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BOOK REVIEW

From science as "special" to understanding its errors and justifying trust

Editors' Note:

This essay takes the form of a moderated dialogue among three authors, each of whom recently published a book about the epistemic status (or "specialness") of science in contemporary society. An appreciation of their philosophical differences provides science educators with intellectual resources to better navigate their ongoing work. While social media is often a venue for discrediting scientific viewpoints, within enlightened educational settings the "practice turn" is a defining feature of doing science (Furtak & Stroupe, 2020; Larkin, 2019). Because of their different backgrounds (i.e., historian, researcher, and philosopher of science), the books' authors offer varied representations of science. The subtle variations in their perspectives are the focus of this essay. Applying his expertise as a participant in the Science Education *community, this essay's author effectively facilitates a conversation among the three books. While the deliberations are often philosophical in nature, the implications for science teaching and learning are substantial.*

BOOKS REVIEWED

McIntyre, L. (2019). *The scientific attitude: defending science from denial, fraud, and pseudoscience*. Cambridge, MA: MIT Press. ISBN: 978-0-262-53893-0. $17.95.

Oreskes, N. (2019). *Why trust science?* Princeton, NJ: Princeton University Press. ISBN: 978-0-691-17900-1. $24.95.

Zimring, J. C. (2019). *What science is and how it really works*. Cambridge: Cambridge University Press. ISBN: 978-1-108-70164-8. $25.99.

What makes science "science"? This classic question, central to teaching the nature of science (NOS) and scientific practices, is addressed in three new books. One is by a philosopher, Lee McIntyre (who I will often cite simply as M); one by a research scientist, James Zimring (Z); and one by a historian of science, Naomi Oreskes (O). All three hope to address the current crisis in science denial and misinformation, exemplified by the cases of climate change and vaccination safety. Much of the material (perhaps over half) will surely be familiar to educators: the many forms of logical reasoning and the core role of empirical evidence and testing. However, unlike similar books on the same topic from one or two decades ago, these authors all notably discuss as central the themes of error in science and the role of social epistemology in remedying error. Indeed, this reflects a major shift among philosophers and sociologists of science, one highly relevant to educators.

Here, I will describe some of the shared themes, then highlight the distinctive content and perspective of each volume. I will then further compare and contrast their views on ideas especially relevant to education, and comment on some unresolved problems made more prominent by their discussions. Along the way, I hope to contextualize these efforts among other similarly themed books in the past few decades.

First, the common thematic elements (see Table 1). Educators have long wrestled with the conundrum of the "tentative" nature of science. On the one hand, science is admittedly fallible, provisional, and contingent. On the other, it is "durable" and vigorously defended as trustworthy (M, pp. ix, 1–8, 155; Z, pp.1–2, 10; O, pp. 18, 73–74). How does one

TABLE 1 Comparison of major themes

Theme	McIntyre	Zimring	Oreskes
Demarcation	••	•	•
Priority of the empirical	••	••	
Deduction, induction, and other logics	•	•	•
Underdetermination/Duhem-Quine	•	••	•
Historical change of scientific methods and standards	•	•	•
Errors	•	•	•
Social checks and balances	•	•	•
Controlled experiment and errors in causal reasoning		••	
Role of accident, chance, historical contingency		•	
Core role of predictions	•	•	
Role of honesty	•	•	•
Role of consensus	•	~	••
Role of expertise		~	••
Historical case studies			••

resolve this tension? These three authors provide a common answer: one needs to be more open about error in science. There is a clear admission of and engagement with scientific errors (Z, Ch. 4–8, p. 379), science "gone wrong" or "gone sideways" (M, Ch. 7–8, p. 188); or "science awry" (O, Ch. 2). Indeed, for Zimring and McIntyre (at least), science is demarcated from nonscience and earns privilege as a way of knowing through its practice of correcting errors.

One first needs to acknowledge the *sources of error* in science. Only then can one articulate how those errors are discovered and fixed. Being explicit about the errors allows one to say more clearly how any scientific claim may be qualified. What possible errors have been checked for (or not)? What controls have been run (or not)? What vetting has been done (or not)? These factors contextualize any particular scientific claim and provide more concrete and precise grounds for its justification and for identifying remaining uncertainties (Z, p. 242, O, p. 248).

What types of errors are there? See Table 2 (compare to inventory presented earlier in this journal by Allchin, 2012, p. 912). For example, there can be statistical flaws, such as cherry-picking of data, curve-fitting, p-hacking or small sample size, which all reflect "sloppiness or laziness" or the unguarded influence of "ideological or psychological factors" (M, p. 82–84; see also Z, pp. 31–32, 185–207; O, pp. 114–116, 229–230). Many errors arise from the way the brain works. Zimring describes them nicely: "As fantastic as the human mind can be in navigating the world, we likewise make fantastic mistakes; worst of all, we are all too often entirely unaware of the errors we have made" (Z, p. 125; see also O, p. 53). Such cognitive shortcomings include, most notably, confirmation bias (M, pp. 84–85; Z, pp. 268–276; O, pp. 69–143). Theory-laden interpretation of evidence (a tenet in the familiar NOS "consensus list") fits here (Z, Ch. 3 and 6). Keeping in mind that "scientific ideas are affected by their cultural and social milieu" (another tenet from the consensus list), one may include ideological blind spots as well as gender, racial or political bias (O, pp. 43–49, 76–104). Add, too, the well known fallacies of reasoning, such as affirming the consequent, typically catalogued in a critical thinking course (Z, pp. 47–53, 202–206, 214–245, 291–298). In many ways, specifying these error types helps radically transform the issue of trust in science. The problem shifts from science writ large (characterized only vaguely as "tentative") to individual scientific claims (some highly trustworthy, others less so).

But science is also able to cope with errors. Some are addressed through various scientific practices. For example, to limits errors in causal reasoning stemming from confounding variables, one conducts controlled

TABLE 2 Sources of error identified by the books' three authors

Source of error		McIntyre	Zimring	Oreskes
	Failure to respect/heed empirical results	•	•	•
Experimental	Failure of instruments (artifacts) or human senses (perceptual illusions)		•	
	Experimental confounders		•	
	Lack of professional expertise or skill			•
	Observation bias, observer bias, placebo effect		•	
Statistical	Mistaking chance for real effects (e.g., "hot hands" & clustering illusion, base rate fallacy)	•	•	
	Small sample size, anecdotal evidence, "hasty generalization"	•	•	
	Data-dredging, p-hacking, curve-fitting	•	•	
Psychological	Confirmation bias, cherry-picking of data	•	•	
	Correlation/causation		•	
	Availability error, extension neglect, lottery fallacy, failure to consider alternatives, what-you-see-is-all-there-is	•	•	
	Reasoning fallacies (affirming the consequent, patternicity, limits of induction, failed heuristics)		•	
Discursive	Gender bias, racial bias, class bias			•
	Professional hubris			•
	Dishonesty (fraud) by researchers	•	•	
	Conflict of interest	•		•
	Media, social media	~		•
	Unchecked trust in "authority"	•	•	
	Gullibility? self-deception? self-delusion? willful ignorance? wishful thinking? stubbornness? dogmatism?	•	•	

experiments or randomizes clinical trials (Z, Ch. 8). To avoid mistaking chance for a real effect, researchers use statistical analysis—although it requires competence and understanding of *p* values (M, pp. 82–84, 91–96, Z, pp. 245–261; O, pp. 228–244). Ironically, the "scientific method," as canonically conceived (and taught, however, blindly), can actually foster errors. Investigators who focus just on finding positive evidence or who adopt a simple dichotomous view of testing hypotheses (e.g., in this journal, Lawson, 2010) are susceptible to missing critical relevant evidence. That is, all three authors agree that the hypothetico-deductive method (HD)—roughly: derive prediction, observe, accept-or-reject (Hempel, 1966)—tends to accentuate conceptual blind spots (M, pp. 29–34, 94; Z, pp. 56–59, 63, 77–81, 91; O, pp. 24–26, 32–39). Researchers may foster epistemic security, however, by relying on more than their methods or their own limited perspectives. That is, they turn to each other.

A key element in error correction, according to all three authors, is the scientific community. Individuals may make mistakes. But groups less so. McIntyre expresses the new view succinctly: "Science *as an institution* is more objective than its practitioners. The rigorous methods of scientific oversight are a check against individual bias" (p. 112, italics in original). Zimring echoes this:

> *While specific observations or particular studies may be carried out by one (or a few) individuals, the broader determination and interpretation of those studies is a function of a scientific society. Thus, while nature may be an essential arbiter of scientific thought, how nature is explored and interpreted is ultimately decided by a large committee of humans with a complex set of rules and dynamics—fundamentally, a social construct.* (p. 301)

Epistemology itself is no longer a matter of individual rational agents. Rather, it is to be (re)conceived at the *social* level. For example, Zimring endorses the virtues of falsification, yet acknowledges that individual scientists rarely achieve this ideal. Nonetheless (he contends), it may be found at the community level (Z, pp. 307, 313). Likewise, McIntyre concedes that "the scientific attitude"—roughly, deference to empirical evidence—is, in practice, only fully realized at the community or institutional level (M, pp. 85–91, 112–113). Namely, science at the social level works like a system of checks and balances.

How does this work? First, scientific publications are subject to *peer review* (M, pp. 98–105; O, pp. 53, 58, 130–131; Z, pp. 274–275, 301). On occasions (especially when results are unexpected or puzzling), other researchers may try to *replicate* the original study and either confirm its findings or identify its errors (M, pp. 56, 105–112; Z, pp. 146–151, 268–273; O, pp. 228–234). Overall, there is *critical dialogue*—one reason scientists convene at conferences (Z, p. 274). Hence, the concurrence of multiple individuals with diverse perspectives is paramount. Science relies on *consensus* (M, pp. 152, 156, 164, 172; Z, p. 329; O, pp. 127–133, 141–146).

In short, educators should engage with error as an integral part of NOS, and discuss the practices, values, and attitudes associated with finding and fixing errors (see also Firestein, 2016; and in this journal, Allchin, 2012).

While the three books share these themes, they also differ in their perspectives and approaches. For example, McIntyre's book will appeal to those with traditional rationalist sentiments (also echoed in his earlier popular books, *Respecting Truth*, and *Post-Truth*). While disavowing aspirations to establish a sharp demarcation criterion, his efforts are very much in that vein (Ch. 1, 4). His title, after all, is "the" scientific attitude, not "a" scientific attitude.[1] That ethos, he contends, embodies two principles: "(1) we care about empirical evidence" and "(2) we are willing to change our theories in light of new evidence" (p. 48; also pp. 1, 179, Ch. 3).[2] Educators will recognize these ideas, of course, as *empiricism* and *tentativeness*, two tenets in the familiar NOS "consensus list." However, McIntyre shifts the focus from the *methods* of science (which evolve over time) to an enduring behavioral *disposition*—and this he presents as a significant and major shift (Ch. 2–4). Many philosophically inclined readers may find this a clever workaround to the notoriously intractable problem of demarcation. Still, the philosophical content and rhetorical stance here largely echo familiar themes. For example, Popper and falsifiability (and open society) remain central. But the reorientation, if taken seriously, would mean that teachers should focus more on inculcating basic values or habits of mind, than on scientific content or inquiry skills. At the very least, the focus on science-as-*attitude* poses a potent educational question: how might teachers instill deference to and respect for empirical evidence, along with the humility to concede one's mistakes? Nurturing autonomous thinkers has long been an implicit goal for educators. The reorientation suggests teaching a stronger image of interdependence, mutual trust, and skills for supportive critical exchange.

After articulating his basic principles, McIntyre elaborates on how scientists mitigate error through peer review and replication (Ch. 5). He then celebrates the emergence of modern medicine (Ch. 6), disparages pseudoscience, fraud, and denialism (Ch. 7–8), and gives qualified hope to the social "sciences" (Ch. 9)—all with relatively familiar rhetoric and oft-used examples (e.g., Agin, 2006; Daempfle, 2013; Helfand, 2016; Pigliucci, 2010; Pigliucci & Coudry, 2013). He concludes by defending again the "special" value of science from a philosophical perspective (Ch. 10).

Zimring's book, by contrast, exudes the concrete pragmatism of a practicing scientist. He, too, promotes the ethos of demarcation, but in an explicitly less grandiose, more "deflationary" (and thus more realistic) view (pp. 5, 9–10, 14, 99, 279–280, 377, 379). Zimring presents his view in three parts: (a) the logical ideals of science and their limits, (b) the perceptual flaws and biases of human cognition, and (c) the remedies—what ultimately make science so distinctive. In the section on logic, Zimring begins with hypothetico-deductive testing, then leads the reader comfortably through the philosophically weighty issues of the Duhem-Quine problem, the slippery nature of auxiliary hypothesis, and underdetermination (Ch. 1–2). He uses informal but vivid examples to illustrate that "science is an outgrowth of normal human observation, reasoning, conclusion, and prediction" (p. 353; see also pp. 13–14, 83–91, 95–99, 102, 356, 358). That is, with or without science, people seek empirical validation and respond when evidence does not match expectations. They strive for coherence in their "web of belief" (as conceived by Quine; Ch. 3). Zimring thus offers a healthy antidote to the earlier popular claims that science is special because it negates or transcends common sense (as promoted by Lewis Wolpert in his 1993 *Unnatural*

Nature of Science and Alfred Cromer in his 1993 *Uncommon Sense: The Heretical Nature of Science*; Zimring, rather, echoes Jacob Bronowski's 1978 *Common Sense of Science*).

Scientists, however, are distinguished by giving primacy to empirical data. They thus limit themselves to studying natural and predictable phenomena (Ch. 4–5). Even so, human observations and reasoning seem beset with numerous flaws. These include imperfect perception (Ch. 6), poor understanding of randomness and probability (Ch. 7), and misleading tendencies in interpreting causation (Ch. 8). The outlook may seem bleak:

> *Scientists and nonscientists both have fallacies in their hypothetico-deductive (HD) thinking, make mistaken observations, have cognitive biases, and fall in love with their hypotheses, noticing observations that confirm and ignoring observations that refute. Scientists and nonscientists are both susceptible to social pressures, social biases, and manipulation (intentional and unintentional) by the groups and societies in which they find themselves.* *(Z, pp. 353–354)*

Yet "science makes particular note of the source of these errors and develops its methodology (over time) to mitigate these errors" (p. 354). Science focuses on "refining natural human thinking to compensate for errors we make" (p. 356). Prominent among the tools for managing errors are (a) controlled experiments, which help identify and eliminate confounding variables, and (b) a proper understanding of statistics (Ch. 8–10). Not least among the methods of science is the social dynamics of science, used to correct individual biases (Ch. 11). For Zimring, this system of error-correction is what we might legitimately call the scientific method, and what ultimately demarcates science from nonscience (Ch. 12–13).

In the third book, Oreskes brings a historian's perspective to the central problem. But she is far less concerned with defining science than with articulating its credibility. Namely, as her title indicates, not "what is science?", but "why trust science?" It is a subtle, but important shift. Readers may be familiar with Oreskes' earlier book, *Merchants of Doubt*, which described how monied interests have repeatedly sought to undermine scientific consensus in public discourse with impressions of uncertainty. These political efforts at deceit form a strong context to her approach (which echoes her 2014 TED talk, perhaps familiar to some educators). Oreskes first threads through the history of the philosophy of science (from Comte, through Popper, Duhem and Quine, to Kuhn). Then she describes the sociologists in the 1970s and 1980s who exposed how political biases haunt the history of modern science. These studies laid bare a blinkered "idolatry of science" (p. 46). Oreskes then mindfully credits feminist philosophers for developing social epistemology (originally conceived as a remedy to gender bias). Their work helped transfer the epistemic responsibilities of science from its "special" methods and (ir) rational individuals to communities, which could (as noted above) balance diverse perspectives. Consensus, Oreskes notes, is critical to trust. Finally (bearing in mind, now, the wayward claims of the petroleum industry), Oreskes comments on the additional roles of expertise and honesty. (Again, the problem of trust differs markedly from the goal of demarcation. As described below, she makes another important shift: carrying the "science" problem from characterizing its internal workings into the realm of consumers of science, where the issue of trust is paramount.)

Oreskes then applies her framework of consensus among relevant experts. She hopes to address the skepticism of many non-scientists, who ask rather plainly: "If scientists sometimes get things wrong—and of course they do—then how do we know they are not wrong now? Can we trust the current state of knowledge?" (O, p. 74). Again, there is a telling shift from trusting science as an institution writ large, to assessing *when* precisely to trust science, *and when not*. Through five extended historical case studies, Oreskes illustrates the importance of the several factors she has identified as underwriting trust in science: consensus (continental drift; eugenics), diverse scientific communities (the limited energy theory of female behavior), and qualified expertise (hormonal birth control; and dental flossing). In each case, the synoptic scope of history allows one to appreciate what happens in the long-term when any one of these factors is absent. The lessons are summarized as a set of diagnostic questions for the lay person to ask (pp. 143–144, 250). The second half of the volume is then devoted to other scholars commenting on Oreskes' remarks, followed by her replies.

While the three books all focus on the credibility of science, they also differ in important ways. Comparing them highlights a number of points salient to educators. Most notably, perhaps, while the core idea of social epistemology originally grew out of the historical awareness that science repeatedly exhibited gender bias—and while all three authors cite feminist philosopher Helen Longino as an important benchmark—only Oreskes discusses gender bias fully as a source of error (highlighted in two of her case studies). The same applies to other forms of cultural bias based on race or ideology. While the system of error-correction seems organized precisely to accommodate just such cases of bias, McIntyre and Zimring exclude them as if even mentioning them might taint the image of science, which they each regard as "special." (In 12 pages of introduction and epilogue, McIntyre uses the term "special" 14 times, "distinctive" 11, "defend" 11, and "emulate" 12; Zimring uses the label "special" three time on the first page.) There seems to be continued resistance to sociological contributions to understanding the nature of science (see also in this journal: Allchin, 2004; Kelly, Carlson, & Cunningham, 1993). McIntyre and Zimring also heap scorn on individual cases of fraud and "self-delusion" (M, pp. 149–152, 174; Z, pp. 98, 268–276), although these, too, should be routinely resolved if one has faith in the social error-correcting system. Ironically, they still seem wedded to rationalist ideals at the individual level, and chary of sociological insights.

The neglect of sociology is both ironic and unfortunate. Ironic because sociologists have already commented on the social dimension of knowledge. Almost a half-century ago, Robert Merton (1973) focused on the conditions for the growth of certified knowledge. He did not focus on methodology, but on four core social norms: organized skepticism, communalism, universalism, and disinterestedness. These norms are largely the same as the community criteria formulated by Longino (see O, p. 53)—and which seem so novel and revelatory to two of these authors. Similarly, the centrality of the concept of consensus through critical communities was described decades ago by John Ziman (1968). The peripheralization of sociology is also unfortunate because many relevant insights are being overlooked. For example, Pierre Bourdieu, Bruno Latour and Steve Woolgar, and David Hull have all described the economy of credit that governs the production of new knowledge. Whereas McIntyre portrays science as coalescing from individuals all sharing his "scientific attitude," these earlier thinkers show how the institutional structure of science establishes rewards and incentives whereby this very attitude arises as a motivational by-product. As we will see below, the challenge of transferring knowledge from expert to nonexperts is another sociological problem, encountered but not fully addressed by these two authors.

All three authors want to depict real science (M, to defend it; Z and O, to inform literate citizens). Zimring thus introduces contemporary cases and personal anecdotes, to great effect. By contrast, Oreskes draws on history, her area of expertise (and a standard resource for understanding NOS in the science classroom). Her extended cases help convey the texture of scientific practice in an authentic context (just as they do for students). McIntyre and Zimring also appeal to historical examples. But their use of cases as evidence for their philosophical claims is highly problematic. They select only the cases and only the details that suit them, and as a result the philosophical overlays distort the historical facts. For example, both discuss at length the case of Ignaz Semmelweis and childbed fever (M, pp. 52–59; Z, pp. 308–311). Yet the account by Carl Hempel (1966) that both rely on is ill informed and quite misleading (Allchin, 2003b, pp. 337–339). McIntyre's and Zimring's tellings are styled to champion Semmelweis's (virtuous) empiricism over his critics' (antiscientific) xenophobia, theoretical hubris, and social prejudice, but they omit many relevant historical details that, if included, would ultimately contradict the very lessons they hope to convey. They similarly rely on myth-conceptions of Galileo, Priestley, Blondot, Wegener and Fleming. Both are guilty of Lawson's shoehorn (Allchin, 2003a). The claims about the nature of science suffer accordingly. History can surely inform our understanding of how science works. However, when history is used as evidence, it must be—just like evidence in science—accurate and complete. Both authors condemn the cherry-picking of evidence and theoretical bias in science. That standard is no less true in philosophy.

Let us take stock. How do our three authors inform the contemporary cases of vaccines and climate change? What solutions do they imply? For McIntyre (pp. 143–147), the vaccine case is "ugly," poisoned by undisclosed conflict of interest in Andrew Wakefield's original study. (Belatedly, we learn that honesty seems to be another "core principle of scientific practice.") The science has since been properly corrected. So, the system at works? However, McIntyre does not

explain how correction might occur in the public domain. Scientific knowledge is supposed to be unproblematically obvious, it seems. The persistence of erroneous public views he ascribes to the media and Hollywood celebrities and, indirectly, the gullible public themselves—who apparently lack a scientific attitude? No clear remedy, here, except rueful name-calling (M, pp. pp. 43, 149–159, 174). For Zimring, the case of vaccines illustrates the devious error of conflating correlation with causation (pp. 1, 21–22, 212–214, 217, 230–234). Yes, vaccines and autism are correlated. But the correlation is ultimately spurious (an artifact, he explains carefully, of typical early childhood medical histories and disregard for base rates). Here, Zimring celebrates the iterative process of testing and how the plausible hypothesis was eventually rejected. Again, science seems to have done its job: no particular solution for the public's perceptions, except perhaps for them to know and apply the subtleties of scientific reasoning themselves. For Oreskes, vaccine safety epitomizes the vital role of expertise and scientific consensus in public trust in science (pp. 15–19, 69, 129). Scientists widely concur: vaccines are safe. That should suffice. One study alone is never enough to go on. So, in a sense (one may infer), it never mattered that Wakefield's study was bogus; it was never viewed as discounting all the other vaccination studies. The problem is not within science itself. Rather, it is politics in the public domain. There, one may find an *apparent* lack of consensus and *apparent* controversy. But such doubts are actively fabricated in the media by particular interests. Honesty does matter. But here the conflict of interest is in communicating science, not among scientists themselves. Many people seem to trust celebrities and political leaders. But they are not the experts. The remedy for concerned citizens is thus to limit their attention to the proper scientific authorities, who can speak for expert scientific consensus.

What about climate change? Here is another case where trusting scientific credibility could not be more urgent. For Zimring, the case echoes somewhat the situation with vaccines. The denialists just fail to do good science. "Only nonscientists reject global warming theory because it doesn't predict weather patterns with certainty or because some anomalies exist in the data" (pp. 101-102, 324-327). Disagreement and tolerance of error, Zimring notes, are normal parts of science. Citizens should thus simply reject opinion and embrace the empirical evidence (p. 131). McIntyre, too, castigates denialists as "tiresome," "gullible," "self-righteous," and "charlatans" (pp. 155-166). He blames "a grave misunderstanding of how science actually works" and the "stealthy emotion" of motivated reasoning, "when we allow emotions to influence the interpretation" of data (p. 163; see also O, pp. 72, 153). Perhaps he hopes to win over naysayers by denouncing their misconceptions. But any constructivist educator will surely gauge such a strategy as unpersuasive and ineffective. Indeed, McIntyre does acknowledge that the denialists "would deny that they are denialists" (p. 163). In the same way, anti-vaxxers imagine that *they* are the defenders of good science, battling corporate cover-ups (p. 145). That leaves us, it would seem, at a paradoxical impasse. However, one might dwell on the notion that the denialists *do* trust science. If so, they trust the *wrong* science, because they are misinformed. That shifts the problem significantly from lack of "scientific attitude" or inadequate understanding of NOS (M, pp. 132, 164, 179), to science media literacy. Zimring, likewise, regrets how nonscientific authorities (corporate interests) try to interfere with the legitimate climate science (pp. 324–327). For him, it is about brute authority (although, ironically, elsewhere he declares that science is essentially and unequivocally *anti*-authoritarian—pp. 132–134, 316, 319, 326).

Oreskes, for her part, has campaigned publicly to expose the "merchants of doubt" about climate change (and other issues). She reminds us that "in recent decades, some groups and individuals have actively sought to undermine public trust in science as a means to avoid policy action that may be warranted by that science" (p. 224). Again, she argues for heeding the authority of the consensus of qualified experts, honestly reported (pp. 17–19, 69–73, 129–130, 153–159, 223–228, 245–246). Empirical evidence may be important, but (contra Zimring) one also needs the expert's experience to interpret it. Citizens who believe that they can make conclusions from shards of evidence on their own are mistaken. They are ill-equipped to detect cherry-picked data or misleading graphs and statistical analyses. Consensus is important as well. One can almost always find dissenters, but (and here, Zimring concurs) they do not constitute science, as vetted by the whole community. A narrow understanding of the nature of science is not enough, either. Politicized agents leverage the principles of skepticism and falsifiability (benchmarks for McIntyre, pp. 57, 153–157, 174–175), to create an aura of uncertainty where none exists. Finally, one needs honest communication (O, pp. 17, 129). Conflicts of interest (not naive pseudoscience) pervade pronouncements in the public discourse on climate change. "Discrediting science is a political strategy. Lack of public trust in science is the

(intended) consequence" (p. 225). The prospective solution, then, is "exposing the ideological and economic motivations underlying science denial" and to identify the relevant body of experts (p. 246). In a sense, it is a political counter-strategy, based on understanding the social dynamics of epistemics and on a holistic view of NOS.

The upshot of considering these contemporary cases, which provide substantial context and motivation for these three books, is that a full view of the relevant epistemics for scientific literacy must now include how scientific claims flow into culture—foregrounding the nature of science communication. All claims are *mediated*. Thus, the sources of error in many *public* scientific claims arise in the media, not among scientists. Many such claims "have been shown by evidence to be false. Yet they persist" (O, p. 70). Why? Those truly concerned about public understanding of science need to address misinformation and competing claims purporting to be science (Z, p. 360; O, p. 245). The nature of science now seems to include *science media literacy*. At the core, citizens are epistemically dependent on experts. As argued potently in this journal by Norris (1995, 1997), the educational goal of intellectual independence is utopian. Trust is essential. What can we say about the social architecture of trusting expertise in society (O, pp. 152–159)? Notably, the relevant questions shift from "What is science?" to "Who is a scientist?" or "Who is an expert?" (O, pp. 130–131). From "What is the evidence?" to "Who can I trust to speak for the evidence?" Not generically, but specifically. It is a tectonic shift in epistemic orientation. Worse, the imitators of science endeavor to disguise themselves. They feign every feature that philosophers or educators say makes science "science." They appeal to evidence (which is cherry-picked); they appeal to experts (dissenters, not consensus); they appeal to peer-viewed journals (but hide conflict of interest, or the sham nature of the journals). In this environment of subterfuge, a simple answer to "what is science?" or "what makes science 'special'?" no longer suffices. The perils of epistemic trust and science media literacy help define the educational challenges ahead (Höttecke & Allchin, forthcoming).

In closing, one should note that while focusing on error-correction in science can be valuable, it is easy to run afoul of the mythos that science is *self*-correcting (see M, pp. 138, 147, 171; Z, pp. 79, 124, 134, 228, 233, 234, 273, 319). Oreskes rightly asks, "*How* is science self-correcting?" and she answers quite poignantly, "it is not so much that *science* corrects *itself*, but that *scientists* correct *each other*" (p. 51, italics in original). Thus, error-correction is contingent on the motivation and resources to probe for errors. It depends on a critical and diverse scientific community. Without these, errors may linger unnoticed. Many scientists and others seem to adopt uncritically a teleological view that error-correction is inevitable, and scientific progress too, and that "the truth will out." "Eventually" (M., pp. 134, 138, 171, 175). Or "with time" (Z, pp. 79, 124, 229, 233, 234). But correcting error takes work, not the passage of time. It does not occur on its own. Accordingly, some substantive mistakes have persisted *for over a century*—for example, Newton's formula for the speed of sound in different media, or the viceroy and monarch as an example of Batesian mimicry (Allchin, 2015). So, again, the challenge moving forward is to clarify the methods and conditions for error-correction, and to include these as core elements in teaching the nature of science.

CONFLICT OF INTEREST

The author declare that there is no conflict of interest.

ENDNOTES

[1] McIntyre seems to have missed an earlier book with the same title. Grinnell (1987) articulates many of the ideas which McIntyre seems to present as novel. For example, Grinnell emphasizes the network of investigators that evaluate each other's work, leading to an intersubjective consensus.

[2] Rush Holt (Chief Executive Office of the American Association for the Advancement of Science) expressed the same sentiments in an editorial in *Science* on February 1, 2019: "The essence of science is to demand evidence at every turn and to discard ideas when they are shown not to comport with the evidence" (Vol. 363, No. 6426, p. 433).

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