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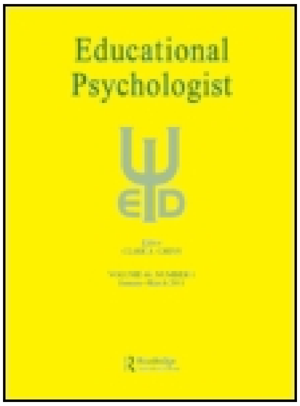

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The Public's Bounded Understanding of Science

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The Public's Bounded Understanding of Science

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This introduction to the special issue *Understanding the Public Understanding of Science: Psychological Approaches* discusses some of the challenges people face in understanding science. We focus on people's inevitably bounded understanding of science topics; research must address how people make decisions in science domains such as health and medicine without having the deep and extensive understanding that is characteristic of domain experts. The articles reflect two broad streams of research on the public understanding of science—the learning orientation that seeks to improve understanding through better instruction and the communications orientation that focuses on attitudes about science and trust in scientists. Challenges to understanding science include determining the relevance of information, the tentativeness of scientific truth, distinguishing between scientific and nonscientific issues, and determining what is true and what is false. Studying the public understanding of science can potentially contribute to psychological theories of thinking and reasoning in modern societies.

Advances in science and technology have led to enormous growth in scientific knowledge. It is important for all citizens to understand or at least be aware of currently accepted scientific information. With such awareness, the scientific knowledge base can inform our general understanding of the world and ourselves as well as provide a basis for daily-life decisions. Public controversies such as the debate in the United States about evolution versus intelligent design (Taylor & Ferrari, 2011) exemplify the central and often contested role of science in informing our understanding of the natural world as well as ourselves. As well, many concrete decisions in our personal lives benefit from considering science-based arguments on these issues. Health and nutrition are prominent examples, but there are also socio-scientific issues in the political domain (e.g., climate change and what, if anything, to do about it).

In addition, advances in science and technology have led to wide-scale availability of science information, notably via the Internet, in both traditional modes (e.g., journals, television) and digital modes (e.g., animations, streaming video). But availability does not mean accessibility or comprehensibility: What experts and specialists in a field "take" from such information resources will invariably differ from what the general public understands from the same resources. Two important reasons for this are (a) differences in relevant knowledge and its organization that specialists/experts bring to the information, as compared to the general public, and (b) differences in knowledge of the conventions for communicating science information that operate within communities of scientists but not within the larger population (Goldman & Bisanz, 2002). When scientists write for fellow scientists, they assume shared knowledge of both content and conventional discourse forms. However, even when science information is popularized in journalistic news reports, science digests, or feature stories on advances in health care, members of the scientific community bring different epistemic stances to that information than do members of the general public. These differences in

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epistemic stance also lead to differences in what scientists as compared to the general public understand from these communications.

We think it is productive to acknowledge the very reasonable expectation that even the most well-educated members of the general public will have a more limited, or bounded, understanding of science, compared to that of science experts. It is this *bounded understanding of science* that people will typically rely on when they develop a personal stance toward a scientific issue, such as climate change, or make decisions about personal health and medical concerns. Our claim is that the ways in which the public uses science information to make personal, professional, and civic decisions are rational responses to the inevitable limits on their understanding of the science.

Acknowledging the bounded nature of the general public's science knowledge is crucial for psychological and educational research that seeks to better understand and enhance the quality of science understanding, decision making, and debates that involve scientific and socio-scientific issues (e.g., energy saving or genetic engineering). It could be argued that a limited or shallow understanding of topics such as energy types or stem cells will suffice for the general public's involvement in policies on these issues, as long as these understandings are scientifically appropriate and free of misconceptions; however, we disagree. Deeper understanding is often necessary simply to understand the scientific phenomenon at the heart of policy issues. For example, Shea (2013) conducted detailed analyses of the coverage of genetic issues in the science section of the *New York Times* from 2010 to 2011. She found that understanding these articles required at least a basic grasp of some of the "big ideas" of genetics (e.g., genetic information contains universal information specifying protein structures; cf. Duncan, Rogat, & Yarden, 2009), and in some cases advanced genetic principles that go beyond what is typically taught in schools. In addition, public controversies often invoke knowledge claims that involve deeper and broader knowledge to validate.

Furthermore, people's interests are not driven by the science they think they understand. Survey data and case studies attest to the role of personal relevance in determining the science in which people become interested. For example, people surveyed in the United States claimed to be very, or at least moderately, interested in attending to news reports of new medical discoveries, economic issues, and environmental pollution (Besley, 2014, p. 10). Similarly, case studies that examined how people became involved with science showed that specific concrete issues or problems could rapidly extend the breadth and depth of relevant science knowledge (Layton, Jenkins, Macgill, & Davey, 1993; Ryder, 2001). For example, parents who wanted to decide about vaccinating their children were dealing with claims of far greater causal complexity than anticipated, including how vaccinations impact the human immune system. When they were asked by medical authorities to think not only about the effects on their children but also on public health the question expanded the science involved even further to epidemiology and public health (see Sandoval, Sodian, Koerber, & Wong, this issue). Indeed, many of the present-day topical issues that have personal relevance for the general public are based on conceptual networks of enormous depth and breadth. These far exceed the bounded understanding we could reasonably expect to find in the general public. These include genetic engineering, climate change, the impact of nutrition on health, and therapies for cancer.

Thus, we argue that the *boundedness* of science understanding poses practical challenges for the public as they endeavor to pursue interests in science issues of personal relevance in the face of such limitations. It poses theoretical and educational challenges for researchers and educational practitioners in their attempts to explain and enhance the general public's understanding and use of science information. All of the articles in this special issue deal with the fundamental question these challenges raise: How does the general public understand science (the *Public Understanding of Science*, or PUS[1]) or engage with it (the Public Engagement of Science, or PES), largely outside of the context of formal schooling? The articles reflect various perspectives on this issue, including psychological, developmental, communication, and learning sciences.

In the remainder of this article, we elaborate on the notion of *bounded* understanding of science, relating it to psychological research on *bounded rationality.* We then discuss what we know and what we need to know about how members of the general public evaluate and use science information given their bounded understanding of science.

THE BOUNDED UNDERSTANDING OF SCIENCE

Knowledge in science is expressed as theories and the evidence that supports them. Scientific theories are often described as networks of arguments comprised of propositions about the phenomena of the real world as well as about the tools and methods that are necessary to generate data relevant to theories. The arguments describe phenomena (relationships between entities) and provide causal mechanisms as well as evidence for the assumed causal mechanism. Evidence consists of data and the reasoning or principles that justify using particular data to support particular claims about causal mechanisms (see Sandoval et al., this issue). Typically theories about a specific set of

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[1] The topic of this special issue is often called "Public Understanding of Science." We use capitals and the abbreviation PUS and PES when referring to endeavors/campaigns for the improvement of understanding or accepting science. When using these terms without capitals we refer to the understanding of science held by the public (i.e., by laypeople) as a research topic for the Social Sciences.

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phenomena (e.g., kinds and states of *energy* or of *stem cells*) are embedded in more general theories. Furthermore, scientific theories, research methods, and technology tools are reciprocally related. For example, quantum physics theories about energy and matter are strongly influenced by the possibilities as well as the limitations of large hadron colliders including big computers necessary to analyze data coming from the colliders. Conversely the technology tools and methods were developed in response to the types of data that theories of modern quantum physics needed to support them.

Theories can vary in depth as well as in breadth. *Depth* refers to the degrees of *causal* complexity necessary to explain a scientific concept. *Breadth* refers to the relationship between topics. Keil (2008) pointed to the

> seemingly unbounded levels of causal complexity. Ask a simple question, such as what stem cells are and how they work, and the answer can be expanded on in ever deeper and more complex ways. Stem cells may initially be described as cells that have the potential to become any one of the many cell types within an organism. A request for more detail may reveal broad classes of cell types that can be created. . . . If one is driven to gain the deepest explanation possible, one gradually gets exposed to much of developmental biology and molecular biology, as well as areas of chemistry, physics, and even other more distant fields. (pp. 1036–1037)

Thus, understanding can occur at multiple levels of depth regarding the mechanisms, conditions, and circumstances under which these mechanisms express themselves in surface phenomena. For example, mechanisms of cell cleavage apply to different kinds of cells, but they are bound to certain conditions, resulting in different kinds and processes of cleavage.

Each explanatory level is connected to other concepts at a similar level of depth, defining breadth relationships. Just as depth of causal complexity is virtually unbound, so also is breadth in that relationships to other concepts and topics at similar levels are virtually unlimited. To illustrate, some features of *cell tissues* are important only on deeper levels of the network of *stem cells*; however, *cell tissues* itself is a topic that has its own network. Shifting from *stem cells* to *cell tissues* could be described as a breadth relationship or horizontal shift within a complex network. A broad theory would then cover the complexity of biological as well as chemical concepts, mechanisms, and data, encompassing in this example stem cells as well as the role of cell tissues in stem cell functioning.

The reciprocal relationship between theories and the tools/methods for generating theory-relevant data also contributes to depth and breadth considerations. Procedural and methodological questions are in the focus of the daily work of scientists in research labs (Knorr-Cetina, 1981). Vertical as well as horizontal extensions of a theory often create the need for new disciplines. The emergence of *biochemistry* reflects the progress that was made in unraveling the relationships between biological and chemical mechanisms when studying life. And in the case of stem cells, a deep understanding of them involved knowledge from several disciplines, conceptual knowledge about the phenomena as such, and knowledge of the tools for "seeing" the phenomena.

The unbounded causal complexity of phenomena has contributed to a narrowing of scientific fields of specialization and domains of expertise. A parallel narrowing has occurred within medicine where general practitioners have been replaced by a plethora of narrowly defined medical specializations (e.g., internal medicine, ears/nose/throat, pediatricians). Specialization places limits on what will be understood about other areas of science. If even scientists' understanding of science outside their specific area of expertise is becoming more limited due to specialization, it is hardly surprising to propose that the general public's understanding of science is limited in depth as well as breadth. It is interesting to note that the scientific community has responded to the challenge of interdisciplinary communication in an age of increasing specialization by establishing social routines that bridge the divisions (Bromme, 2000).

We further contend that the understanding of science held by the public will always remain a *bounded understanding*. Of course, there exist members of the general public who are very well informed about various science phenomena and in that sense have a more unbounded understanding of some topic or area of science. Expert knowledge is not confined only to those who are certified experts based on an extensive training/education. Expertise can also be built up in the context of civic engagement. Prominent examples are concerned citizens who build up expertise regarding the topics with which they are engaged, for example, in environmental or health-related movements (Collins & Pinch, 1998). Further examples are those who build up structures of specialized expertise when engaged with providing entries in Wikipedia (Halatchliyski, Moskaliuk, Kimmerle, & Cress, 2014). These people have acquired specialized knowledge structures that involve deeper layers within particular network(s) of theoretical propositions. They are therefore not counterexamples to our assumption that the *boundedness of understanding* is a general feature of the general *public's* understanding of science.

BOUNDED UNDERSTANDING AND BOUNDED RATIONALITY

Our proposal that the science knowledge base of the general public reflects a bounded understanding is a deliberate reference to the notion of *bounded rationality*, a concept that has been very important for psychological research on reasoning. Simon (1955) first introduced *boundedness* as the difference between the actual decision behavior of people

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and mathematical models for optimal decisions. Subsequently, Kahnemann and Tversky elaborated the concept of *bounded rationality* by scrutinizing heuristics people used intuitively when an exact calculation of probabilities would have been more appropriate to the "decision making under uncertainty" tasks they were posed (Kahnemann, 2003). They described certain reasoning fallacies people were prone to, demonstrating that these reasoning strategies were "bounded" relative to the mathematical rules that were appropriate. Initially, Kahnemann and Tversky interpreted these findings as illustrative of the limitations on reasoning. More recently, they emphasized the value of these heuristics for intuitive decision making, a process that is both necessary and effective under certain circumstances (Kahnemann, 2011). Other researchers have emphasized the adaptive quality of reasoning strategies that make smart use of "fast and frugal" heuristics (Gigerenzer & Brighton, 2009).

The research program on reasoning about uncertainty is of immediate relevance in the context of PUS issues, and it offers a fruitful analogy for the public research on understanding science. The immediate relevance for studying PUS follows from the ubiquity of probabilistic judgments, for example, in the context of health, nutrition, or the economy. Probabilistic judgments are necessary in many fields of science and therefore also in the public understanding of these fields (Maier, Rothmund, Retzbach, Otto, & Besley, this issue; see Patt & Weber, 2013, for an overview with regard to the public understanding of climate-related uncertainties). But understanding science encompasses additional cognitive processes and structures beyond probabilistic judgments. It involves the acquisition and use of abstract conceptual knowledge and of all kinds of appropriate evidence, and it includes argumentation about the relationship between claims and evidence (see Sandoval et al., this issue). The bounded rationality research program on reasoning is also helpful for PUS research because it offers two fruitful analogies. Just as everyday reasoning about probabilities makes use of some mathematical rules (e.g., from arithmetic) and nevertheless ignores other axioms (e.g., Bayes' theorem), the public understanding of science involves the use of some science concepts but ignores other segments of the underlying conceptual complexity. We argue that key cognitive questions for the public understanding of science are about how people think and judge scientific claims *without* a full understanding of such claims and the evidence offered to support them (see Cummings, 2014, with regard to medical knowledge). What are the "fast and frugal" heuristics they use?

APPROACHES TO THE PUBLIC UNDERSTANDING OF SCIENCE

We distinguish between two coarse groupings of approaches to research on the public understanding of science: those oriented to learning and those oriented to communication.[2] Both approaches are concerned with questions of how to define, measure, and improve public understanding of science, but the perspectives they take differ in fundamental ways. The learning orientation is represented in a number of identifiable disciplinary communities, namely, Educational Psychology, Learning Sciences, and Science Education. The communications orientation is represented in Communication Sciences, Social Psychology, and to some degree in Sociology and Science & Technology studies.

The learning orientation construes the topic mostly as scientific literacy, and the focus is typically on learning and understanding content that, at least in principle, *could* be understood by the nonexpert public. The communications orientation construes the research topic mainly as Public Understanding of Science (PUS) and Public Engagement with Science (PES). The two orientations differ with regard to their ways of dealing with the boundedness of understanding. The learning approaches aim for overcoming the boundedness by improving knowledge and understanding, whereas the communications approaches typically (and sometimes implicitly) concede the boundedness of understanding by focusing on attitudes about science and trust in scientists treated as dependent variables. When public attitudes diverged from accepted and current science information, earlier work within the communications approach had typically attributed this to the public's lack of accurate science information and limited scientific literacy. It was assumed that a more positive view of science and scientists would follow directly from "educating" the public. This deficit view was criticized (Nisbet & Scheufele, 2009) and has been largely discredited by data that show only small relationships between the amount of knowledge about science and attitudes about science (Allum, Sturgis, Tabourazi, & Brunton Smith, 2008). More recently, the impact of knowledge and values on trust in science as well as the social (Bauer, Allum & Miller, 2007) and media context (Brossard & Scheufele, 2013) of processing science-related information is being investigated with a focus on the attitudes about and perception of science. Of course, attitudes and perceptions of science (so-called Nature of Science attitudes) and beliefs about knowledge (Epistemic Beliefs) have also been researched within the learning approaches, but here mainly as factors that impact the understanding of science. Nowadays, the learning and communications approaches converge somewhat around the heuristics that people seem to use in evaluating science information; for example, source evaluation and trustworthiness.

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[2] We are aware that there are interesting cases in which learning researchers focus deliberately on PUS and PET, for example, research on the "big" public debates about socio-scientific issues like climate change (see Sinatra, Kienhues, & Hofer, this issue).

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The Learning Orientation to Research on Bounded Understanding in Science

Learning orientations pursue research questions that push the bounds of what people understand about science. That is, research in this tradition seeks ways to deepen and enhance how people explain phenomena of the natural world, the kinds of causal explanations they comprehend and construct, and the intentional strategies they adopt to enhance their own learning and understanding. These efforts are situated within societal systems that adopt "full understanding" goals that are appropriate for the learner's age or educational level. Nevertheless, "full understanding" is always some subset of what expert scientists understand about the topic. In other words, learning approaches seek full understanding of science, recognizing that the definition of "full understanding" is situated within developmental constraints. But the expectation is that, in principle, learners could achieve this level of "full understanding."

Of course a key issue for learning orientations is how to determine appropriate levels of "full understanding" for learners of different ages/developmental levels. In the past this was done often more intuitively, based on the experiences of teachers, textbook producers, or science educators. Recently, systematic *learning progressions studies* scrutinize the range of concepts and procedure that could and should be taught to specific age groups of students. Typically, they define a low and a high anchor of conceptual complexity. Then they scrutinize the logical as well as the psychological constraints for arranging the sequences of curriculum units within these two anchors. In one example of this approach, Neumann, Viering, Boone, and Fischer (2013) determined that a basic understanding of energy forms and sources were reasonable targets for sixth-grade students (approximately 12 years of age). When these students are in higher grades, they are expected to develop an understanding of energy conservation. In a second example, Duncan et al. (2009) described possible learning progressions with regard to genetics. They postulated that the most advanced level reasonable for high school students would involve not only molecular models of genetics but also the particle model of matter (which is a part of quantum physics). They pointed to the need to establish empirically if such a conceptual complexity could actually be taught in high school.

Efforts to establish learning progressions and determine what levels of complexity are appropriate at what point are complicated due to the relationship of the boundedness of understanding to the development of science as well as to the instructional history of the learners in question. When Newton and Leibniz in the 17th and 18th century developed differential calculus algorithms, these mathematical methods were clearly expert knowledge; nowadays they are taught in advanced courses in high school in the United States and in the higher grades of secondary schools in Germany. That is, they have been deemed understandable by adolescents, at least those who have had an opportunity to learn and have acquired enough of the underlying mathematical concepts. Thus, there is no *fixed* limit on what can be taught and learned. Instead, it depends on instructional approaches and materials, the learning environment, students' preceding learning histories and capabilities. However, there are limits and even successful science, technology, engineering, and mathematics students will leave secondary and even postsecondary schools with a bounded understanding of science.

Related to the issue of determining appropriate levels of "full understanding" is the more general issue of how the goals of formal science education are conceptualized and defined. In the United States, there is a long history of debate about this issue. Most recently, the debates about the goals have favored goals that prepare the public for coping with science-based knowledge claims (Duschl & Osborne, 2002; Kolstø, 2001). This goal is one of the core ideas of the Next Generation Science Standards, published in the United States within the past year (Next Generation Science Standards Lead States, 2013; cf. Pellegrino, 2013). It is also a rationale for those who advocate teaching "the whole science," including the social processes and practices of establishing scientific truth (Allchin, 2011). Indeed, in recognition of the reality that science education through college level can only achieve a bounded understanding of science, some have argued that science education should strive for educating "competent outsiders" of science instead of producing "incompetent insiders" (Feinstein, 2011; cf. Sandoval et al., this issue). The notion of a "competent outsider" emphasizes that the typical citizen simply does not have the full understanding of concepts and methods that experts have; thus, they cannot evaluate knowledge claims in the ways that experts would.

The emphases on preparing the public to deal with science-based knowledge claims and on producing competent outsiders leave open the empirical question of how people actually cope with science-based claims that are partly beyond their own understanding. Although there appears to be an at least tacit acceptance of the idea that people in and outside of school deal with science in a way that is constrained by their limited understanding of science, there is still an adherence to the ideal of *full understanding* at least when it comes to setting standards for scientific literacy. To determine what kind of understanding should and could be achieved in education, it is necessary to study how people actually understand science *in the context of their use of scientific knowledge* (Feinstein, 2011; Ryder, 2001; Shea, 2013).Visitors to science museums and patients who look up medical information about their conditions make use of science in different ways, but they both do it heuristically within the constraints of their bounded understanding of science. In the remainder of this article, we explore several dimensions of using science information. The five other

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articles in this special issue also exemplify a variety of uses of science in a range of everyday contexts.

USING SCIENTIFIC INFORMATION

Increasingly, psychological research on *bounded rationality* has revealed the circumstances under which people effectively make use of heuristics in order to deal with uncertainties and probabilities even without doing elaborated calculations. Similarly, a research agenda on the public understanding of science should contribute to understanding how people *successfully* cope with scientific knowledge claims that are at least partly beyond their own understanding. The heuristics they rely on become more apparent in the context of using science information to accomplish some task, especially those that involve evaluating recommended courses of action or alternatives. Such a research program is not based on the assumption that these heuristics reflect some type of deficient processing. Rather we view these heuristics as adaptive problem-solving responses in the face of constraints on relevant knowledge and understanding.

Affordances and Challenges of the Internet

With increasing frequency, the Internet is the vehicle people use when they look for information on specific scientific issues. The latest estimates indicate that upwards of 60% of Americans report using the Internet for this purpose (Besley, 2014). Youth report that online resources are their most important source of knowledge about science (Anderson, Brossard, & Scheufele, 2010). They frequently consult online resources such as WebMD, blogs, Wikipedia, and popularized accounts of scientific findings.

There are a number of advantages of searching the Internet for science-related information. Regardless of the type of problem for which information is sought (e.g., individual, social, societal, global), it is very easy to obtain a host of scientific or science-based information. Even when focused on a specific topic, Internet searches return a heterogeneous chorus of voices. Such open access to science-based information enables participation in scientific discourses in ways never before possible. However, these positive affordances of Internet searching bring a number of new challenges for the general public. The unfiltered access to science information means that the user must now do the filtering and evaluating of information returned by searches to decide what information to accept and what to reject (e.g., Goldman, Braasch, Wiley, Graesser, & Brodowinska, 2012). These challenges include relevance judgments, interpretation of tentative findings, evaluating whether arguments are based on scientifically accurate claims and evidence or are based on nonscientific dimensions of problems, and ultimately determining who and what to believe.

Determining the relevance of the information. The first challenge is the location of the relevant information, because the wealth of information makes it hard to determine what is relevant and what should be ignored. Text-processing research has shown that relevance (for the search goal) is a strong constraining factor for the further processing of information (Braasch et al., 2009).

Coping with the tentativeness of scientific truth. The general public typically expects science to provide sound and definitive information. However, by its very nature scientific information is provisional and tentative because it is based on the presently available evidence. As new evidence becomes available through further experimentation, new technologies, and innovative methods claims and theories undergo revision. Thus, there is a certain aspect of uncertainty in what is taken as scientific "truth."

Of course, there are large bodies of scientific knowledge that can be taken for granted and for which, at a practical level, the provisional nature of scientific evidence does not matter. However, the general public often seeks information in just those areas of science that are most tentative and for which the evidence is particularly provisional, perhaps contradictory, and frequently controversial (e.g., genetically modified food). In fact, it may be because of the tentative nature of knowledge in these areas that the public looks to science for "the answer."

There is another reason that the truth status of scientific information is often in the public eye. Within the social system of science, the topics studied and the originality of research are important criteria for evaluating the quality of scientists' work. This characteristic increases the likelihood that the general public is exposed to and actively involved or drawn into discussions over new and frequently controversial findings that question the status quo and may raise methodological issues. Such situations call for further research (Irwin & Wynne, 1996) and public support for funding to conduct it is often sought.

Distinguishing between scientific and nonscientific aspects of problems. Problems of everyday life and social policy have both science- and nonscience-related dimensions to their framing, possible solutions, and side effects. Indeed, many socio-scientific issues (see Sandoval et al., this issue) include inherently nonscientific aspects, including dimensions related to political issues, or ethical and religious norms. Even on those issues where there is agreement among the majority of scientists about the science (e.g., climate change), there is often continuous debate related to questions that are fundamentally not answerable on the basis of the science (e.g., funding to cope with consequences of climate change). In these types of debates, the science often becomes comingled with political, economic, and even moral aspects of a problem. In the process of

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debate, advocates for different positions may adopt the tactic of fostering the deliberate fabrication of doubt about the science (Powells, 2011; see also Sinatra et al., this issue, and Maier et al., this issue). In this regard, it is instructive to note Hillocks's (2011) distinction among three types of argument: of fact, of judgment, and of policy. Scientific theories are arguments of fact; socio-scientific issues reflect judgments and policies about the arguments of fact. For example, in the case of vaccinations, a policy of requiring mandatory polio vaccines prior to school entry can appeal to evidence based on a causal model that explains why vaccines against polio reduce its incidence. It would be hard to imagine an argument of judgment, because there would seem to be consensus that avoiding polio is a good thing. Thus, the scientific model of the relation between polio and vaccination against it would seem to be strong evidence in favor of vaccinating children.

The blurring of the scientific and the nonscientific aspects of problems and their solutions is a tactic used in persuasive oration. It increases the challenges the general public faces when they attempt to evaluate the heterogeneous and often contradictory, or seemingly contradictory, information related to the particular problems for which they seek concrete answers. Distinguishing the science from the nonscience is crucial in validating what they have found. Doing so involves strategies for determining who and what to believe.

Determining what is true and what is false. Epistemic cognition research has argued that the question "What is true?" is the core of everyday reflection on knowledge, especially when it comes to the evaluation of competing knowledge claims (Bromme, Kienhues, & Porsch, 2010; Chinn, Buckland, & Samarapungavan, 2011; Ferguson, Bråten, & Strømsø, 2012). The general public can rely on two fundamentally different strategies to assess the validity of competing knowledge claims (Bromme, Thomm, & Wolf, 2013): first-hand evaluation or second-hand evaluation.

First-hand evaluation is about the question "What is true?" The veracity of a knowledge claim can be assessed directly by comparing it with other pieces of knowledge (personal experience and abstract knowledge about the issue) or by thinking critically about its logical coherence and cohesiveness. In many cases, a *second-hand evaluation* is necessary, because the veracity of knowledge claims can be assessed only indirectly by asking, Who to believe? In other words, the question "Which knowledge claim is true?" often has to be transformed into the question "Which source of knowledge is credible?" This question differs logically and psychologically from the "what is true" question in terms of the reasoning processes and knowledge structures required to answer it. It is a question about trust in different sources.

Information sources vary on many dimensions, each of which can influence the credibility and usefulness of the content. Authors vary along a number of dimensions including credentials, affiliations, expertise, motivations to write (e.g., share knowledge, argue for interpretation or theory, make recommendations, persuade readers to buy products, entertain), and the role in generating the knowledge presented (e.g., conducted experiment, took medicine personally, read others' findings; Goldman, 2004; Goldman et al., 2012; Stadtler & Bromme, 2013; see also Britt, Richter, & Rouet, this issue). When and where (e.g., journal article, textbook, media report, blog post) the information is published is also relevant, with recency being an important dimension for science information especially. These source features are important because they interact with assumptions about good science. That is, judgments about what to believe are based on knowledge of the characteristics of "good" science, including objectivity, recency, and the status of the knowledge claims in the science community with publications in peer-reviewed journals having higher status than self-publications on a personal blog. The source features mentioned above relate to these characteristics. Evaluating science information on these source features sometimes obviates the need to evaluate the knowledge claims themselves. If an author is known to have a partisan position in a heated public debate, the position taken by that author could be questioned just because of this information, independently of the underlying science.

Trusting or distrusting authors instead of judging the truth of their knowledge claims is a way of deferring to others (Sperber et al., 2010; with regard to science knowledge, see Brossard & Nisbet, 2007; Keil, 2010). In the context of science these others typically should be experts or those who are trained to report scientists' findings (see Maier et al., this issue; Schwan, Grajal, & Lewalter, this issue). Of course, decisions about who to believe also could be biased. Lewandowski, Ecker, Seifert, Schwarz, and Cook (2012), Sinatra et al. (this issue), and Maier et al. (this issue) provide overviews of the personal conditions and emotional and motivational bases for biased processing of information. Such biases apply not only to personal answers to the "what is true" question but also to assessing "who to trust." Deference to others is not a guarantee that bias will be avoided. Rather it is a strategy that requires reasoning other than the direct assessment of the plausibility of a science-related knowledge claim.[3] In the final analysis, trust is about people and about social institutions. Although

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[3] Cummings (2014) emphasized that reasoning strategies which defer to the authority of others are "informal fallacies," albeit she underlines the importance of such strategies for the public understanding of science. In contrast, Chinn et al. (2011) argued that deference to others and thereby trust matters not only in the context of the public understanding of science but also within science. Several philosophers of science have argued that the work of scientists is based on mutual trust (Origgi, 2004).

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people can and do make use of knowledge and reasoning strategies to evaluate science information, they are not confined to science and their understanding of the natural world. They also can make use of their knowledge of the social world when searching for answers to questions about the natural world.

Decisions about when to rely on others in making decisions about what and who to believe require metacognitive assessments as well as ideas about the nature of knowledge and science. As indicated earlier, the Internet has made accessible to all information that was heretofore available only to specialists and experts in their fields. As a result, the general public can now search not only for scientific evidence that has already been prepared for consumption outside the scientific community but also for information actually intended only for the scientific discourse community (Goldman, in press). The availability of such heterogeneous material has increased the importance of a variety of forms of evaluation, including most especially metacognitive assessment of one's own understanding. Availability per se is no longer an indicator of the degree to which the information is intended for a highly specialized versus more general audience. Judgments about whether it is worth investing effort in trying to comprehend a retrieved source depend, in part, on attribution of the causes of difficulties in understanding (Kienhues & Bromme, 2011). Judgments that it is will lead to continued first-hand efforts; judgments that it is not will lead to dependence on experts.

We have conducted a series of studies seeking to examine the conditions under which laypeople are aware of their dependence on experts. Specifically, we tested whether the judged complexity of science-related information affected nonexperts' decisions about their ability to evaluate the information content for its veracity. In an initial study we established the easiness effect (Scharrer, Bromme, Britt, & Stadtler, 2012): text comprehensibility not only influenced participants' agreement with the text claims but moreover clearly affected their perceived decision capabilities. Participants showed higher levels of trust in their own decision about the claim and regarded themselves less in need of expert advice after reading comprehensible as compared to incomprehensible arguments. In two further studies, we identified conditions that may prevent or mitigate the easiness effect. We found that information controversiality (Scharrer, Britt, Stadtler, & Bromme, 2013) as well as laypeople's assumptions about the epistemic complexity of the scientific topic (Scharrer, Stadtler, & Bromme, 2014) moderate the easiness effect. This series of studies exemplifies the interrelationship between metacognitive judgments, kinds of scientific claims and assumptions about epistemic features of the knowledge when subjects are confronted with knowledge claims that are beyond their understanding. Sinatra et al. (this issue) provide a systematic overview of these and additional personal conditions that affect the general public's strategies for coping with science information.

Media Contexts of Science Information

The Internet is but one context for experiencing science (Britt et al., this issue). Other venues include the mass media (Maier et al., this issue), and informal institutions such as science museums and zoos (Schwan et al., this issue). How science-related information is selected and how it is presented in the mass media as well as science museums and zoos is based on the goals and agendas of those venues and on assumptions about audience. That is, journalists have particular goals in crafting reports of science, and these may differ from those of the scientists who generated the information being reported (Goldman & Bisanz, 2002). Informal contexts seek to engage audiences with science and design exhibits and experiences to meet these goals as well as the constraints inherent in the context. For example, estimates are that the average amount of time a visitor spends at a zoo exhibit is about 2 min (http://www.elephantsincanada.com/education-and-conservation). As well, journalists and exhibit designers make assumptions about the interests and understandings that their audiences bring to their encounters with the science. These assumptions guide the science accomplishments that journalists choose to write about and the types of exhibits and experiences that zoos and museums develop. Furthermore, the way in which science is written about in the media and the designs of exhibits reflect assumptions about the understandings that audiences bring and the ways in which they will process the information.

Processing is of course strongly influenced by the kind of media that provide such information. A science museum presents authentic objects, video and audio material, and text (Schwan et al., this issue). Therefore psychological research on the public understanding of science has to rely on theories and approaches that mirror the media contexts in which science is experienced. With respect to the Internet, theories of text processing, and especially theories of multiple documents comprehension are pertinent (Britt et al., this issue; Goldman, 2010; Goldman, Lawless, & Manning, 2013; Stadtler & Bromme, 2013). For example, whether conflicting claims are distributed between different documents or are within one document impacts the ways in which people cope with conflicting science claims (Stadtler, Scharrer, Brummernhenrich, & Bromme, 2013). Other factors that seem to enhance integration across documents are readers' goals and rhetorical connectors (Stadtler, Scharrer, Skodzik, & Bromme, 2014). Once individuals have noticed a conflict, it is likely that they will try to generate explanations for this state of affairs (Bromme et al., 2013; Stadtler, Scharrer, & Bromme, 2013). Readers may for instance attribute a conflict to the nature of knowledge in the field of interest (epistemic explanation). Alternatively, they may attribute the occurrence of a conflict to the sources who present the information, for instance, their (lack of) expertise or vested interests (source explanation;

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Goldman et al., 2012). These results exemplify that reasoning about science-based knowledge claims is dependent upon reader's goals, more general ideas about why conflicts between science-based claims occur at all, and ideas about source features. Of course the factors scrutinized here are only a segment of the many internal and external factors that impact people's understanding of science.

ARTICLES IN THIS ISSUE

The arenas for experiencing science as well as the uses that the general public makes of science information are as numerous as the internal and external factors that impact the processing of these experiences. Therefore it is necessary to pursue different research approaches and to make use of different theories. The articles in this special issue[4] review cognitive, social, and affective psychological processes that come into play in contexts of the public understanding of science. They do so by looking at several contexts, where science information becomes available for the public. Such contexts include use of the Internet to look up science-related information, television and print media that cover public debates on socio-scientific issues, and informal institutions such as science museums and zoos.

Each of the five articles in the special issue provides a comprehensive view of research on a significant facet of the public understanding of science. Schwan et al. (this issue) discuss science learning in museums, science centers, zoos, and aquariums, all sites where there is enormous potential to reach large segments of the public and improve science understanding. Maier et al. (this issue) show how both science literacy and science media literacy in the public can be promoted by drawing on research on mass media production and on how people process science information in the mass media. Britt et al. (this issue) turn to the issue of how people process scientific texts, focusing on explanatory and argumentative texts as well as processes of executive control. Sinatra et al. (this issue) examine core psychological challenges to the public understanding of science, including the need for significant epistemic growth, the problem of motivated reasoning processes, and the need to achieve conceptual change on difficult science topics. Finally, Sandoval et al. (this issue) discuss many of the issues discussed in all the other articles from a developmental perspective, as they examine growth in children's early competencies to engage with science.

Each article focuses on a set of psychological constructs (e.g., reading, motivated reasoning, epistemic beliefs) and the relevant psychological theories within the context of the public's experience of science. The articles discuss various variables and theories from educational and developmental psychology, and furthermore from social and media psychology as well as from communication science in the light of the contexts in which the general public experiences science. Of course, even the diversity of the contributions in this special issue only map some of the territories that need to be studied for a comprehensive view of the public's science understanding. Nevertheless, together they can contribute to a better understanding of how people cope with science that is partly beyond their understanding but that is fully relevant to their lives. The work and perspectives discussed in this set of articles can inform educational improvement as well as PUS and PES activities. Furthermore if it is the case that science is ubiquitous in modern societies and that science understanding impacts our general understanding of the world and of ourselves within the world, then studying the public understanding of science has the potential to contribute to a more general psychological understanding of thinking and reasoning in modern societies.

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[4] This special issue encompasses not only different fields within psychology and communication science but also an international perspective. All contributions have a binational authorship, from the United States and from Germany. The contributors from Germany are all involved in a research program called "Science and the General Public: Understanding Fragile and Conflicting Scientific Evidence," including about 16 projects from psychology, communication science, educational research, and the sociology of science (http://www.scienceandthepublic.de). The articles evolved from a conference between researchers involved in the German program and a group of researchers in the United States who are exploring similar issues of scientific literacy and public understanding and engagement with science.

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