From Nature of Science to Nature of Science *in Society*

by Douglas Allchin

Abstract. In addressing social justice we focus on the reliability of scientific claims relevant to the distribution of privilege, profit, and power. Epistemic understanding and analysis are needed politically to expose false claims, illegitimate justifications and bogus expertise, as well as to support findings that document or demonstrate injustice. Current approaches to nature of science in education (NOS, represented by a familiar "consensus list") are largely internalist, decontextualized, and based on idealized norms. They do not address actual practices, potential errors, or the cultural dynamics of scientific knowledge. Thus we advocate a shift in focus to the nature of *science-in-society* (NOSIS). The revised approach of NOSIS adds cultural epistemics, which includes science communication, credibility, expertise and conflict of interest. It also highlights certain errors in science with cognnitive roots in cultural ideology (gender, race and class biases; and the naturalizing error). NOSIS also aims to delineate epistemic and ethical justification, how they are integrated in social settings, and how values shape the funding and pursuit of research. We provide a critique of the current problem, a programmatic sketch of the new alternative, and many examples that illustrate how NOSIS is relevant to instilling or restoring social justice.

1 Introduction: From Social Justice to Nature of Science

Social justice may seem an unlikely topic for a science classroom. Science teachers prepare to teach by learning science, not ethics or politics. They become well versed in scientific concepts and the epistemic tools of empirical investigations, not in justifying moral claims, or methods of discussing values or negotiating between conflicting interests. Still, plain unadorned science can be relevant to fostering social justice in many ways. For example, DNA evidence can help exonerate persons wrongly convicted of murders and, over many cases, demonstrate systematic racial injustice. Epidemiological patterns can help establish how environmental risks have fallen disproportionately on already impoverished communities, or how workplace safety rules adversely affect certain already disadvantaged populations. Economic analysis can expose the disparities between politicians' claims about tax policy and the ultimate realities about who benefits and who bears the costs. One could easily expand this list to include such issues as equity in access to birth control or other health services; understanding the relationship between lack of economic opportunity and youth gun violence; or unequal barriers to participation in democratic elections. Trustworthy information and evidence matter. Ironically, perhaps, science can contribute to social justice not through any direct political action, but by assessing the reliability of claims relevant to political arguments. *Our analysis here builds on this philosophical dimension of science in potentially promoting social justice: through epistemic understanding.*

While much science education remains focused on content, or scientific concepts, a growing international consensus has highlighted the role of teaching the *nature of science (NOS)*, or "scientific practices," or how science works (Allchin, forthcoming; Allchin, Andersen & Nielsen, 2014; Hodson, 2008; OECD, 2017). *Namely, how does science develop its claims* *and, more importantly perhaps, how does it establish their reliability, or trustworthiness?* The growing tradition in NOS education forms a foundation here.

Historically, of course, many scientific claims have later proven unreliable. All scientific knowledge is "tentative," or provisional. Errors occur with regularity. However, in some cases the errors have had important cultural or political implications, affecting issues of social justice. For example, in certain episodes, scientists endeavored to portray gender, racial, or class disparities as "natural," or as validated by science (Allchin & Werth, 2017; Barkan, 1992; Gould, 1981; Schiebinger; 1989, 1993). Such claims were then used to maintain customs of social privilege, to restrict freedoms, to limit immigration, to hinder social advancement, and/or to deny educational opportunities. Later research exposed the flawed assumptions or methods and other lapses in reasoning. Using history as a guide, it seems vitally important in a social context to know how to identify such erroneous claims when they arise. Understanding how science works means also understanding how or when science does *not* work. When is science vulnerable to bias and to reaching unreliable conclusions, even if apparently supported by some evidence? *Students will ideally learn how both types of claims might develop, and how to differentiate between them—namely, both when to trust scientific claims and, equally, when to doubt them*.

Socially, the authority of science matters, especially in politics. In a sense, science is power. Thus, it should surprise no one that some individuals and monied interests try to secure that authority for themselves, even if their claims do not accord with scientific consensus (Allchin, 2012; Rampton & Stauber, 2002; Oreskes & Conway, 2010; McGarity & Wagner, 2008). The imitators of science flood print and broadcast media, the Internet, social media, and electronic communications with claims that are deliberately misleading and/or have no scientific merit. These misrepresentations present citizen-consumers with additional challenges: interpreting who is a scientific expert and who is not, and evaluating which sources of information are credible, and whose testimony should be trusted. In our view, many issues of social justice are now played out at this level, where non-scientists hope to eclipse the science that would otherwise threaten the benefits they receive from the current power structure. The issue of reliability in science communication adds a significant dimension beyond the standard assessment of scientific evidence and arguments. In our view, educators must thus shift from a framework of the nature-of-science (NOS) to one of the nature-of-science-*in-society* (NOSIS). It is our chief aim in this paper to profile this expanded view of NOSIS and to articulate what concepts or types of understanding one needs to add to conventional treatments of NOS, and to illustrate their relevance in some sample cases where social justice is at stake.

2 The Limits of an Idealized, Internalist Nature of Science

Concepts of NOS coalesced in the late 1990s around a set of principles shared across major international curriculum documents, what has come to be known as the "NOS consensus list." Ironically, the "consensus" list no longer enjoys a very wide consensus (Allchin, 2017a; Hodson & Wong, 2017). In developing new approaches, it is important to understand the earlier flaws. In general, although the blooming of NOS concerns was inspired largely by cases in the history and sociology of science, the outcome was largely shaped by earlier traditions in philosophy — which focused on the demarcation criterion (defining what makes science "science") and on articulating an idealized view of the methods of science, in contrast to its actual practice (Rudolph, 2005; Allchin, 2013, pp. 107-120). The emphasis was on ideas, theory, scientific reasoning, and training future scientists more than on the cultural consequences of science and developing informed citizens or consumers of science. That is, the view was largely internalist. The consensus view lacked contextualization. Accordingly, classrooms widely adopted decontextualized "blackbox" activities and "cookbook" inquiries (for example, Lederman Depository, 2018) that treated scientific justification as simple and unrealistically formulaic.

One can track this limitation through all the particular concepts in the consensus list. For example, one benchmark observes that "science occurs in a social and cultural milieu." Yet, "society" is typically interpreted narrowly here, just as a source of funding and of research "needs" (limiting science to its positive contributions to culture). There is little engagement with the challenges of conceptual bias (gender, race, class) or of conflicts of interest in sponsoring research. Nor is there typically concern about how scientific findings and resultant technologies can disturb social norms, or how the banner of "objective" science might disguise the advance of private or partisan interests. The abstract ideal in the flawed model for teachers displaces the concrete and real. Second, the consensus list rendered the "human dimension" of science to humanize the profession (in the interest of recruiting future scientists), rather than to reflect on the consequences of human errors and prejudices (Brush, 1974; Allchin, 2004). Third, among historians and philosophers of science, "theory ladenness" originally referred to the cognitive entrenchment that can limit the scope and trustworthiness of scientific claims. When reformulated for science educators, however, it came to mean that advances relied solely on bold hypotheses (in contrast to raw observation). Overall, then, the cautionary critical perspective is eclipsed by an idealized, romanticized view of science. According to the consensus list, "science is tentative"—and few would disagree. However, the consensus-list tenet functions primarily as a disclaimer to shield the authority of science. Few science educators tackle seriously the problem of scientific error (due to the biases noted above). They currently disregard the cultural mischief that can occur while scientific uncertainty persists (Oreskes & Conway, 2010; Michaels, 2008). The tenet that "science is empirical" also seems quite unproblematic on the surface. Yet the contextual problem of differentiating empirical from ethical, political or other value statements is rarely addressed. Nor is the challenge of integrating ethical and epistemic justifications, as is typical in socioscientific issues (Raveendran & Chunawala, 2015; Sadler & Zeidler, 2005). The NOS consensus view implicitly promotes a naive scientism. It strongly implies that science is autonomous and hence cannot be directly relevant to issues of social justice. The very phrase "nature of science" invites an image of science as a discrete entity embedded in the "natural" world, which can be sharply delineated and isolated from society (Allchin & Werth, 2017).

By contrast, the growth in international support for teaching NOS has almost always been linked to its role in informing citizens and consumers, as a part of functional scientific literacy (Allchin, Anderson & Nielsen, 2014; OECD, 2017; Ryder , 2001). Students need to understand science in a social context— precisely what is missing from the internalist, idealized consensus-list view (Rudolph, 2005). Hence, we shift our view explicitly to the nature of science *in society*, or NOSIS.

3 Contextualizing the Nature of Science *in Society*

Let us articulate, then, what factors might be appropriate in a fuller, more socially relevant recharacterization of NOS.

First, we acknowledge the challenge of expertise and division of labor in modern society. Not everyone is, nor can be, a scientist. Current curricula that aim to train students in "scientific practices" so that they can be fully independent scientific reasoners are unrealistic. Not every individual can be skilled enough to check every scientific claim, review the evidence, and make their own fully informed judgment. Not even other scientists, when the issues are beyond their area of expertise. As cogently argued by John Hardwig (1991), our society is built on *epistemic dependence*. One inevitable task of education for functional scientific literacy, then, must be to teach students how to deal with that second-hand reliance on the knowledge of scientists (Norris 1995, 1997). When is trust in scientific claims by others warranted, and when is it not?

An immediate consequence of this awareness is opening a role within science education itself for understanding science communication and public understanding of science. The system of checks and balances that foster reliability *within* a scientific community—part of the internalist view of NOS—is well known. Here, instead, we must address "science in the wild," outside the watchful domain of professional scientists. There must be epistemic understanding of how scientific knowledge, after review by scientific experts, is conveyed (or misconveyed) through social networks. How can selective transmission or outright distortion or misrepresentation affect what is *perceived* as "science"? Not everything that is presented as a scientific claim is, in fact, validated by scientific consensus. Society is filled with science con-artists (Allchin, 2012a, 2018; Rampton & Stauber, 20xx). Conflicts of interest abound. Students need to understand the architecture of epistemic trust in society, including concepts of expertise, credibility, credentials and testimony (Allchin, 2012b; Goldman, 1999; Zemplén, 2009). What are the politics of *what counts as* science in the public realm? A first component of NOSIS, then, is how we establish the trustworthiness of scientific claims in a social context outside the scientific community, in the shadow of epistemic dependence.

Second, citizens and consumers are ideally aware of how scientific consensus is established and when, by contrast, it may be considered incomplete. For example, the familiar NOS concept of "tentativeness" includes the notion that scientists sometimes present their claims with qualifications or with the expressed acknowledgment of some uncertainty. So understanding the nature of statistical uncertainty, as one common case, is important. Appreciating the subtleties of incomplete research—indeed, that almost all new research initially comes with such caveats—is equally foundational. In other cases, scientists identify potential uncertainties. These reflect the depth of evidence and the extent to which alternative interpretations of the data have been explored and ruled out or remain open.

Understanding the limits of scientific claims can be critical for public policy—in considering the likelihood and scope of alternative outcomes. Decision-making under scientific uncertainty differs from cases based on surer, more well established knowledge. For example, to hedge against alternative futures, one may apply variants of the Precautionary Principle, to minimize potential harm or the scale of adverse effects. Again, while scientists can be comfortably indifferent to the yet-unknown in the abstract, the real-world consequences matter in a social context. A second component of NOSIS, not found is NOS, is thus the dimensions of uncertainty in science.

In other cases, scientists make mistakes. A claim made confidently or with assurance on one occasion may later be retracted, or found to be mistaken. Concepts or explanations may change. Why? It is not helpful merely to contend that some scientists may, on some occasions, err. There are identifiable causes of errors, at least in retrospect. So, looking forward, one wants some guidance about what occasions (and for what specific reasons) a specific scientific claim may be justifiably questioned. Knowing the ways in which a scientific claim can fail is ultimately just as important as knowing what seems to justify it (Allchin, 2012c). How does science work (NOS) and, equally, how does it sometimes *not* work? A third component of NOSIS is familiarity with common sources of error in science, such as missing controls, misapplied statistical models and confirmation bias.

Several forms of scientific error are especially important in education, as they can have a significant impact on social justice before the errors are identified and remedied. Historians of science have documented countless major cases involving gender bias, racial prejudice, and adverse outcomes for lower classes (Gould, 1981, 1983; Schiebinger, 1989, 1993). The source of the error may typically be characterized as a collective blind spot by a scientific community without the relevant balance of cultural perspectives. Namely, in the past, male scientists have generally not noticed the flaws of their own gendered assumptions, until an alternate gendered voice emerged to keep their conclusions in check (Fee, 1979). Likewise, white Europeans failed to see their assumptions (and thus mistakes) about races and other cultures—until persons from those cultures had standing to challenge their weak evidence in scientific discourse (Barkan, 1992). Wealthy individuals have easily overlooked what seems obvious to those without such wealth (Allchin, 2016; 2017b, pp. 43-59). The general lesson is that scientific evidence is interpreted by scientists, and the cultural perspectives of the scientists can matter. One perspective keeps another in check and accountable to the evidence. Diversity in scientific communities matters—not just as on the principles of social justice, but because it is integral *epistemically* to reliable outcomes. Philosophers have now articulated more fully the significance of *social epistemology*, at a level above the methods profiled in conventional NOS (Harding, 1991, 1998; Longino, 1991, 2000; Solomon, 2001). The basics of social epistemology are another concept key to NOSIS that is not included in NOS (Allchin, 2004).

Another form of error with great significance to social justice is the naturalizing error (Allchin & Werth, 2017; Raveendran & Chunawala, 2015). In these cases, a cultural or political ideology becomes embodied in the scientific conclusions. The invisible assumptions become inscribed in nature as unquestionable “facts”. Nature, in turn (due to our native psychology), is viewed as inevitable or unchangeable, even intentional or purposeful. The bias or power structure, a result of social history, thereby comes to be seen (illegitimately) as “natural.” Furthermore, the cultural view seems endorsed by science as “fact.” For example, the conventional stereotyped image of natural selection tends to inappropriately naturalize competition as an integral component of “progress.” The scientific concept originated among the Victorian elite, but now seems (with circular reasoning) to implicitly justify open-market views and current economic stratification (Allchin, 2017b, pp. 43-59). Also, strict categories of male and female are not warranted biologically, but do help reinforce gendered division of labor and power structures (Allchin, 2017b, pp. 114-124). Many views of genetics also portray DNA as destiny, implying that efforts towards social justice are doomed to fail in the context of inherited, “natural” differences (Allchin, 2017b, pp. 141-145; Heine, 2017); Lewontin, Kamin & Rose, 1984). These scientific errors are especially important in education because of the circular link from culture to science to culture again. What appears as scientifically justified may not be, upon closer examination and critical analysis by diverse participants.

Bias in science also occurs in research sponsorship. The growth of knowledge depends on sources of funding. If certain avenues of research or certain investigative problems are privileged, with disproportionate funding, research is led in certain directions at the expense of others (Kitcher, 2001). Wealthy interests can thereby influence what science concludes—often in ways that perpetuate that wealth or foster profit for particular individuals. For example, agricultural biotechnology is based on conceptualizing crops as genes and as individual plants threatened by weeds, pests and limited resources, rather than as a complex interaction of social systems that foster monocropping and large-scale mechanized farming (Levidow, 1998). That view favors property owners who can increase the productivity of their land and wealthy farmers who can invest in the capital equipment. In both ways, viewing biotech as central peripheralizes the role of laborers and the unequal social distribution of wealth. Biotechnological research can only yield answers that implicitly reaffirm the interests of the wealthy. Similar biases govern research on marketable pharmaceuticals versus alternative pain treatments (such as acupuncture) that are more labor-intensive and inherently less profitable to business investors. Major research on ethnobotanical remedies likewise tends to focus on identifying active ingredients (that can be patented and thus owned as exclusive intellectual property), rather than on analyzing the preparation techniques and therapeutic practices that would generally be more widely accessible and less costly to individuals. What is known scientifically—appearing altogether objective because of a body of evidence—can actually be distorted by funding. The bias in research choices is also a core NOSIS concept, again not included in conventional NOS.

Finally, as noted above, science is empirical. But this NOS awareness alone leaves the student unprepared for addressing the intersection of facts and values in a social context. More support is needed for differentiating the descriptive and the normative, and for distinguishing epistemic and ethical modes of justification. For example, scientists cannot use an ethical principle of fairness to help them determine empirically how much global warming is expected in the next century: that is an empirical question. Likewise, no scientist can conduct a valid experiment to tell us ethically whether a certain vitamin-enriched crop (such as golden rice) is culturally appropriate, or whether society should accept the values of the intellectual property issues and agribusiness practices associated with such crops. While facts and values must ultimately be integrated, they follow separate forms of justification and validation. Appeals to empirical data or material demonstrations of causes differ from arguments based on ethical principles and shared emotions, such as respect for life and personal autonomy. One cannot collapse the two into a single category of "arguments." This normative/descriptive (or ethical/epistemic) distinction helps to characterize science and is a necessary element in a complete science education that purports to prepare students to deal with scientific claims in complex social decision-making contexts.

A second challenge is learning about how to integrate epistemic and ethical justifications in particular cases (Raveendran & Chunawala, 2015; Zeidler, et al., 2002). One argument cannot justly eclipse the other. But how does one manage their interaction? For example, prospective decisions might be clear if all the facts were known. But all too often there is scientific uncertainty. Politically, opponents will each want to enlist the authority of science to bolster their views (Martin, 1991). But without definitive science, alternative decision-making principles may be needed. In this case, one might defer to the Precautionary Principle of "first do no harm" (articulated in several versions), which accepts the uncertainty and indicates how to manage the spectrum of possible (unknown) facts (Foster, Vecchia & Repacholi, 2000; World Commission on the Ethics of Scientific Knowledge and Technology, 2005). Other cases of the intersection of ethics and science will invite creative problem-solving, imagining new ways to accommodate two parallel arguments at the same time (Johnson, 1994). Solutions may need to address multiple criteria simultaneously. That's a particular way to approach decision-making that differs from ethics or science independently, but which is essential in a social context.

All these adjustments to the conventional NOS perspective (summarized in Table 1) help contextualize science in social contexts. The view of NOSIS here echoes similar earlier analyses by Kolsto (2001) and Ryder (2001), each of which tried to articulate what science the student-as-citizen-consumer needs to know. NOSIS takes a more expansive view of science and the nature of science, as already suggested in the broadly inclusive Whole Science approach (Allchin, 2013; 2017a; forthcoming). Namely, epistemic issues span the justification of claims as they move from research settings to publication and discourse among scientists, and on through to society, from the lab bench to the judicial bench, or from test tubes to YouTube. Finally, NOSIS integrates the NOS tradition with another significant, parallel tradition in science education: science, technology and society (STS) and its more contemporary variants focused on socioscientific issues (SSIs) (Ekborg, Ideland, & Malmberg, 2009; Raveendran & Chunawala, 2013; Zeidler et al., 2002; Zeidler et al., 2011)

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4 Applying NOSIS to Social Justice

Reconceptualizing NOS is not intended here as a purely academic or philosophical exercise of conceptualizing or demarcating "science." The ultimate aim is to prepare students as citizens and consumers, for them to be alert to scientific claims in social contexts, analyze them, and be well informed when engaging in personal and public decision-making. Students need to learn when scientific claims are sound and when they are suspect (in all discursive contexts). In this section, we present several contemporary cases (summarized in Table 1) where the broader conception of NOSIS offers concrete guidance where conventional NOS is insufficient. Here we hope to articulate more clearly and illustrate the links between NOSIS and social justice, as based on effective epistemic analysis.

Perhaps the most significant socioscientific issue currently is global warming and climate change. Yet many political leaders (notably in the U.S.) dismiss the scientific consensus, calling it a hoax, a scam, a fraud (Allchin, 2015). The problem here is not inadequate conceptual understanding of the greenhouse effect, or of the nature of theories versus laws or of the role of creativity in science. Nor is it about general acceptance of or belief in the authority of science. Rather, it is public contention about what the science legitimately claims. The problem is in *communicating* science and in understanding *scientific expertise and credentials*. Who is a credible spokesperson for science? No one individual is competent alone to adjudicate all the evidence relevant to climate change (it is far too vast and specialized). Epistemic trust is essential. So, for public policy, learning the structure for warranting trust in third-party scientific claims is just as important as the original research itself. Here, the naysayers lack the appropriate credentials, and their motives for distorting the science are frequently apparent. That is an element of the nature of science *in society*.

Equally important, the sociopolitical eclipse of facts about climate change does not affect the populace uniformly. Those who profit from the carbon-based energy economy (oil and coal industries) continue to benefit, at the expense of increasing the risks and long-term costs for everyone else. Those who generate greenhouse gases disproportionately (generally, developed nations) prosper, while the environmental consequences mount globally. Discounting the legitimate science perpetuates injustice. In addition, the science can identify who (historically) has generated the greenhouse gases, and thus who may be considered primarily accountable for remedying the situation now. Achieving restorative justice is intimately linked to a scientific analysis of who caused the problem, how they benefitted, and thus who is responsible now, and to what degree.

Consider, by comparison, recent efforts in India to validate Ayurvedic remedies (Kumar, 2017). According to the ancient texts, an elixir made of cow urine, dung, milk, yogurt and clarified butter (called anchagavya) is supposed to cure such conditions as diabetes, cancer, schizophrenia, and autism. Testing this proposed medication clinically would certainly exhibit the empirical dimension of science—as dictated in conventional NOS. But current studies are being promoted by nationalists intent on *validating* those cures, not examining their efficacy objectively. The "science" is expected to lend greater authority to viewing India as a superior culture. The political intent, aligned with a presumptive outcome, seems to pollute the investigation from the outset. In a similar way, extreme nationalists have suggested that ancient texts provide evidence that Indians flew interplanetary spacecraft and also worked with stem cell therapies (Desai, 2014; Khan, 2018). These cases illustrate how the public perception of science is susceptible to political conflict of interest—reflecting the need for understanding NOSIS.

Misleading or erroneous support for folk remedies has particular social consequences, as well. If cheap folk remedies can be portrayed as effective, then no one need provide access to a modern—and more costly—health care system. The responsibility of ensuring health care for the poor would conveniently disappear. As a result, the poor would continue to suffer from illness, while the wealthy pay their way to health, compounding any unjust class disparities that already existed. Lessons on NOSIS will highlight the ways that conflicts of interest in science (either in funding or interpreting results) may foster social injustice.

Consider next the case of Avastin, a drug for treating breast cancer. Initially, it was approved for use based on standard clinical tests. Later, however, evidence for significant side effects emerged and the drug was withdrawn (U.S. Food and Drug Admin., 2011). The standard NOS concept of "tentativeness" is easily invoked in such instances to explain the scientific error or conceptual change. Namely, as we delve deeper and collect more data, we may revise our theories and even fundamentally alter our conclusions.

However, appeals to tentativeness and a "skeptical attitude" can have ironic consequences in political contexts. Indeed, the virtue of doubt has been enlisted repeatedly to *forestall* government policies for protecting human health and the environment. The strategy contends that without proof, informed policy is not possible and any action must wait until better knowledge is available. For example, the tobacco industry claimed that there was not sufficient evidence on the effects of secondhand smoke, so (they argued) cigarette sales ought not be regulated. Available evidence was wholly discounted by leveraging a (over)simplified NOS concept. The same political playbook — advising caution by appeal to tentativeness — was echoed in the U.S. in cases of acid rain; chlorinated fluorocarbons (CFCs) and the ozone layer; DDT use; formaldehyde; hexavalent chromium; vinyl chloride; lead; and ephedra (Kenner, 2014; Michaels, 2008; Oreskes & Conway, 2010). NOS can be corrupted and mishandled when contextualized in society. That's why teaching NOSIS rather than NOS assumes a vital role in science education.

In other cases (as noted in Section 3 above), the science is admittedly incomplete. Conclusions are not yet possible, even "tentative" ones. Science is *uncertain*. That applies to many cases of technological risk, such as the installation of hydroelectric dams in Uttarakhand province in India in the early 2000s. With no sure indication of adverse effects, construction proceeded. That led to disaster in 2013. With heavy rains, several dams failed. Nearby construction debris and mud from unmanaged excavation areas was washed downstream. Villages were wiped out. Over six thousand people died (Joshi, 2016; Ministry of Environment and Forests, 2014). Here, an appeal to the "tentativeness" of science after the fact may seem disingenuous. The victims of the Uttarakhand disaster were the local residents. Those who benefitted from the dams, by contrast, were the wealthy industrialists and the Indians in other, more prosperous states who drew electrical power from the dams. The risk of the projects was not borne by those who benefitted most, but by those with marginal economic status. In the absence of scientific clarity about the risks—all too obvious now, after the dam failures—the local populations had little political leverage to oppose the dams. Because a fuller role for environmental science was eclipsed in planning the projects, in retrospect the disaster may seem "unexpected" and can easily be framed as an "accident" triggered by heavy rainfall, a "natural" event for which no one can bear responsibility. But a deeper scientific analysis clearly exposes the inherent risks. The disaster could well have been avoided if the dam-makers had investigated the environmental risks and addressed them at the outset. The social injustice in the disaster ultimately resulted from a disregard for the need for science and respect for its results. Many years later, similar events have led to a major dam collapse in Laos (Ives, 2018). Science and scientific uncertainty can each be used towards political ends—a key awareness for the scientifically literate citizen, but not found in conventional NOS profiles.

The episode of Uttarakhand dam episode also underscores the importance of social versus scientific contexts in addressing scientific uncertainty. Scientists, of course, are typically loathe to advance claims without sufficient evidence. Their principle might be summarized as, "first, publish no wrong." In this case, they could not confidently predict the consequences (in part, because little research was done). That might be an appropriate idealized epistemic posture, aptly reflecting the NOS tenet of "tentativeness." But in a real social setting, that posture becomes grossly inappropriate. Policy-makers needed to also consider the ethical dimension of possible environmental consequences, whether fully documented or not. The burden of proof should have been on demonstrating the absence of significant risk. Socially, scientific uncertainty indicates the need for precaution, using an ethical guiding principle of "first, do no harm." Epistemic and policy postures under scientific uncertainty differ. The relevance of that difference and of the Precautionary Principle is precisely why students need to learn NOSIS in lieu of conventional NOS.

The cases described thus far should make it clear that the ideals of science profiled in conventional NOS lessons are not always found in a social context. Science underwrites power and scientific claims and scientific authority are often contested. Accordingly, no one should be surprised that monied and ideological interests inevitably endeavor to "bend" science (McGarity & Wagner, 2008). Thus, the scientifically literate citizen should always be alert to those with conflicts of interest who may try to distort, discount, or deny good science (Allchin, 2012a, 2018). For example, how should one interpret the debates over the safety of nuclear power? Operators of the plant in Fukushima, Japan, defended its safety, back-up systems and response protocols, of course—until the disaster in 2011. Likewise, officials at the Kudankulam plant in Tamil Nadu, India, continue to assert that their design is safe, although six workers were severely injured when a pipe burst in 2014. The plant has been fined for numerous operational violations and has experienced numerous shutdowns for steam leakage and other problems (Economic Times, 2017). While the companies should have the best access to useful information about safety, the history of their claims indicates that they cannot be trusted as reliable. Even when the Tokyo Electric Power Company first issued its analysis of the causes of the Fukushima “accident,” it was sharply criticized for its narrow focus and effort to justify the company’s response. Another report followed. Concerns about reliability are more acute in such cases because while the risk probabilities are low, the magnitude and scope of errors is potentially quite large. So citizens need to be educated about the effects of conflicts of interest in those presenting evidence and scientific arguments, not just about weighing whatever evidence is offered to them.

The challenges of conflict of interest extend to research ethics, as well. In another case in India, in 2009 several aid agencies sponsored clinical trials for vaccines against cervical cancer. Many of the patients were from poor tribal populations and were not fully informed about the risks of the study. Nor were the side effects well monitored. The U.S. drug company, Merck, seemed eager to earn approval for—and profit from—mandatory vaccination programs. Eventually, a U.S. researcher revealed Merck’s aggressive marketing tactics and its failure to fully disclose risks (Attkisson, 2009; Bagla, 2013; Chamberlain, 2015). Here, the vulnerabilities of the tribal population underscore again how real scientific practices can sometimes amplify rather than solve social injustice. That, too, is an important lesson about the nature of science, available if one expands its meaning to include the nature of science in society.

5 Conclusion

Achieving social justice hinges in part on proper public understanding of scientific facts or perspectives. Injustices, in many cases, arise by appeal to scientific claims that are biased or strategically misstated. They may exhibit cognitive errors, hide key assumptions, or misrepresent expertise. In policy or economic settings, bogus, distorted or misleading science can shape social privilege, economic advantage, or individual rights. The savvy citizen or consumer, vulnerable to such tactics, should ideally be positioned to expose any flaws or pretenses in those claims. This requires understanding how science works, not just ideally, but in actual practice. It requires understanding not just how knowledge is produced within a scientific community, but also how it is conveyed through social settings, as well. How does science ultimately justify its claims and how, at other times, does it fail? Current internalist and romanticized approaches to the nature of science (NOS) are inadequate in such contexts. Students require instead a robust understanding the nature of science-in-society (NOSIS).

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Table XX.1 Features of NOSIS not found in conventional NOS

	Example Cases
Cultural Epistemics	
epistemic dependence; scientific expertise, credibility, and credentials	• anti-vaccine movement (Britain and USA); • purported role of vitamins in preventing AI (Goldacre, 2010) • contagiousness of AIDS (USA) (Toumey,
role of science communication, including conflicts of interest	• nationalistic promotion of Ayurvedic medi • recruiting poorly educated women for cerv (India); • denial of anthropogenic global warming an (USA); • lack of public disclosure of fracking chemi
scientific uncertainty	• dam safety (Uttarakhand, India; Attapeu, L • false image of uncertainty about secondhar workplace chemicals (USA)
scientific errors	• XMRV virus as cause of chronic fatigue sy • delayed detection of side effects of Avastin
scientific errors: gender, race and class bias	• historical IQ testing and immigration (USA • Davenport's historical view of pellagra as g 2016)
scientific errors: the naturalizing error (values masquerading as facts)	• genes as determinants affecting cultural po class; • natural selection as a socioeconomic proce status and cultural privilege; • dichotomy of sexes, gender identity, and tr
ideological and cultural biases; social epistemology	• inclusion of AIDS activists in research revi 1995); • historical craniology and women (Fee, 197
Intersection of Facts and Values	
different bases for justifying facts versus values (epistemic and ethical forms of justification)	• safety and nutritional composition of GMC • homosexuality and gay rights

integrating facts and values in decision-making	• Precautionary Principle: Uttarakhand dam • Precautionary Principle: nuclear power pla Brazil); • anti-fluoridation controversy (science vs. p Martin, 1991); • meaning vs. magnitude of technological ris
sources of research funding and their biases	• agricultural biotechnology as biased towar large-scale monocrops • ethnobotanical remedies -- research & inte availability & distribution • energy research on large-scale (industrial) (household) sources (Terrapon-Pfaff