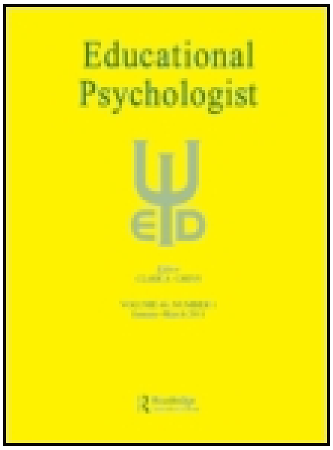

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Scientific Literacy: The Role of Goal-Directed Reading and Evaluation in Understanding Scientific Information

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In this article, we examine the mental processes and representations that are required of laypersons when learning about science issues from texts. We begin by defining scientific literacy as the ability to understand and critically evaluate scientific content in order to achieve one's goals. We then present 3 challenges of learning from science texts: the intrinsic complexity of science phenomena, the need to coordinate multiple documents of various types, and the rhetorical structure of the texts themselves. Because scientific information focuses on models, theories, explanations, and evidence, we focus on how explanatory and argumentative texts are processed. Then we examine 2 components of executive control in reading—goal-directed guidance and evaluation of content—that readers can acquire and adopt to deal with these challenges. Finally, we discuss 3 implications that these theories and empirical findings have for interventions intended to improve laypersons' understanding of scientific information.

The Internet has created a greater public need for scientific literacy. Information that was once accessible only in university libraries or occasionally published in more popular form by responsible sources is now directly available to all. Furthermore, credible research and reporting competes with amateur blogs, entertainment summaries, and outright misrepresentation for public attention and resources. To some extent the increase in accessibility of accurate information has been a boon. The Internet makes it easier to find and consume scientific information. With powerful search tools, people can quickly identify and access relevant articles. They can fill in gaps in their knowledge by accessing pedagogical texts written at various levels of difficulty. They can find commentary that provides contextual information about a topic or methodology. In some cases they can even contact the authors themselves and ask specific questions about a published report.

With these benefits, however, have come serious challenges. The constant need for material by the many sites that report scientific information means that people are likely to find information that is misleading or inaccurate, even from educational and news sites (Chung, Oden,

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Joyner, Sims, & Moon, 2012). A 1999 *Nature* study of reliability of information on controversial topics (Allen, Burke, Welch, & Rieseberg, 1999) found that about one fifth of the material was factually inaccurate, about one third was interpretatively misleading, and about three fourths was unreferenced. Such inaccurate information also tends to live on and on despite updated reports or even outright retraction.

Another challenge is that readers, now exposed directly to scientific discourse, are likely to encounter disagreement among experts and not understand how to interpret it. For scientists, disputes are common and take place within a culture that values and uses disagreement to advance understanding. Lay readers typically lack an understanding of this culture but find themselves in the epistemic position of having to reconcile discrepancies and tolerate uncertainty. Thus, disagreement and hedging is often misinterpreted as ignorance or uncertainty on the part of a particular scientist or even an entire field; a lack of consensus on a tangential issue might be misunderstood as lack of agreement on a greater one.

Finally, lay readers face the challenge of trying to tell who is a credible expert and who is not. Anyone may publish on the web; many can also write scientific-sounding articles capable of deceiving lay readers. Many self-help forums, for instance, are frequented by self-appointed "experts" who might sound authoritative to naïve readers. So although the Internet has simplified our access to scientific information it has also removed or at least enabled a bypass of traditional filters and interpreters and exposed lay readers to both the full complexity of scientific discourse and a host of fraudulent claimants.

These challenges are not new. In a general sense, they are the same challenges that anyone must master during the course of gaining expertise in some discipline. What has changed is the sudden exposure of these challenges to unprepared readers and a massive increase in scale, both of the number of readers and amount of material. This situation demands that we ask ourselves how we can better prepare students and the community at large to meet these challenges. Obviously we cannot train everyone to be scientists. Instead, we must examine whether there are general skills and heuristics in critical thinking and reading that can be conveyed through schooling and other means to the public. In this article we propose that with some support, readers can improve their ability to manage their reading goals and evaluation of information—exactly the type of skills that will help them cope with these challenges.

The discussion that follows is limited to people seeking and reading authored texts from books or websites, as opposed to more interactive activities such as forums or social media. Nor do we discuss the challenges to reading that arise from the constraints of digital displays such as small display size and suboptimal linking of pages and the differences between print and online reading any further, as this discussion would extend beyond the scope of this chapter (see Rouet, 2006, for a review).

Instead, we focus on questions such as, What is scientific literacy? Why are science texts challenging to readers? What do nonscientists need to know and do to consume scientific information—real or fake—from the web? What can be done to prepare students to reflect critically on the information they find during inquiry-based learning activities?

To address these questions, we begin by offering our definition of *scientific literacy* as the ability of people to understand and critically evaluate scientific content in order to achieve their goals. This definition goes beyond providing a list of concepts or science principles that need to be learned or specifying scientific and technical vocabulary that might be necessary (Brossard & Shanahan, 2006). It is more in line with recent calls to focus more seriously on the skills and knowledge required to read and use texts in science beyond simple comprehension of the main point of a single, linear text (Council of Chief State School Officers, 2010; Norris & Phillips, 2003; OECD, 2011) and complements the call to connect these skills to the real-life uses of an engaged public (Feinstein, 2011; Liu, 2009).

Our definition stresses two essential aspects of scientific literacy. First, reading about science is a goal-directed activity in which readers' orientation toward information resources is guided by their needs, purposes, and objectives. Although readers can have many goals, from locating a specific fact to understanding how something works and why, we focus on the more challenging goal of understanding. As such, we limit our discussion to the goals of explanation and argumentation rather than searching. Second, scientifically literate readers need to spontaneously and strategically evaluate texts according to scientifically appropriate criteria (e.g., soundness of a scientific explanation and relevance of reasons provided). Evaluation entails checking the content of a text against one's background knowledge and beliefs and against other documents. Although such ability is limited by lack of domain knowledge, there are nevertheless general strategies in which a reader may engage related to the structure of scientific content that may provide some value. Although goal-driven and evaluative processing are both affected by one's epistemic cognition, this topic is covered in detail in another article in the special issue (Sinatra, Kienhues, & Hofer, this issue) and prior work (Chinn, Buckland, & Samarapungavan, 2011) and so will not be covered here. Also, graphs and other media are important means of presenting scientific information; however, due to space limits we consider only texts.

We conclude that one's ability to assemble information, to gain control over biasing influences of one's own beliefs, and to strategically evaluate the content and sources of scientific information is an integral part of consuming scientific information from the web and that these and related skills deserve more attention in contemporary science teaching. In a world replete with information sources and media, one must acquire an accurate understanding of how scientific knowledge comes about in order to correctly interpret scientific information. We discuss some of the educational implications of these claims in the final section of the article.

WHAT MAKES SCIENCE READING CHALLENGING?

Scientific texts typically seek to describe some phenomena and explain how it occurs. Reading and learning from such texts can be challenging for several reasons. We focus on three challenges: the complexity of the described phenomenon, the need to coordinate multiple documents of various types, and the rhetorical structure of the texts themselves.

Complexity

Science texts frequently describe and explain complex phenomenon. Even in cases where an observed event is itself commonplace or apparently simple, the explanation for how it occurs and under what conditions might be complex. Consider a phenomenon such as the observed increase in average global temperature. In one sense, it simply means that temperature measurements gathered from many recording stations around the world and from satellites are, on average, recording higher values than they did in the recent past. To gain an understanding of what this means and why it might be occurring, however, could require reading texts relating to the measurement of global temperature, measurement of atmospheric CO_2, the greenhouse effect, the effect of orbital and solar cycles on climate, paleoclimatology, measurement of gasses in glacial ice cores, pan evaporation rates, gas absorption spectra, climate modeling, natural sources of greenhouse gases, and so on. Even if climate change were not a controversial topic, simply reading to seriously understand the phenomenon could be a daunting undertaking for the average reader.

This complexity is due to the need to connect all of these disparate pieces of information into a single, integrated representation. In text-processing theory, this is referred to as a *situation model* (Kintsch & van Dijk, 1978) or *mental model* (Chi, 2000; Graesser, Singer, & Trabasso, 1994; Johnson-Laird, 1983). Reading in general is viewed by researchers as the construction of a mental representation of a text's meaning through processes of symbol recognition, activation of meanings, and integration of knowledge (Graesser et al., 1994; Kintsch, 1998). The most durable representation, the situation model, is a referential representation that captures the meaning of the described situation enhanced by connections with the reader's world knowledge and related inferences (Kintsch & van Dijk, 1978). The use of the term "situation model" alludes to the origin of text-processing theories in research on narrative texts. Thus, when writing in the context of science and expository texts, many authors prefer the more general term "mental model" or "integrated mental model" when referring to a representation constructed from multiple documents (Britt & Rouet, 2012; Goldman, Lawless, & Manning, 2012).

The elements of a mental model for the scientific phenomena (Graesser & Franklin, 1990; Johnson-Laird, 1983; Mayer, Dyck, & Cook, 1984) would include nonhuman entities (e.g., vehicles, farms, forests) in addition to agents (e.g., humans) presented as *states* (e.g., trees are in the soil, greenhouse gases are in the atmosphere) and dynamic *events* (e.g., fossil fuels are burned, forests are cut down). These states and events can lead to other states and events, which can be viewed as explanatory processes or causal relations (e.g., increasing fossil fuels use leads to more carbon dioxide in the atmosphere, which leads to increased trapping of heat, which leads to increase average global temperatures). These nonagentive causal relations are at the heart of a mental model for these scientific phenomena. Needless to say, the more entities, states, and events in an explanation the more effort a reader must expend to represent this information. More challenging epistemically, however, is the multiple-causality of scientific phenomena (Bråten, Britt, Strømsø, & Rouet, 2011), and these multiple causes can be independent or coordinated in complex ways.

It is important to note that complexity itself is not unique to science texts. Narratives and other genre may also deal with complex topics. Indeed, historical explanations also entail coordinating multiple, independent, and interdependent causes (Britt, Rouet, Perfetti, & Georgi, 1994). However, the entities (human agents) and causes (human motivates and states) in narratives are more familiar to readers than the nonhuman entities and causal mechanisms used in science texts. Science explanations might deal with things like elementary particles winking in and out of existence, entities with multiple dimensions, the very small (atomic) and very large (astronomical) scale of objects. These are not things that people can readily imagine and are frequently only understood by scientists themselves in the context of mathematical notation and formulas.

The type of language used to describe science phenomena is also more demanding than nonscience language. There is more unfamiliar, technical vocabulary, use of abstract concepts, and description of methodological procedures. Science texts are informationally dense and often written in an authoritative, impersonal style (Fang, 2008; Lee & Spratley, 2010; Shanahan & Shanahan, 2012).

The extent to which a lay reader of science texts encounters complexity depends on the reader's goal and the resources available. For instance, a grade school student given only the school textbook might answer a question like, "Why is the earth getting warmer?" with a simple answer from the text like, "Because people are burning more fossil fuels." The textbook written for their grade level hides much complexity and focuses on teaching concepts and basic regularities and processes. In contrast, someone wishing to debate a climate change denier would need to read many documents and construct not only an elaborate explanatory model but one that is elaborated with supporting observational data and common criticisms and responses. We discuss reader goals in more detail in a later section. Most readers' goals fall somewhere between these extremes and typically involve informing some personal decision, such as deciding whether to or how to reduce one's carbon footprint.

Multiple Documents and Sources

Outside of school contexts, learning about a scientific topic frequently involves reading multiple texts. Take a common activity such as idly reading a health finding from a news web site. At the very least, one is likely to encounter a similar report of the same finding from other news sites or possibly encounter references to it in future articles. If a reader wants to learn more about a topic, the web offers a broad range of document types and sources—popular news and magazine articles, illustrations, Wikipedia excerpts, self-help forums, blogs by anyone, journal articles, official publications and even book excerpts and self-published books. Each of these document types has different characteristics (e.g., structure, reliability, usefulness) that can influence how readers comprehend and evaluate the information.

The recognition that readers frequently need to integrate information from multiple sources gave rise to the Documents Model (Britt, Perfetti, Sandak, & Rouet, 1999; Perfetti, Rouet, & Britt, 1999; Rouet, 2006). According to this model, *understanding* in a multiple document learning situation is the creation of an integrated mental model of the information contained in those documents. Although there may be cases where readers create separate, unintegrated representations of each text (Britt et al., 1999), readers more typically have a goal of learning about a scientific phenomenon, causing them to integrate content across reading experiences into a single representation. The Documents Model also arose from the recognition that texts are written by authors with a particular perspective and level of knowledge who are writing with certain rhetorical goals that influence how the information will be represented. When the reader has the goal of ensuring the reliability of the content or when the documents contain conflicting information that cannot simply be integrated coherently, the Documents Model framework posits that readers can explicitly associate content with the source that created or published it within a representational space called an *Intertext Model*. The Intertext Model represents information about the content and sources of each document (a Document Node) and the relations among sources and between source information and content (via Intertext Links). Readers can represent information about the author, setting, document, and rhetorical goals. Authors can have different occupations or credentials (e.g., scientists, doctors, politicians, students, activists, member of political or social organizations, business person, self-help member, friend, blogger), different levels of knowledge (e.g., scientific training with or without specialty in topic, medical training with or without specialty in topic; person with disease; no specific training in scientific methods or formal training in field), different motivations for writing (e.g., share knowledge, argue for interpretation or theory, make recommendations, persuade reader to buy product, entertainment), and role in creating the presented information (e.g., conducted experiment, took medicine personally, read others' findings, pure invention). Document characteristics also vary. Documents have a particular genre (e.g., journal article, textbook, media report, blog post) and time of publication. Each of these author and document characteristics can influence a reader's assessment of the credibility and usefulness of the content as well as influence a reader's interpretation of the actual content. Therefore, readers may explicitly represent this source information. As with the other types of representations, information in the Intertext Model can be information explicitly mentioned (e.g., author's name or publication outlet) or inferred (e.g., author's bias and quality of the publication outlet).

Despite readers' need to use source information, several studies have found that they usually do not spontaneously attend to source information in a useful way. Even very young readers attend to sources and source-to-content links (who said what) when reading stories about science and health topics, but they seem not to be able to appropriately use the features of the source to make judgments of who would be most knowledgeable (Macedo-Rouet, Braasch, Britt, & Rouet, 2013). Likewise, Braasch et al. (2009), looking at individual differences in middle school students' evaluations of source characteristics, found that readers who were unable to differentiate useful from not useful sources also had inappropriate evaluation behavior, relying on irrelevant source attributes and not inspecting content carefully. Such variability also exists for high school and college students with respect to their attention to and evaluation of sources of documents (Britt & Aglinskas, 2002; Goldman, Braasch, Wiley, Graesser, & Brodowinska, 2012; Stadtler & Bromme, 2007, 2008; Wiley et al., 2009) and embedded sources (i.e., those referenced within a document; Strømsø, Bråten, Britt, & Ferguson, 2013). Spontaneous evaluation of sources is particularly challenging because sites often do not provide enough information about the source to support evaluation. Locating such missing information for web pages, when possible, requires search skill and sometimes knowledge of Internet features (e.g., web archives, domain ownership registrations; Britt & Gabrys, 2002; Rouet & Coutelet, 2008).

One area where source information is particularly useful is in dealing with conflicting information. Given the complexity of scientific phenomena and the need integrate information into a single, coherent explanation, readers will frequently have to deal with inconsistent or conflicting information (Baker, 1979; Otero & Kintsch, 1992). Conflicting information is especially important in science because it is an essential part of how a scientific community tests its knowledge and arrives at established truth. Conflict indicates the existence of alternative explanations or disputed claims or, in the case of conflicting evidence, signals that an explanation may lack sufficient support. Therefore it is important to better understand how readers detect and resolve such conflicts.

Recently, Stadtler and Bromme (in press) proposed a Content-Source Integration model (CSI) that presents three ordered stages to dealing with conflicting information. First, readers must detect that a conflict is present. Many studies have shown that readers of expository texts will often fail to detect within-text inconsistencies (Glenberg & Epstein, 1985; Noordman, Vonk, & Kempff, 1992; Otero & Kintsch, 1992). However, other studies have shown that there are conditions under which readers are able to detect inconsistencies in science texts, such as when both pieces of information are coactive (Glenberg & Epstein, 1985; Wiley & Myers, 2003), when readers are directly asked a question about the key information to make the necessary inference (Singer, Halldorson, Lear, & Andrusiak, 1992; Singer, Harkness, & Stewart, 1997) when readers can make the coherence-building inference (Otero & Kintsch, 1992; Singer & Gagnon, 1999; Wiley & Myers, 2003) and when they are given a reading goal that encourages the inference (Noordman et al., 1992).

In the second CSI stage, readers attempt to restore coherence by ignoring it, creating inferences to reconcile the conflict, or attributing it to conflicting sources. Rouet, Britt, Caroux, Nivet, and Le Bigot (2009) found that when participants were asked to write a one-sentence summary of short news reports with discrepant information, they demonstrated several strategies, including changing the information so it was no longer contradictory and selecting one side to believe or qualifying the discrepant information as the view of particular sources, thereby enabling the coherent coexistence of discrepant information. In addition, Braasch, Rouet, Vibert, and Britt (2012) found that readers paid greater attention to sources, as indicated by an increase in gaze fixations to and better recall of source information, when a text presented conflicting content.

Finally, in the third CSI stage, if the second stage methods cannot restore coherence then, according to the CSI model, readers will attempt to evaluate which proposition is true and thereby resolve the conflict. The selection of what to believe or ignore can be based on one's discipline-specific knowledge of content and methods to obtain reliable information or one may simply select the side that is consistent with one's own beliefs or worldview or even change one's own beliefs (Chinn & Brewer, 1993; J. Maier & Richter, 2013a, 2013b; Otero & Kintsch, 1992). It is likely that the accessibility of domain-specific knowledge plays a role in the sequencing of Stage 2 and Stage 3 methods. For instance, if one immediately recognizes that some information has been discredited or is part of a standard argument, the conflict might be immediately resolved without much effort on the part of the reader. Such is certainly true for domain experts. For lay readers, the extent to which they must engage in more deliberate methods for resolving controversy depends on their level of domain knowledge and perhaps their immediate reading situation (e.g., recognizing that an article that has just appeared in some search results is the one just mentioned by another article as having been clearly biased author).

As the preceding discussion indicates, the wide variety of sources a science reader may encounter adds significantly to representational complexity and processing. Readers too will vary in their ability to evaluate and utilize source information. As we describe later, however, this is one area where much support can be given to help them with this task.

Text Structure (Genre)

The expository nature of science texts may also present a challenge for less experienced readers. Most people learn to read by reading stories. Thus they become acquainted with narrative structure at an early age and sometimes never encounter other writing genre until well into their schooling. Likewise, most casual reading is also narrative—in the form of novels and short stories. Although such works do contain descriptive and expository elements, the representational structure one constructs is essentially temporal and entity relationships involve the actions and motivations of human agents. Comprehending a story draws heavily on what one knows of social relationships, cultural mores, and intuitive models of personal motivation and social causality.

For the most part, people do not spontaneously acquire such similar intuitions about natural phenomena, and when they do they are frequently wrong (Chi, 2005; Chinn & Brewer, 1993). Indeed, scientific methods exist in part as a means of overcoming intuitive biases, such as that of inferring causality from contiguity in time. People must formally learn about the entities and relationships that compose the representational structure of scientific explanations. Science texts may propose and describe entities with specific properties (e.g., molecules), nonagentive causal mechanisms (e.g., forces), consistent relationships among variable properties and measurements (e.g., Boyle's law). Yet in the end they are fundamentally explanations and sometimes arguments and use common rhetorical structures such as causal statements, collections, descriptions, problem/solution, and comparisons (Meyer, 1975). Readers can learn to recognize such structures and how they "work" (Lee & Spratley, 2010; Shanahan & Shanahan, 2012;

Osborne & Patterson, 2011). In the next section, we present an analysis of both explanations and arguments and discuss how their comprehension is linked to the evaluation of knowledge claims.

Explanations. Explaining how or why phenomena occur is a key goal of scientific research; thus exposition constitutes the primary genre of scientific writing. Explanations may be characterized as a series of causal statements that assert that a state or event occurs as a result of some other process, mechanism, or influence. For example, consider the explanation that the current increase in the average global temperature is caused by greater human fossil fuel consumption. In this case, one can create a detailed explanation by making clear the intermediate steps between this factor (e.g., greater human fossil fuel consumption) and the occurrence of the outcome (e.g., increase in the average global temperature). After Hempel and Oppenheim (1948), we use the terms *explanans* and *explanandum* to refer to the chain of linked factors and the to-be-explained outcome, respectively. We add the term *initiating factor* to refer to the reputed cause or the start of a particular causal chain. Figure 1 shows an idealized representation of part of an explanation for "the recent increases in average global temperature." Two initiating factors, "Man's increased fossil fuel consumption" and "the increase in deforestation for farmland," are included to explain the outcome or explanandum. In this case, both initiating factors go through the same two intermediate factors or explanans ("increased CO_2" and "increased heat trapped"). Each arrow indicates a hypothesized causal relationship and together the statements form a set of connected causal claims (i.e., *causal chain*).

Even simple explanations can involve extended causal chains that may be challenging to represent. Consider the following paragraph about nuclear power generation from Millis, Morgan, and Graesser (1990).

> Nuclear power comes about from a process that involves atoms, heat, and turbines. To get the process started, a neutron is purposefully sent into an atom to make the atom split into two particles. When this happens, heat energy is released, and the water in the surrounding tank is heated. The resulting steam drives a series of turbines.

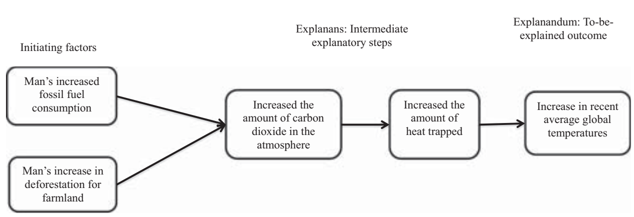

FIGURE 1 Graphical representation of an explanation for the Explanandum (i.e., to-be-explained outcome): "increase in recent average global temperatures." *Note.* The arrows indicate causal relationships. If I remember the Hempel-Oppenheim model of explanation correctly, the distant causes (named "initiating factors" in the diagram) might also be part of the explanans (together with appropriate general laws).

A causal chain representation of this paragraph could be represented as follows: neutrons are sent into atoms → atoms are split → heat energy is released → water in surrounding tank is heated → steam is created → steam drives a series of turbines → electricity is generated. To comprehend this passage, the reader must attend to and represent the key lexical terms that indicate processes (e.g., "sent," "split," "released," "heated") and causal terms (e.g., "comes about from a process," "to make," "when this happens," "the resulting"). It also requires inferences such as connecting the water being heated with the resulting steam. This example is a simple, single chain describing only a process. Our global warming example in Figure 1 is more complicated. It has two initiating factors leading to two complementary chains, and it describes a departure from a homeostatic condition. To explain recent temperature changes, the reader would need to attend to terms indicating both change due to normal processes (e.g., normal fluctuation of carbon in atmosphere and greenhouse effect) and to terms indicating a perturbation of these processes (e.g., greater fossil fuel consumption leading to increases in the amount of carbon dioxide in the atmosphere).

Several studies by Millis and colleagues have examined readers' representation of texts that describe the causal processes involved in natural (e.g., how we interpret pain signals, how stalagmites are formed; Millis, Graesser, & Haberlandt, 1993) and man-made (e.g., how a computer works, how nuclear power is generated) mechanisms (Millis et al., 1990). They found that even very short expository texts were challenging and, surprisingly, the presence of connecting words did not significantly improve memory for the explanation. For instance, Millis et al. (1993) examined whether temporal ("before," "and then"), causal ("which causes," "which enables"), or intentional ("so that," "in order that") connectors improved memory for the explanation relative to a no-connector condition. They found that causal elements were better recalled when they were segmented into sentences without connectors than when they were joined with temporal connectors. Recall, though relatively low in all conditions, was no different for the causal and intentional connector conditions than for the no-connector condition. These results suggest that readers of expository texts may have difficulty retaining information organized as causal chains even when lexical information is present to help them.

Readers' poor memory for simple causal chains may be due to their not inferring the causal relationship in the no-connector condition or to their failure to represent the relationship very deeply, even in the connector condition. The latter appears to be more likely when one considers studies showing that readers do create causal inferences for these short expository texts. For example, Millis et al. (1990)

used a prompted think-aloud paradigm that asked participants to state how, why, or what happens next during reading. They found that points in the texts that support inferences for representing causal relationships were associated with longer reading times, suggesting that readers do make some type of inference during reading. This conclusion is also supported by studies that have used a probe paradigm (Singer et al., 1992; Singer et al., 1997). For instance, Singer et al. (1992) gave participants short passages with sentences that were either causally consistent (e.g., *Dorothy poured the water on the bonfire – The fire went out)* or inconsistent (e.g., *Dorothy poured the gasoline on the bonfire – The fire went out*). Immediately following the sentences, participants had to respond to a timed probe task (e.g., *Does water/gasoline extinguish fire?*) that stated the proposition needed to establish the causal relationship between sentences. Participants spent less time verifying the consistent target probe indicating that they spontaneously generated the causal inference required to validate the truth of the causal relationship.

Instead, the less than optimal memory for simple causal chains may be due to readers' failure to use their genre knowledge to guide macrostructure processing. According to Kintsch and van Dijk (1978) and Kintsch's (1988) construction-integration model, readers construct an initial propositional representation of the meaning of a text and then iteratively apply macrorules to integrate and refine the representation. Representations of information that is deemed more important continue to be processed; representations of less important or less relevant information cease to be processed. The inappropriate application of macrorules for determining what is relevant to the expository genre may explain how inferences can be created but not recalled. If readers deem initiating factors or connections among explanans as not relevant, then this information and relevant inferences may be deleted during the integrative stage of processing. The elements of the explanations (i.e., the nodes in Figure 1) may be temporarily available to the reader depending on the specific features of the text (e.g., elements coactive) and important inferences may be established and even validated in the immediate moment. However, if the reader does not have an explanation schema that enables him or her to assign a specific status to each of these elements and to connect them meaningfully their resulting macrostructure may have little to do with the chain represented in Figure 1.

Some support for this view that representing explanations is due to a failure to represent the relationship very deeply comes from intervention studies. McCrudden, Schraw, Lehman, and Poliquin (2007) showed that readers learned causal chains better when given the external memory support of a causal diagram while reading the text than those that read the text alone. Also, Chi (2000) found that self-explaining helped students learn causal explanations. It may be that both of these interventions helped students better understand what is relevant and what is not when they construct and organize the information in their mental representation.

Scientific explanations are challenging to some readers. One has to use new terms that indicate process or change (increase, vary) as well as those that indicate relationships (e.g., leads to, causes) and assemble them into an explanatory structure. Readers must connect multiple explanans at the right level of grain size and represent multiple complementary or competing initiating events. Finally, they have to distinguish more important from less important information, paying special attention to connecting words and making knowledge-based and text-based inferences to increase completeness of the explanation. As we discuss next, we expect that interventions that help students learn about the structure of an explanation should help them to not only remember the information but also use it later in such situations as when another text presents information that complements or contradicts an initial text.

Argument. Scientific texts not only provide explanations for phenomena but also frequently present support (i.e., arguments) for those explanations or for the "goodness" of solutions based on those explanations. At its essence, science is about accurately describing and explaining the natural world. When a finding is new or contrary to common belief, it requires defense in terms of the method used to make an observation or in terms of rational inference. Indeed, it is sometimes difficult to distinguish explanation and argumentation in scientific writings, but like Osborne and Patterson (2011), we believe such a distinction is essential. Here we consider explanation as dealing with "how" or "why" questions and argumentation as dealing with "how do you know" questions.

The rhetorical function of arguments in scientific discourse is to convince readers that a scientific claim (e.g., a theoretical assumption, an observational or factual statement) is true. From this perspective, it is clear that readers can make sense of an argument only if they evaluate its validity. Similar to explanations, certain kinds of evaluative processes seem to occur routinely in argument processing. However, these processes are often confined to a quick evaluation of the plausibility of claims, whereas other aspects of argument validity such as relevance and sufficiency are often neglected. In this section, we describe the structure of arguments and discuss how arguments are processed, represented, and evaluated.

Although there are descriptive frameworks of argument, mostly based on Toulmin (1958), and more recent attempts to model argumentation (Nussbaum, 2011), there is no standard model of argument processing. Arguments do, however, tend to conform to a standard structure that one might characterize as an argument schema. When texts, such as web articles, are clearly structured as arguments (e.g., editorials, journal articles), experienced readers can use their familiarity with such rhetorical structures to more easily represent information (Britt & Larson, 2003; Chambliss, 1995; Knudson, 1994; Wolfe, Britt, & Butler, 2009). The typical structure of an argument is a claim, the acceptability of which is open to dispute, supported by one or more reasons or evidence and sometimes an acknowledgment and refutation of one or more counterclaims. For example, in Argument 1, next, the main claim is an explanation that fossil fuel use is causing increased global temperatures through increased carbon dioxide in the atmosphere. An implied counterargument, that levels of CO_2 fluctuates in cycles, is rebutted by two supported claims: that atmospheric CO_2 is at a higher level than any previous time in earth history, backed by a figure, and that the level has increased steadily since 1957, backed by a reference to the Keeling curve.

> Man's increased fossil fuel consumption is causing an increase in the average global temperatures. Fossil fuel consumption increases the amount of carbon dioxide in the atmosphere. Although the amount of carbon dioxide in the atmosphere fluctuates in cycles, it is currently at a level higher than any previous time in the history of the earth (see figure) and as the Keeling curve shows, there has been a steady increase in CO_2 since 1957.

Ideally, a reader with the goal of comprehending another person's argument will be able to draw on their genre knowledge, an argument schema, to enable them to set appropriate subgoals. Such subgoals include things like identifying the main claim, connecting and evaluating the support for claims, and representing challenges from counter claims and their backing.

To be useful, an argument schema must be activated prior to or during reading. The reader must detect that he is in fact reading an argument, something that many readers have trouble doing (Chambliss, 1995; M. Larson, Britt, & Larson, 2004). Detection may be aided by the presence of text cues that indicate that a statement is a claim that requires support. Britt and Larson (2003) proposed several linguistic cues that might trigger the detection of a claim. Modals (e.g., should) and uncertainty markers (e.g., probably) could lead to anticipated evaluation of a statement as a claim as compared with the same statement in an unmarked form. Other triggers include conflict with prior knowledge and beliefs; certain salient evaluative terms (e.g., "is immoral," "is harmful"); predictive statements (e.g., "will reach the tipping point by"); and, finally, simply providing obvious support (e.g., "because"). M. Larson et al. (2004) found that for all skill levels, the presence of explicit markers for argument elements led to better comprehension of a set of arguments.

Once a reader detects a claim, he or she should attend to the actual asserted propositions that require support. The type of claim will determine the type of information that can be used to support it. Scientific claims can include policy, value, factual, and causal claims (Rottenberg, 1988). *Policy* claims refer to a need for a solution or some behavior (e.g., the government should mandate carbon emissions control). *Value* claims assert a stance on the desirability (importance, benefit, cost) of something (e.g., the government was right to restrict carbon emissions of factories in the United States). *Factual claims* assert that some thing or state exists (e.g., average global temperature is rising). Finally, *causal claims* are assertions of the veracity of a causal explanatory mechanism. So the reader has to precisely notice and remember what is actually asserted. Many readers, however, have trouble precisely recalling the claims of simple arguments (Britt, Kurby, Dandotkar, & Wolfe, 2008). In a set of experiments to examine argument representation, Britt et al. (2008) had readers rate their agreement with either policy (e.g., "Recycling should be federally mandated because it helps to protect the environment") or value (e.g., "Recycling is very beneficial because it helps to protect the environment") arguments. Then they were asked to immediately recall the argument or the claim. Britt et al. found that approximately 25% of the time participants could not correctly recall the main verb phrase of a claim for which they had just provided an evaluation.

To create an integrated model of the explanations and support across documents, the readers will need to use their genre schemas to guide how they read and represent information. Using an argument schema involves knowing more than that a good argument "has a lot of facts to support one's claim"; it also involves the subgoals one might use to approach a text. For example, a subgoal may be to find support for a claim from another document that was not written for the purpose of supporting that particular claim. Another subgoal may be to evaluate whether the support an author provides is coherent, relevant, and accurate. A third subgoal may be to integrate information that does not support the claim and actually shows that the claim may not be true.

To conclude, arguments play a central role in scientific discourse. Proponents of scientific theories use them to persuade their community of the accuracy of the theory. Policy advocates use argument to convince the public and political leaders to take a course of action. Typical arguments include a claim and the reasons or evidence that support the claim. The comprehension of arguments, however, entails several challenges for lay readers. One challenge is to identify which part of an argument forms the claim and which are supporting reasons, especially in cases where claims and reasons may be presented in different parts of the text or even in different texts. Another, perhaps even more serious difficulty is that of evaluating the adequacy, goodness, or relevance of the reasons with respect to the claim they are meant to support. This requires an analysis of the content of the claim (e.g., factual, causal, or policy type of claim) and some reasoning about the link between the claim and the proposed reasons, which is often partly implicit and may also require domain knowledge not available to the lay reader (Toulmin, 1958).

In this section we have argued that text structure presents a challenge when lay readers engage with single or multiple scientific texts. This is due to the intrinsic features of the two prevalent text structures found in scientific discourse, namely, explanation and argument. Explanation is a difficult text structure because it is based on the causal linking of causal factors (i.e., explanans) to the outcome to be explained (i.e., explanandum). This type of structure has been found difficult to construct and maintain in memory. Argument is a difficult text structure because it requires the linking of claims to supporting reasons or evidence. The nature of the connection between claims and support may change as a function of the nature of the claim, which makes it difficult for lay readers to identify the claim and the reasons and to evaluate the goodness of reasons with respect to the respective claims.

In the next section we examine the conditions that may help lay readers overcome the difficulties of understanding science texts, whether due to the intrinsic complexity of science issues, multiplicity of texts and sources, or the challenges of the typical text structures that make up scientific discourse. We focus on how any training and educational supports could be tailored to help develop self-regulated, autonomous scientifically literate readers.

HOW CAN LAY READERS IMPROVE THEIR READING OF SCIENCE TEXTS?

To the extent that a reader has domain training, reading behavior will usually be strategic, efficient and successful. A domain expert knows many useful things: special search tools, which sources are more trustworthy, how various document types are structured, findings of seminal articles (Rouet, Favart, Britt, & Perfetti, 1997; Wineburg, 1991). Most consumers of scientific information, however, are not domain experts and are unlikely to expend much effort gaining such specialized knowledge. Instead, they must rely on general heuristics, augmented by a rudimentary understanding of scientific method and general principles gleaned from school.

What are these general heuristics, and is it possible to explicitly teach them? In other words, what can lay readers actually do to improve their ability to learn from science texts? In this section we examine two components of executive control in reading: goal-directed guidance and evaluation of content, both of which can vary from effortful and strategic to more effortless and routine. It is our contention that readers can acquire and adopt these heuristics to become better critical consumers of scientific information.

Goal-Directed Reading of Scientific Texts

Early models of text comprehension rarely considered that individuals usually read texts with specific goals in mind. Only recently have text comprehension researchers begun to acknowledge that reading processes and outcomes heavily depend on reading tasks and goals (Linderholm & van den Broek, 2002; McCrudden & Schraw, 2007; Rouet & Britt, 2011; Snow & the RAND Reading Study Group, 2002). Given the plethora of scientific information on the web and its complexity, setting appropriate goals and being able to align cognitive activities with these goals should be considered essential components of scientific literacy.

When presented with an environment, such as the web, that contains multiple documents (a set of texts written by different authors) on a topic, one has to decide what to read and how to read given one's goals and available resources. According to one recent framework, MD-TRACE (Rouet & Britt, 2011), these decisions are guided by one's *Task Model*—a representation of the primary goal and intermediate subgoals, action plans, and strategies for how to achieve the reader's primary goal along with criteria for evaluating success. For example, if one is interested in learning about how solar panels work, a primary goal might be something like achieving satisfactory comprehension of how a panel converts light into electricity. To achieve that goal, the reader might adopt a subgoal of locating a diagram that illustrates the process. When establishing subgoals, readers use their genre knowledge both for selection of an action (e.g., what type of information might be available, where it is located) and for evaluation of success (e.g., what constitutes a "good enough" explanation). Selection of relevant information can be made on the basis of topical overlap; usefulness for the task; and, at least for science topics, reliability of the information. Evaluative criteria might be provided externally, as is the case for school or work assignments, or internally, as readers gauge their own satisfaction with their level of understanding. The task model thus guides decisions on what to read (e.g., Wikipedia article), when to read it (e.g., free time at a computer), how much effort to put into reading (e.g., skim, skip, deeply read), how to locate it (e.g., search engine), and whether to seek more material (e.g., need for counter or corroborated information). One might think of the function of a good task model as that of helping readers to construct the "text" they need from the textual resources that are available but overwhelming and partly irrelevant. For our solar panel example, the goal of achieving satisfactory comprehension would guide the reader to skip web pages discussing how to purchase and install solar panels but to spend more time on pages with process diagrams and descriptions of the photovoltaic effect from general science magazines.

According to MD-TRACE, readers create a task model when they initially undertake a reading task. The model's content depends on the reader's knowledge and experience. Whereas a domain expert's task model might be quite detailed, a novice's may contain only a vague plan. For example, a recent study by Kopp (2013) presented undergraduates with a search-result listing and document set of global warming sources and asked them to write an argument about the extent to which mankind was responsible for average temperature changes. When asked prior to the task to describe their goals and how they were going to accomplish them, most of the students mentioned a vague relevance goal that was usually limited to finding information to support their point with an occasional mention of limiting themselves to unbiased sources. Such subgoals, along with other elements of the task model, can change, however, as readers progress through the reading task. In Kopp's study, when reading a document set that included unreliable sources and multiple perspectives, readers began to mention additional subgoals including seeking counterarguments or limiting their selection to recent sources and knowledgeable experts. Thus, the task model, which guides moment-to-moment reading decisions, can be updated throughout the task as more information is acquired and as goals become refined into subgoals and either satisfied or blocked.

People often read science texts with some type of understanding goal, such as figuring out how installing solar panels reduces electricity costs or how a new drug is metabolized by the body. In either case, because one is primarily interested in constructing an explanatory model, part of the goal criterion must include some notion of adequacy. Explanations are possible at many levels of detail. Readers must continually assess whether the representation they construct is sufficient to satisfy their goal. Table 1 lists several actions that a scientifically literate reader could take to guide the construction of an adequate integrated model of the phenomena from texts. With respect to explanation, readers need to seek out information to make sure that a "complete" set of initiating factors is pursued with special attention to well-established ones and to seek out infor-mation to make sure all factors are coherently connected to the to-be-explained outcome.

TABLE 1
Goal-Directed Evaluation: Actions a Skilled, Critical Reader Needs to Do to Determine Relevance or Usefulness to Task

	Reader-Directed Goals to Determine Task Relevance
Explanation	• Seek out information to make a sufficiently complete explanation that does not ignore known initiating factors. • Seek out information, such as important intermediate factors, needed for coherence of explanation.
Argumentation	• Qualify or disregard information that is unsupported or whose accuracy is disputed. • Identify elements of explanation that require support (e.g., truth of explanandum, existence of initiating factors, cogency of claim-support relationship, or connections among elements) and seek information that provides such support. • Seek additional information (if necessary) to establish sufficiency of support.
Sources	• Seek characteristics of the source (e.g., expertise and bias), outlet, and recency of information to decide whether an element or relation should be represented (either qualified by source or not).

In addition, because science is about making true and accurate explanations, readers must ensure that their understanding is correct. Culturally, we tend to accept as true both the teachings of our early schooling and the pronouncements of science. For the most part this is both necessary and desirable for pedagogy. Thus, for school-related goals and for most science topics, constructing an accurate representation is mostly a matter of correctly representing the contents of a textbook or authoritative science text(s). Most scientific fields have broad agreement on many core principles and their relationship to phenomena (scientific facts or laws). For some phenomena, however, there may be disagreement among experts. There may be competing explanations for how some phenomenon comes about. There may be methodological disputes. There are occasionally changes in accepted fact (e.g., status of Pluto as a planet). There is even sometimes error and outright fraud. In such cases, nonscientist readers typically do not have sufficient domain knowledge to adjudicate disagreements on their merits. They can, however, make use of general heuristics of argument evaluation to enable some degree of assessment. The second row of Table 1 lists several actions that a scientifically literate reader could take to guide their comprehension of argument content in science texts. The final row of Table 1 shows actions related to source information. These actions include making sure that support is provided for claims that require support and that the support is relevant and sufficient and reliable.

By setting appropriate goals and monitoring their comprehension, readers can work to ensure that their understanding of a science phenomenon is adequately complete and accurate. Such goals are ideally established at the outset of a task. Otherwise, the extent to which they are set during reading will likely be in reaction to the types of materials the read, instructional supports, or goal failures. Indeed, recognition of reader-driven goals highlights the importance of teaching readers about schemas for typical science genre (e.g., explanations and argumentation). To be truly useful, this schema knowledge has to be provided in a way that helps the reader see the importance of initial creation of a detailed and discipline-appropriate task model early in the task.

Evaluation of Science Texts

A second key aspect of our definition of scientific literacy is that readers need to be able to evaluate scientific information. Evaluation involves a judgment about the acceptability or "goodness" of some piece of information and some cognitive action that is taken as a result of that judgment. Such judgments are usually based on checks of consistency with prior knowledge or beliefs and coherence with other

TABLE 2
Evaluating Content: Actions a Skilled, Critical Reader Needs to Do to Determine Spontaneously or Strategically Evaluate Scientific Content

	Evaluating Content	
	Against One's Prior Knowledge	*For Consistency With Content From Other Documents*
Explanation	• Evaluate whether other potential initiating factors are missing based on comparison to prior knowledge. • Evaluate relations among elements for coherence of relations against prior knowledge. • Evaluate consistency of relations among elements for missing relations against prior knowledge.	• Evaluate whether all potential initiating factors or relation mentioned across documents are represented. • Evaluate relations among elements for coherence within and across documents. • Evaluate potential co-referents across documents.
Arguments	• Evaluate whether factors or relations seem plausible or true by comparing to prior knowledge. • Evaluate consistency of support with respect to prior knowledge • Evaluate appropriateness and limits of methods to produce evidence. • Evaluate assumptions and unstated inferences for believability. • Evaluate extent to which other unstated facts and principles corroborates or refutes the degree of believability or confidence in the claim-support relationship.	• Evaluate whether factors or relations seem consistent within or across documents. • Evaluate extent to which support provided can increase the believability in the specific claim asserted (evaluating type of support – type of claim relationship). • Evaluate support that data presented in graphs or tables give to claims asserted.
Sources	• Evaluate whether known perspectives have been represented.	• Evaluate whether all important perspectives (expertise, bias) have been investigated for potential initiating factors or relation and are represented. • Evaluate characteristics of the source (e.g., expertise and bias), outlet, and currency of information to decide whether element or relation should be represented (either qualified by source or not).

related information or adherence to established standards. The kinds of cognitive actions one might take range from acceptance to qualifying the information to outright rejection.

It is important to recognize that comprehension and evaluation processes are interdependent. One must comprehend what is presented by a text in order to evaluate it, and evaluative processing helps one monitor comprehension and integrate new content with prior knowledge and other text representations. Evaluation also guides a reader's decisions to include or exclude particular content from their representation of the situation. Our focus on the role of evaluation in scientific literacy is consistent with that of recent educational standards efforts. For instance, recent U.S. educational standards call for comprehension task such as summarizing, inferring, comparing, explaining (Anderson et al., 2001) or extracting main ideas, representing evidence, integrating multiple sources of information in order to address a question or solve a problem and synthesize information into a coherent understanding of a process or phenomenon (Council of Chief State School Officers, 2010). Many of these "understand" or "comprehend" tasks actually require processes that would be considered more evaluative, such as making judgments based on criteria and standards (Anderson et al., 2001) and evaluate sources of information, analyze evidence, notice inconsistencies (OECD, 2011).

In Table 2, we present several examples of evaluations that readers of science texts can make. Readers can evaluate explanations, argumentative support, and sources by checking a document's content against their prior knowledge and beliefs and for consistency with content from other documents. Evaluation is something a reader does to some extent spontaneously, but they can also engage in it deliberately and strategically.

Evaluation of explanations. Without much domain knowledge, the extent to which a reader can evaluate a scientific explanation is limited. In general, one can think of such evaluations as involving checks on completeness, coherence, and consistency with both one's prior knowledge (limited though it may be) and with other sources (Hempel, 1965).[1] Evaluations of accuracy, which involve testability and consistency with high-quality experimental evidence, are covered separately below in context of evaluation of arguments. The first row of Table 2 lists some types of evaluations a reader might use for comprehending explanations.

Readers perform some kinds of evaluations spontaneously. Checking the plausibility or consistency of new information with what is known already about the phenomenon is a routine part of building a representation of a text (Johnson-Laird, 1983). There is some evidence that readers spontaneously evaluate causal claims when they possess the pertinent and accessible prior knowledge and the texts

[1]Several other scientific evaluation criteria have been proposed (e.g., Simplicity/Parsimony, clarity and precision, predictive power, and tentative; Hempel, 1965) that are not covered here due to space.

they read are not very demanding in terms of cognitive resources (Singer et al., 1992). More recent research has also shown that evaluation can occur very early during the reading process. Hagoort, Hald, Bastiaansen, and Petersson (2004), for instance, demonstrated that readers react to certain violations of their world knowledge (*Dutch trains are white*) as fast as they do to semantic violations (*Dutch trains are sour*), with both types of violations producing an almost identical event-related potential (ERP) reaction 400 ms after the presentation of the sentence. Likewise, Richter, Schroeder, and Wöhrmann (2009), using a Stroop-like paradigm, showed that reading invalid or implausible statements (e.g., "Perfume contains scents." "Soft soap is edible.") causes a disruption in immediately responding to a spelling or color judgment task. The result was that affirmative responses were slowed down when they were incongruent with the truth value of the sentence, suggesting that readers cannot ignore when sentences present information at odds with easily accessible prior knowledge (see also Isberner & Richter, 2013, 2014). A number of reading time studies and experiments with ERPs suggest that such basic evaluative processes occur regularly and early in text comprehension (see Singer, 2013, for an overview).

One way to explain these findings is to assume that when readers construct a situation model, new information is regularly checked for consistency with prior knowledge and beliefs as well as antecedent text and tends to be rejected if the consistency check fails (Richter et al., 2009). In line with this idea, Schroeder, Richter, and Hoever (2008) demonstrated a close bidirectional relationship between the situation model for expository texts and the plausibility of text information. Plausible information was more likely to be integrated into the situation model than implausible information, that is, information that was part of flawed arguments. On the other hand, information that was already part of the situation model was more likely to be judged as plausible. Similar plausibility effects were found in the comprehension of multiple texts on a controversial issue from educational science (J. Maier & Richter, 2013a).

Spontaneous consistency checking is highly dependent on the timely activation of relevant knowledge or prior information. Factors that can influence this reactivation include the degree of overlap among concepts and terms, the elaboration of the concepts in the text and the distance between prior information and the current sentence (O'Brien & Myers, 1999). Reactivation is also aided by retrieval cues in the text, which allow the distant information to be reinstated (Lea, Mulligan, & Walton, 2005). This means, however, that unless the reading situation is optimal (high lexical or semantic overlap to reactive inconsistent information from prior text), readers must deliberately search for relevant information from prior knowledge or prior texts. Ideally, this search would be guided by a reader's explanation schema and scientifically acceptable criteria (e.g., completeness, coherence). However, it is currently unknown whether people do so when reading explanations on the web and which criteria they use. Thus, more research is needed to examine people's use of these criteria both spontaneously and strategically when prompted.

One mixed consequence to evaluating new information by comparing it with prior knowledge is that one's prior beliefs are also activated. Although this activated prior knowledge may help to prevent readers from becoming intentionally or accidentally misinformed (Sperber et al., 2010) by detecting information that is implausible, it may also be an obstacle to updating or revising one's knowledge in the light of new information (Richter, 2011). To the extent that the prior knowledge then drives reading, this may contribute to the persistence of false beliefs (Ross, Lepper, & Hubbard, 1975), to the continued influence of misinformation (Johnson & Seifert, 1994), and to related phenomena that are characterized by a resistance to new evidence which discredit recipients' knowledge and beliefs.

Although some consistency checking between one's prior knowledge may occur spontaneously when reading an explanation, readers could benefit from deliberately making such comparisons. Indeed this is exactly the type of controlled processing that a reader could bring to bear to overcome the difficulties of understanding science texts.

Evaluation of arguments. Depending on a reader's goal and the type of documents encountered, he or she may need to evaluate explicit or implicit argument content. Argument evaluations are to some extent normative in nature. Thinkers over the centuries have worked out principles for what constitutes a valid argument and what does not. Some principles (e.g., what constitutes evidence) rely on norms that are domain specific, and thus a reader's ability to evaluate arguments is somewhat dependent on their level of domain knowledge. Other principles, however, are more general and available to less knowledgeable readers. Some of these are presented in the second row of Table 2.

Argument evaluation is generally about judging the degree of support for some claim. According to Blair and Johnson (1987), there are several aspects of support that can be evaluated. The first challenge is to represent and evaluate whether the evidence actually does support the asserted claim (Blair & Johnson, 1987; Britt & Larson, 2003; Voss, Fincher-Kiefer, Wiley, & Silfes, 1993). Blair and Johnson (1987) referred to this as the criterion of *relevance*. Under ideal circumstances, such judgments may occur spontaneously (Voss et al., 1993), but more typically readers must engage in deliberate evaluation. To evaluate the relevance of support, one has to attend to the specific type of claim asserted because different types of claims require different kinds of support. For instance, one can argue about a *policy* claim such as "the government should mandate carbon emissions" by addressing the cost/benefit analysis of the problem (e.g. carbon is or is not harmful, the benefits of activities that produce carbon), by addressing the fairness or practicality of the solution, or the efficacy of the proposed action. Finally, one could argue over the "goodness" of the solution in comparison to alternative solutions. In contrast, the nature of support for scientifically factual and causal claims typically includes experiments, correlational studies, expert statements/opinions, and direct observations. Of interest, support for an explanation (i.e., causal claim) may entail support for the occurrence of the explanandum (e.g., increased average temperatures are happening) or the initiating factor (e.g., increased deforestation is happening) and the intermediary explanans (e.g., increased carbon in the atmosphere is happening), which are the boxes shown in Figure 1.

Deliberately evaluating arguments for relevance can be challenging. For example, Shaw (1996) found that readers do not often spontaneously make argument-based objections. This may be due to the cognitive effort required to represent claims and reasons as such and alternative models that might be needed to evaluate the strength of support relationships. Many readers also have difficulty evaluating arguments that are structurally flawed (i.e., the reason failed to support the claim or there was no reason presented) from those that are structurally acceptable (i.e., the reason supported the claim; A. A. Larson, Britt, & Kurby, 2009). Part of the problem seems to be a lack of attention to the precise claim. The previously mentioned study by Britt et al. (2008) found that readers who more accurately recalled claim predicates were also more accurate at evaluating the quality of the support provided. Fortunately, such difficulties are easily overcome for many readers through simple instruction (e.g., A. A. Larson et al., 2009).

A second criterion when considering quality of support is whether the supporting information is acceptable or "*accurate*" (Blair & Johnson, 1987). Shaw (1996) has shown that undergraduate and graduate students do in fact tend to focus on the believability of claims and evidence when criticizing informal arguments. The mechanism for such evaluations is likely similar to that used for overall consistency checking of incoming information when building a situation model or mental model of the text content (Richter et al., 2009). Certain checks of argument validity may occur spontaneously. Voss et al. (1993) found that attitudes regarding a claim and associated reasons can become immediately activated during reading. For lay readers, spontaneous acceptability judgments are more likely to be based on prior beliefs and attitudes than on specialized knowledge and a scientifically informed epistemic approach.

Indeed, whatever knowledge of scientific principles and methods a lay reader possesses must be employed deliberately. For example, evaluating the type of support can require an evaluation of the quality of the data collection and experimental design. In a recent study, Kopp, Britt, Millis, and Graesser (2012) had college students evaluate short newslike reports of science studies for design flaws (e.g., lack of adequate control or experimenter bias). They found that the students identified only about 24% of the serious problems but after a short training session could detect up to about 50%. Thus, lay readers can bring what science training they possess to bear on evaluation of a text's acceptability but might not do so spontaneously or without effort.

A third criterion when considering the quality of support is whether the supporting information is *sufficient* (Blair & Johnson, 1987). This evaluation means weighing the extent to which the totality of the support can overcome counterevidence or competing claims. To some extent, one may be assisted by examining qualifiers on the claim or supporting evidence and considering the degree to which counter arguments and opposing evidence is rebutted, explained, or dismissed. Qualifiers of scope (e.g., generally, always) and certainty (e.g., probably, suggests) are especially significant in academic and scientific writing (Horn, 2001; Hyland, 1998). On one hand, some researchers argue that lay readers prefer powerful language and have found that participants judge arguments with qualifiers as less persuasive and evaluate the writer more negatively (Blankenship & Holtgraves, 2005), and many readers also show a preference for more certain conclusions (Bråten & Strømsø, 2010), which could partially account for many readers' preference for completely unqualified assertions. On the other hand, as long as the qualifiers were professional (not colloquial like "sort of" or "kind of") and applied to interpretative statements (not data statements), they did not lead to negative perceptions of the argument or the writer (Durik, Britt, Reynolds, & Storey, 2008). Thus, readers are somewhat sensitive to appropriate claim qualification, but much more research is needed to better understand lay readers' evaluation of qualifiers in real-world texts such as news articles reporting on study findings and how training may improve this evaluation. For example, in the Durik et al. (2008) study, those with more science training actually evaluated the qualifiers more appropriately than those with little to no science training. Although valuable, such qualifiers are not always present, especially when counterevidence or alternative explanations are presented in other documents. To the extent they are present, however, readers can learn to recognize them and assess them correctly.

In addition to evaluating limits to asserted claims, readers also need to evaluate sufficiency with respect to the totality of available evidence. Arguments that include consideration of other-side information are typical of professional writers (Wolfe & Britt, 2008) and especially important for science writing given the nature of conflict in the scientific process (e.g., Platt, 1964). For example, support for the causal claim stated previously in Argument 1 would be stronger if relevant alternative explanations for global warming (e.g., an explanation in terms of solar activity) were considered and effectively refuted. Thus, to fully comprehend arguments about scientific information, one must be able to represent alternative claims, conflicting information, and different points of view.

Although little research has examined readers' comprehension of other-side information, research on production has shown that it is challenging even for college students. Many studies have shown that college students tend to have a "my side" bias in that they tend to generate more reasons in favor of a position they support than they do reasons on an opposing side (Perkins, 1985; Toplak & Stanovich, 2003), they tend to ignore other-side information when composing argumentative essays (Kuhn & Udell, 2003; Nussbaum & Kardash, 2005; Wolfe et al., 2009), and they often do not make alternative-based objections when evaluating arguments without task supports (Shaw, 1996). The problem of myside bias, however, is generally not due to readers not reading other-side documents (Wolfe et al., 2009). The problem may be due to the cognitive demands of constructing alternative models of the state of affairs (Shaw, 1996) or the lack of creating appropriate subgoals to find counter information prior to reading (Kopp, 2013). For reading science texts, my side bias presents a problem to the extent that it reflects a person's epistemic view that stronger arguments ignore counterclaims or acknowledgment of deficiencies. Such attitudes can only be overcome through some degree of education in scientific practice and communication.

Evaluation of sources. In addition to providing support in terms of reasons or evidence to determine whether to include an element or causal relation into one's integrated model, readers can also evaluate the quality of information by focusing on its origin or source. Attention to the source can influence what to read, how to interpret the content, and whether to believe the information, with or without qualification as to source (e.g., Bråten et al., 2011; Goldman et al., 2011; Wiley et al., 2009). It can also be useful in part when persuading others of what to believe or when challenged about one's beliefs. An example source evaluation is presented in the final row of Table 2.

Evaluation of source information can result in a reader's determination that the content is not reliable enough to integrate into his or her model of the phenomenon (Perfetti et al., 1999). This evaluation can be made based on features of the author (e.g., author's level of knowledge, motives, or bias) and features of the outlet responsible to distribution (e.g., criteria for accuracy checking and methods employed). More often, however, source evaluation leads to the decision to qualify the information rather than simply not reading it or dismissing it. By associating content with source information, as proposed by the Documents' Model described earlier, readers can represent the information without necessarily accepting it themselves or they can mark the information as tentative, requiring additional evidence or corroboration (Britt, Rouet, & Braasch, 2012).

Readers can also use source information to interpret content and make predictions about it. For example, a reader encountering the term *mental model* might interpret it differently if it were followed by a citation of Gentner and Stevens (1983) than if it were followed by a citation of Johnson-Laird (1983). Even the time of publication can be used to interpret science content because the methods and knowledge available to an author change over time. For example, the assertion that atmospheric CO_2 levels are stable would be interpreted very differently if the document was published in the 1960s (i.e., before the availability of data from Keeling) than if it was published in 2013. In the latter case one might conclude that the author was deliberately ignoring data and come to a more tentative evaluation of text. Understanding how and when readers make such interpretive use of embedded sources is just beginning to receive attention from text researchers (e.g., Strømsø et al., 2013).

Like other forms of evaluation, source evaluation depends on one's level of knowledge. Readers' knowledge about authors, texts, and publishing, both in general and about science in particular, inform their judgments about whether to accept, qualify, or reject the content of a text. Source evaluation also requires some understanding of the processes by which different agents produce and disseminate information about scientific issues and a strategic awareness of when and how one should turn to source information as part of their evaluation of scientific documents. For example, viewing documents as communicative acts and experiencing the author as an entity (Britt et al., 2012). The web makes additional demands on the reader. With cost no longer a barrier to publication, readers are exposed to a deluge of argument and opinion of varying quality. The web also makes available new types of sources and leaves readers in the position of having to figure out how to evaluate such things as hacked private e-mail, leaked early drafts of publications, and "official" minority reports of government subcommittees.

In this section we have endeavoured to describe some things that readers can do to improve their ability to read and evaluate science texts. In accordance with our definition of scientific literacy we examined readers' ability to set goals and make evaluations. We acknowledged that readers have different purposes for reading, not all of which require a deep understanding of a relevant scientific topic. For goals that do require understanding readers can adopt subgoals and manage their reading in a deliberate manner according to their goal and resource constraints. We also described evaluation as a set of judgements a reader makes, both spontaneously and deliberately, about their own representation and the content they add to it. Readers can monitor the completeness and coherence of their explanatory representation and seek out additional information when necessary. They can also evaluate the extent and quality of the supporting evidence for elements of the explanation using both their genre knowledge and source information.

Although such actions are available to lay readers, they are often unfamiliar and require substantial effort. Thus, in the final section we examine what we can do as educators to assist people in acquiring and using them.

HOW CAN WE HELP LAY READERS?

Based on this analysis of scientific literacy, we argue that we need to take seriously the challenges of learning from science texts and the potential benefit of helping readers develop appropriate goals to guide reading and evaluative processing of text. Clearly preparing students for this type of activity is critical in today's information societies as the web becomes the primary source of information for personal, academic, and work-related purposes. We draw three main educational implications from this analysis.

Expanding Science Curriculum

A first implication is that one's understanding of science can no longer be disentangled from one's understanding of how science is communicated in the society—from first-hand, certified sources to low reliable or unknown sources retrieved by a search engine. As a consequence, an introduction to the various ways science gets communicated would seem to deserve some space in a science curriculum. This is not to say that the science teacher need become a communications or reading teacher. Nevertheless, because of the importance of preparing students to learn by themselves through a wide range of information resources, an introduction to the different levels of discourse about science and how to deal with them seems to be warranted. Just like the call several decades ago in the United States to increase hands-on inquiry activities in science classrooms, we believe it is time to provide more opportunities for students to read and reason from more diverse sources of the type they will experience in real life. This call is completely consistent with standards recently adopted in most U.S. states (Achieve, Inc., 2013; Council of Chief State School Officers, 2010). Our outline of what needs to be represented could inform those interested in expanding science curriculum. Sandoval, Sodian, Koerber, and Wong (this issue) show that even young students have the partial knowledge and rudimentary skills that can be further developed.

Expanding the Construct of Comprehension

A second implication is that as a field, we need to expand what we mean by "comprehension." As we have argued here, readers of scientific information rarely read to simply represent and understand a single text. To be relevant to real-world reading situations, text-processing researchers must take a larger approach to defining comprehension. The definition of scientific literacy that we offer is a small step in this direction. Our analysis also points to the need to examine these processes with science topics rather than narrative or general topics due to the application of disciplinary-specific criteria.

It is important to more systematically examine under what conditions readers set goals and subgoals such as those in Table 1 prior to and during comprehension and the criteria they use for evaluating success of these goals. In this article, we put forth the MD-TRACE framework as one possible way to better understanding how people respond to this challenge of developing the skills and knowledge expected of a scientifically literate reader of the web. Several ways to support the development of goal-directed readers are presented in Britt and Rouet (2012). More research is needed to understand how knowledge of arguments and explanations as genre guides reading behavior, memory for texts, and use of that information. It is also important, given the complexity of all the subtasks and processes involved, to examine the efficacy of supports for regulating the creation, updating, and monitoring of the task model.

It is important to more systematically examine under what conditions readers evaluate content during comprehension (e.g., actions in Table 2). Readers sometimes spontaneously activate beliefs and argument-relevant knowledge that is available very quickly. Research also shows that information checking for plausibility against prior beliefs and knowledge is sometimes a routine part of comprehension (Singer, 2013). However, under many circumstances readers are affected by their own biases (myside bias and belief-consistency effect), which can lead to construction of one-sided and impoverished representations of scientific information and arguments. In many situations, readers need to strategically evaluate the quality of scientific explanations and argumentation based on discipline-specific criteria. Under these circumstances, helping students to learn discipline-specific evaluation criteria and to practice applying them would be beneficial, not just for developing an appreciation of the importance of discipline-specific evaluation but also for gaining appropriate epistemic stances. Therefore, more research is needed to better understand the conditions under which readers will spontaneously and strategically evaluate content, what criteria they use, and how this is affected by the situation and materials.

In some cases, simply advising learners to adopt a neutral perspective toward controversial scientific issues is not likely to be effective. One alternative approach is to raise metacognitive awareness of the biasing influence of prior beliefs during comprehension. For example, J. Maier and Richter (2014) found that providing students with a brief tutorial about the biasing effects of beliefs and instructing them to closely monitor their evaluations during reading helped them to achieve a balanced and good situation model of a controversial scientific issue. Another way to overcome such biases is through systematic training of critical thinking and argumentation skills. Stanovich and West (1998) have shown that individual differences in the reliance on prior beliefs in argument evaluation are closely associated with not only cognitive ability but also the general thinking disposition of actively open-minded thinking. Changing such dispositions is likely to take years of systematic training in scientific thinking. Nevertheless, there is evidence that short-term interventions targeted at specific skills can be remarkably successful, for example, in overcoming the myside bias in argumentation (Kopp, 2013; Nussbaum & Kardash, 2005; Wolfe et al., 2009), learning to evaluate arguments (A. A. Larson et al., 2009), and learning to evaluate research studies (Kopp et al., 2012).

A second form of bias described in this article is students' inattention to sources. Many studies have also shown that simple training methods can improve sourcing behavior in primary school (Macedo-Rouet et al., 2013), high school (Brem, Russell, & Weems, 2001; Britt & Aglinskas, 2002), and college (Stadtler & Bromme, 2007, 2008; Wiley et al., 2009) students. Getting students to notice optimal and less optimal strategies also improves their sourcing skills (Braasch, Bråten, Strømsø, Anmarkrud, & Ferguson, 2013). More research is needed to examine the coordination of these component skills and how to potentially automatize these skills, thereby requiring less resources and greater use in appropriate situations. Such research can therefore help outline the conditions for success.

Expanding Materials and Situations Considered

One final implication is that by expanding the definition of scientific literacy, we have to go beyond textbook-style materials in text and in research. For instance, the limited range of source types and genres that students encounter in textbooks are not typical of the range that readers will encounter when reading about science outside of school (e.g., life, work and civic purposes). A related problem is the lack of conflict, opposing perspectives, and uncertainty can all deprive students of the training they need to develop skills and dispositions for dealing with science on the web. The same critique can be made of materials in text-processing experiments. One good example is helping students learn about journalists' approach to scientific information (see M. Maier, Rothmund, Retzbach, Otto, & Besley, this issue). Journalists often evaluate the information from their sources and act as a filter. The media's reporting on scientific research often does not include qualifiers or make uncertainties clear and this affects readers' perceptions of the credibility of reported research (Jensen, 2008). If they believe the information is certain or reliable enough, then they include it in the article, leaving out many markers of the degree of certainty or methodological details of science work that enable the evaluation of its reliability and validity for the reader to evaluate the information on their own (Bloebaum & Noelleke, 2011). A better understanding of the goals of different authors may help readers develop and apply a more appropriately critical stance toward information they find on the web.

CONCLUSION

This analysis of the challenges of learning science from the web and two potential means of mediating these challenges (goal-directed guidance and evaluation of content) may help us help lay readers benefit from the web without all the concomitant negatives.

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