienced a slowdown in recent years. This example demonstrates the importance of multiple scientific practices, notably using models (Practice 2) that explain and not just represent patterns, interpreting and analyzing data (Practice 4), using mathematics and computational thinking (Practice 5), and engaging in argument from evidence (Practice 7).

Analyzing and interpreting data. The World Meteorological Organization defines climate using observational averages from the previous 30 years (Arguez & Vose, 2011). Thus, relevant evidence needed to evaluate a claim about a pause in warming must include at least several decades of data. Climate deniers can choose periods of short-term noise in data that look like cooling. This is called *cherry-picking*. The two graphs in Figure 6 illustrate how climate deniers can misrepresent patterns in temperature data (i.e., by identifying short decreasing temperature time segments within a larger increasing temperature pattern).



Skepticalscience.com

Figure 6. Two views of patterns in data about global temperature change

Using models. Many debates about cutting edge science focus on procedures (i.e. experimental design and the peer review process) and statistics (or pattern-finding as in Figure 6). While these are important issues, understanding models and mechanisms is also critical to making informed judgments. Scientific arguments require a principle-based reason or model to explain a pattern in the data. Thus, a pattern by itself is not necessarily meaningful unless it can be explained in terms of how the material world works (Practice 2, developing and using models).

Even climate deniers generally do not dispute that concentrations of greenhouse gases in the atmosphere are increasing. Statistical arguments by climate deniers (Figures 5 and 6) typically ignore this inconvenient fact. But this fact is at the core of scientists' arguments. Models focusing on heat exchange between the Earth and space (Figure 7) demonstrate that thermal energy MUST be building up in the Earth's atmosphere and oceans. Atmospheric temperature data are just one (particularly noisy) indicator of this underlying trend.

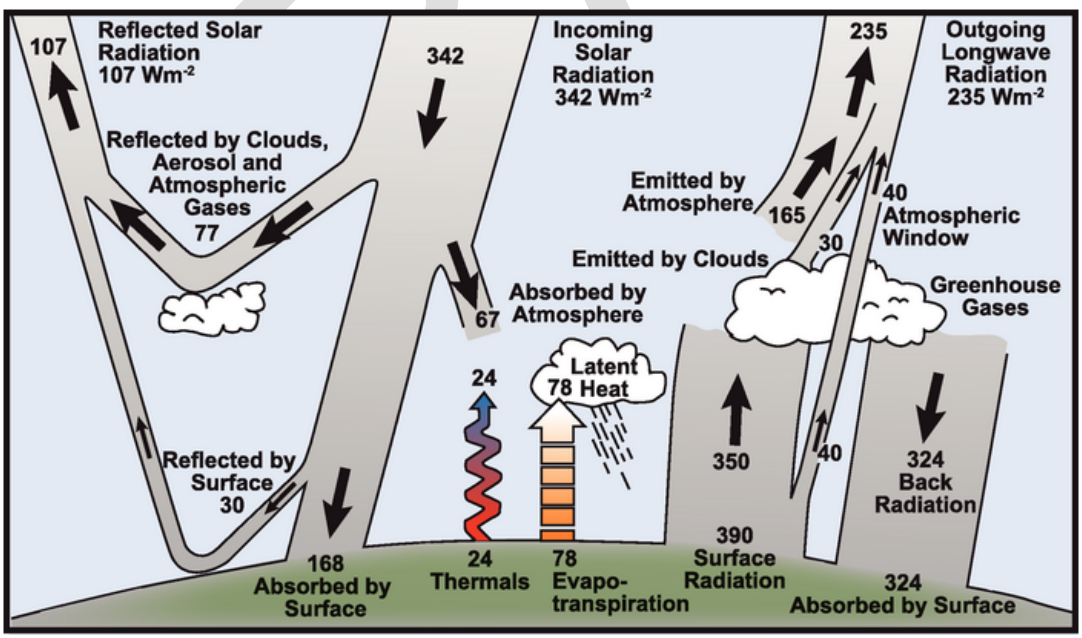


Figure 7. Estimate of Earth's annual and global mean energy balance (Kiehl and Trenberth, 1997) as referenced by the IPCC AR4.

Building scientific knowledge to design solutions

Many people accept that climate change is real and believe we should do something about it. Unfortunately, wanting to do the right thing is not the same as knowing what to do. For example, while many people believe correctly that humans can address climate change by using less gasoline or burning less coal, these same people may also indicate that climate change can be mitigated by cleaning up toxic wastes, fixing the hole in the ozone layer, and decreasing use of nuclear power (Bostrom, Morgan, Fischhoff & Read, 1994; Kempton, Boster & Hartley, 1995; Leiserowitz & Smith, 2010). These latter actions will not reduce emissions of greenhouse gases or mitigate climate change. Clearly, many people need some support in using scientific models (Practice 2) to consider what options may comprise reasonable solutions (Practice 6) for mitigating human-caused climate change.

Using mathematical reasoning. Designing solutions that will stabilize greenhouse gas emissions also requires knowledge of the magnitude of carbon emissions associated with different human actions. How many trees offset the emissions from one coal-fired power plant? Is it more important to improve the fuel efficiency of our cars or the insulation in our homes? A scientist and an engineer at Princeton University together came up with an approach to answering these kinds of questions. Their idea was to compare different strategies for increasing efficiency and conservation, decarbonizing electricity and fuels, or amplifying natural sinks for carbon dioxide (Pacala & Socolow 2004). They defined strategies that produced comparable reductions in greenhouse gases as “stabilization wedges” that when implemented now, take a large bite out of future carbon dioxide emissions (Figure 8).

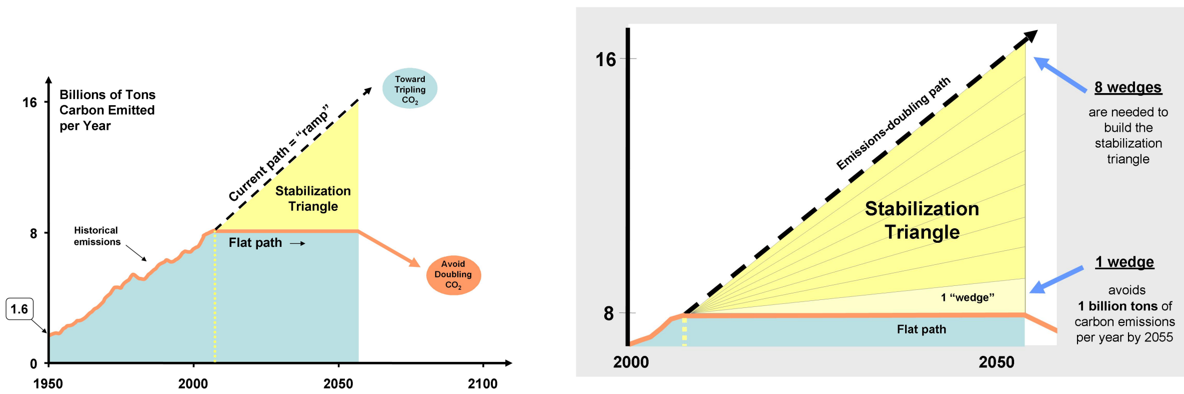


Figure 8. Stabilization wedges, Carbon Mitigation Initiative, Princeton University, http://cmi.princeton.edu/wedges/

The wedges idea can be used as the basis for a slow-thinking approach to designing solutions for climate change that makes use of scientific practices. Individuals can use scientific models to evaluate different approaches for reducing greenhouse gases. In order to understand what makes a wedge a wedge, it is necessary to use scientific practices such as constructing explanations and engaging in argument from evidence (see the Stabilization Wedges Game http://cmi.princeton.edu/wedges/). Choosing which wedges to enact also requires people to draw on a combination of knowledge, values and priorities to compare the costs and benefits of different strategies (Practice 6).

Interpreting and analyzing data. The best ideas for mitigation strategies today may not be the same as the best ideas tomorrow. There are many unknowns in global climate change: How fast will ice caps melt? How will the occurrence of extreme weather events be affected? How much carbon dioxide will the oceans absorb? There are many different potential future scenarios, as illustrated by the IPCC (Figure 9), with different projections that depend, to a large extent, on future human actions. Science can predict what will happen in the future only in broad terms.

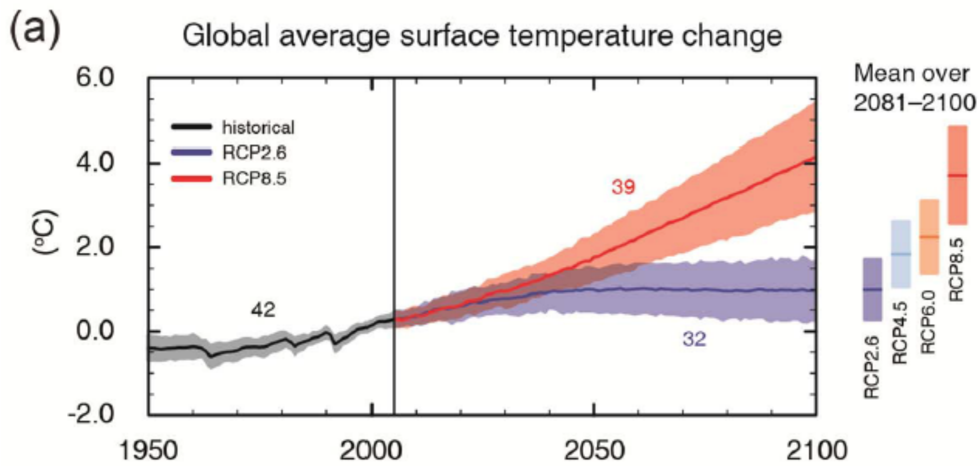


Figure 9. Future scenarios for global temperature from the IPCC AR5.

The National Research Council report *America's Climate Choices* report (NRC, 2011) recommends a strategy for responding to inherent uncertainties associated with a changing climate on its first page:

> … a valuable framework for making decisions about America's Climate Choices is **iterative risk management.** This refers to an ongoing process of identifying risks and response options, advancing a portfolio of actions that emphasize risk reduction and are robust across a range of possible futures, and revising America's Climate Choices responses over time to take advantage of new knowledge (NRC, 2011, p.1).

How can science education help prepare students for a world in which iterative risk management is necessary? *America's Climate Choices* makes it clear that responses to climate change and other environmental issues cannot simply be left to the experts. These are choices that will affect all aspects of everybody's' lives—what kinds of houses we live in, whether and how much we drive, how much electricity will cost—so experts and ordinary citizens need to be engaged in a deliberative process that includes interpreting and analyzing continually evolving data and responding in ways that adapt over time.

Thus, our nation's response to climate change requires an essential role for scientifically literate citizens. Scientific practices cannot tell people the right thing to do, but they can help us with iterative risk management, which involves responding to new evidence as it becomes available and using that evidence to inform plans and decisions about possible solutions.

Conclusion: Scientific Literacy in the Science Classroom

The examples above focused on what people know today about nutrition and climate change. We have tried to show how scientifically literate people can critically evaluate varied sources of information, and use those sources to build scientific knowledge and design solutions.

We have located our examples outside of science classrooms because that's where the practices of scientific literacy are enacted—in the public and private domains of day-to-day life. We close, though, with some thoughts on practices in science classrooms that can prepare young people for scientifically literate reasoning and action. The discussion in this chapter has implications for both the kinds of issues science education should address and the information sources that should be used in science classrooms.

The examples above illustrate that topics students encounter in their daily lives and in the news—such as nutrition and climate change—provide multiple opportunities for engaging in practices to develop and use scientific knowledge. These are also topics that will capture the interest of many students, so they are prime candidates for what Engle and Conant (2002) refer to as "productive disciplinary engagement." Such topics deserve to be included in the required science curriculum because as they engage these topics, students can use scientific practices to (a) slow down and critically evaluate sources of information, and (b) build scientific knowledge to design solutions.

Slowing down and critically evaluating sources of information. Issues that arise in students' lives provide rich opportunities to explore the nature and limits of scientific knowledge and practice. When addressing these issues in science classrooms, though, it has often been assumed that the information provided to students should be authoritative and scientifically correct. We suggest in this chapter that maybe that's not always such a good idea. Science teachers are understandably reluctant to include incorrect claims in their curricula, but the popular media have no such limitations. Outside of school, students are barraged with information of dubious scientific merit, mixed in with ideas and data that have strong scientific support. Given the largely uncontrolled body of science information in popular media, preparing students for life as scientifically literate citizens will necessarily require assistance in learning how to sort out claims of differing scientific merit.

There are a variety of strategies students can use to evaluate the credibility of claims, including judgments about the editorial standards of different media sources, an understanding of the scientific peer review process, evaluations of the quality of data supporting an argument, and strategies for spotting self-interest in the claims that people make (e.g., Covitt, Harris, & Anderson, 2013; Kolstø, 2001, 2006; Nicolaidou et al., 2011; Zeidler & Kahn, 2014). In this chapter, we have focused on one strategy that makes use of the practice of model-based reasoning: Students can learn to judge the quality of arguments from evidence supporting claims that they read: whether those claims are supported by credible evidence and are consistent with accepted scientific models. None of these strategies leads inevitably to the "right answer," but through effective teaching, science education can help students make better-informed judgments about the validity of information they encounter.

Building scientific knowledge to design solutions. Media sources also provide multiple examples of scientific information that students can interpret and use. Nutrition labels, for example, provide chemical analyses of every kind of food found in the grocery store, and they are readily available on line (e.g., www.nutritiondata.com). As discussed above, interpreting these labels involves several different scientific practices. Our discussion focused on how nutrition labels can be practically useful for making nutrition decisions, but we have found that nutrition labels can also be used in other important ways in science classrooms. The labels provide detailed analyses of the chemical content of foods, and (since foods are made from the bodies of plants and animals) of plant and animal tissues. Thus, the labels can be used to help students trace matter and energy through living systems—addressing both an important crosscutting concept and a key disciplinary core idea.

There are many other kinds of data readily available on the Internet that students can use in their scientific practices: weather data, geographic information, data about plants and animals in local ecosystems, etc. These data can be used in classrooms to make science teaching more place-based, more relevant to students' lives, and more interesting. Students will learn important science content in ways that extend their scientific literacy—their ability to find and use the information they need for personal understanding and action.

Public and personal issues also afford multiple opportunities for students to develop new knowledge through experience and to discuss and evaluate recent scientific findings. For example, students could monitor their own weight and health data, or weather and climate data. Students could also monitor energy use in their homes and schools. There are also many programs that engage students in citizen science—contributing to databases that are created by thousands of people sharing observations of similar phenomena from around the country and/or the world. One example is Project Bud Burst (http://www.budburst.org), which engages students in collecting phenomenological data that can be used to study how plant species are responding to changes in climate.

All of these activities afford students opportunities to participate actively in the scientific enterprise on a personal, regional, national, or global scale. Such activities can support students in learning about ways that all citizens can participate in science and about how scientific knowledge is developed. Thus, by teaching for scientific literacy it is possible to engage students in scientific practices in ways that are interesting, relevant, and scientifically valid. We see a great deal to gain and little to lose in using teaching materials and strategies like those suggested above. It is not necessary to compromise the rigor of scientific content to teach for scientific literacy, preparing all students to use science in meaningful ways in their future lives.

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