

## **From Nature of Science to Social Justice: The Political Power of Epistemic Lessons**

by Douglas Allchin

**Abstract.** In addressing social justice I focus on the reliability of scientific claims relevant to political and moral arguments about the distribution of privilege, profit, and power. Epistemic understanding and analyses can expose false claims, illegitimate justifications and bogus expertise, as well as support findings that document or demonstrate injustice. Current approaches to nature of science in education are largely internalist, idealized and decontextualized. They do not address actual practices, potential errors, or the cultural dynamics or contemporary applications of scientific knowledge. A Whole Science approach, by contrast, embraces a fuller spectrum, including science communication, credibility, expertise, uncertainty, and conflict of interest, while still focusing on the core epistemic issue of trustworthy knowledge. It also highlights certain errors in science with cognitive roots in cultural ideology (gender, race and class biases; and the naturalizing error). A Whole Science approach conveys how a broad understanding of NOS and epistemic concerns are concretely 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, in methods of discussing economic or ideological values, or in negotiating authority between conflicting interests. Still, plain unadorned science can be relevant to fostering social justice in many ways. (By social justice, I mean the disparities in wealth, social benefits, and privileges that result from the exercise of power rather than through equal opportunity and free access to common resources; National Education Association, 2017; Center for Economic and Social Justice, 2018). 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 providing reliable knowledge that informs arguments used to justify

privilege, profit, and power. *My analysis here builds on this philosophical dimension of science in promoting social justice: through broad epistemic understanding.*<sup>1</sup>

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, 2017a; 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.

Further, NOS is intended to contribute to functional scientific literacy (Kolstø, 2001; OECD, 2017; Ryder, 2001) or what one panel of the U.S. National Science Foundation called “science in the service of the citizen and consumer” (Toumey, et al., 2010). *Namely, the purpose of NOS instruction is not merely to profile the explanatory power of science, nor strictly to legitimize its cultural authority. Rather, NOS is to aid individuals in a society where public policy and personal decision-making increasingly draw on scientific claims (Rudolph, 2005).*

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 social justice. For example, in certain episodes, scientists endeavored to portray gender, race, or class disparities as validated by science (see below). 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 can 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 a form of 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 (McGarity & Wagner, 2008; Oreskes & Conway, 2010; Rampton & Stauber, 2002). 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. Science con-artists and purveyors of fake news are everywhere, vying for advantage through deceit (Allchin, 2017, pp. 104-113; 2018a; Goldacre, 2010). 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. Many issues of social justice now seem to be played out at this level, where non-scientists hope to eclipse the science that would otherwise threaten the profits and privileges 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 that constitutes most current approaches to NOS. Educators must thus adopt an NOS framework that

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<sup>1</sup>My central theme here differs from the social epistemology notion of *epistemic justice* (articulated by Fricker, 2007). That is, I do not focus here on how social justice *within* science affects the reliability of its claims. Rather, I am concerned with how the reliability of scientific claims contributes to arguments in a public sphere relevant to social justice.

accommodates these issues at the social level. *We need to shift from nature of science to nature of science-in-society* (Allchin, forthcoming; Höttecke & Allchin, 2019; Kelly, et al., 1993; Raveendran & Chunawala, 2013).

Current institutional approaches to NOS are insufficient. 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). The emphasis was on ideas, theory, idealized scientific reasoning, and training future scientists. That is, the view was largely internalist. Accordingly, classrooms tended to adopt decontextualized “blackbox” activities and “cookbook” inquiries (for example, Lederman Depository, 2018) that treated scientific justification as simple and unrealistically formulaic. Ironically, it failed to reflect authentic scientific practice as exhibited in complex historical cases (Allchin, 2013, pp. 107-120). This was an impoverished view of the nature of science. In retrospect, the consensus view lacked the contextualization that seems so clearly essential today. In particular, it was not designed to focus on the cultural consequences of science or to develop informed citizens or consumers of science. To do that, one must follow the scientific claims beyond publication in professional journals into society where they are applied and, sadly, sometimes misrepresented. One must focus on the entire reach of science, from test tubes to YouTube, from the lab bench to the judicial bench, or “*Whole Science*” (Allchin, 2010; 2011; 2012b; 2013; 2017a).

In the following sections, I elaborate on the relevant dimensions of the more expansive Whole Science approach. I describe a number of epistemic elements that are lacking in conventional approaches to NOS, but which are integral to pursuing social justice effectively (see Table 1). These are illustrated with numerous concrete cases, as examples of the kinds of lessons that students might encounter in a classroom transformed to include social justice issues.

## **2 Epistemic Dependence, Expertise and Credibility**

Perhaps the most significant socioscientific issue currently is global warming and climate change. Yet many political leaders and media pundits (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. Nor is it failure to appreciate the nature of theories versus laws, or the role of creativity in science (elements of the outmoded NOS “consensus list”). 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? That epistemic challenge is part of the nature of science (Goldman, 1999).

No one individual is competent alone to adjudicate all the evidence relevant to climate change (it is far too vast and specialized). We all rely on others for expert knowledge. *Epistemic trust* is essential (Hardwig, 1991). One inevitable task of NOS education (for scientific literacy), then, is to teach students how to deal with the second-hand reliance on the knowledge of scientists (Allchin, 2017b, pp. 95-103; Gaon & Norris, 2001; Norris, 1995, 1997; Zemlén, 2009). But with all the potential for misinformation, when is trust warranted, and when is it not? As puzzling as it may seem, learning the structure for warranting trust in third-party scientific claims in a public realm is just as important as the original research itself.

Investigating the expertise of climate change naysayers quickly indicates that many of the most prominent voices are not experts at all. Fred Singer, one of the earliest critics, was a nuclear physicist, with no background in atmospheric or climate science. Steve Milloy, frequently featured on Fox News and labeled an “expert,” was a lawyer and a lobbyist working for a libertarian think-tank. Indeed, one finds that the whole denial movement has been largely funded and promoted by the fossil fuel industry and other political conservatives (Mooney, 2005; Oreskes & Conway, 2010; Union of Concerned Scientists, 2007). That sponsored interference is a clue that climate change science is also a significant social justice issue. The eclipse of facts here does not affect the populace uniformly. Those who profit from the carbon-based energy economy continue to benefit, at the expense of increasing the risks and long-term costs for everyone. Those who generate greenhouse gases disproportionately (generally, developed nations) prosper, while the environmental consequences mount globally. Discounting the legitimate science perpetuates and amplifies 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. Addressing the justice issue involves, in this case, knowing who is an expert and who is not, and demanding politically that scientific expertise matters.

As another example of expertise, consider 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 (Kumar, 2019). The political intent, aligned with a presumptive scientific outcome, seems to discount deference to experts. In a similar way, not long ago extreme nationalists suggested that ancient texts provided evidence that Indians once flew interplanetary spacecraft, worked with stem cell therapies, and performed interspecies surgery that yielded a human with the head of an elephant (Desai, 2014; Khan, 2018; Kumar, 2019). Members of the Indian Academy of Sciences were quick to discredit these claims. These cases illustrate the potential for *political conflict of interest* in public scientific claims. Whether the public is susceptible to such claims depends in part on their ability to understand and discern expertise.

Misleading or erroneous support for folk remedies has an additional social consequence. Namely, if ineffective but readily available folk remedies can be misportrayed as effective, then a government need not ensure access to modern—and more costly—health care. The costs of funding health care for the economically disenfranchised would conveniently disappear. As a result, the poor would continue to suffer from illness, while the wealthy paid their way to health, compounding any unjust class disparities that already exist.

Again, ascertaining scientific expertise matters to social justice. That is a dimension of reliability that needs to be added to the NOS curriculum (Table 1).

### **3 Error, Bias and the Naturalizing Error**

One familiar feature of NOS, through almost all characterizations over the last several decades, is (as noted above) that science is “tentative.” Namely, scientists revise their claims and theories.

Sometimes, that means acknowledging earlier errors or, at least, misleading models. For example, not long ago, the U.S. Preventative Services Task Force revised its recommendations for mammogram tests for breast cancer (Kolata, 2009). For most women, it concluded, screening should begin at age 50. Earlier, it was age 40. But was the change justified? This was announced during a time of social concerns about soaring medical costs. So, was this just a way to cut costs—at the unjust expense of women’s health? Nature of science was relevant, here—but not merely to admit that science is “tentative” and can change. The specific reasoning mattered. One needed an epistemic analysis. At one level, the lesson of expertise applied here. Yes, the panel members were independent, qualified medical researchers. But how did they justify changing their expert view, then? The new recommendations were based on more data and meta-studies, which provided a better overall view of the benefits and risks of the tests (including harm from added exposure to X-rays). The available evidence changed. We have to be ready to revise our theories and even fundamentally alter our conclusions when that happens.

Ironically, in some political contexts, appeals to tentativeness and a “skeptical attitude” can have negative consequences. In many cases in recent history, doubt has been enlisted repeatedly to forestall government policies for protecting human health and the environment. For example, the tobacco industry claimed that there was not sufficient evidence on the effects of secondhand smoke in the 1960s, so (they argued) cigarette sales ought not be regulated. Available evidence was wholly discounted by leveraging an oversimplified NOS concept. The strategy of appeal to tentativeness was used over and over again in the ensuing decades. Industry contended that in the absence of “absolute” proof, informed regulatory policy was not possible, and any action must wait until better knowledge is available. This playbook was echoed in the cases of acid rain; chlorinated fluorocarbons (CFCs) and the ozone layer; DDT use; formaldehyde; flame retardants, hexavalent chromium; vinyl chloride; lead; and ephedra (Kenner, 2014; Michaels, 2008; Oreskes & Conway, 2010). Deeper understanding of NOS is needed, including more nuanced views of “proof” and burden of proof in a policy context..

Genuine errors in science do occur. And they can have a significant impact on social justice, even if only until the errors are identified and remedied. As noted briefly above, historians of science have documented countless major cases involving supposed justification for gender discrimination, 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, 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 on the principles of social justice, but because it is integral *epistemically* to robust 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 in a Whole Science approach (Allchin, 2013, pp. 107-120), essential to a full NOS curriculum.

One type of scientific error has special significance to social justice: the naturalizing error (Allchin, 2008; Allchin & Werth, 2017; Raveendran & Chunawala, 2015). In these cases, a cultural or political ideology becomes embodied in the scientific conclusions. The value-laden assumptions become inscribed invisibly as unquestionable “facts” of nature. Nature, in turn (due to our native teleological psychology), is viewed as inevitable or unchangeable, even intentional or purposeful. The bias or power structure, a result of social history, thence comes to be regarded (illegitimately) as “natural.” Worse, the cultural view seems endorsed by empirical evidence and the authority of science. 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. The solution is not to abandon science (as some contend), but to get the science right.

Scientific errors may seem like the last thing one wants to teach in science, as some admission of its capacity to fail. Yet past errors are also the clues to the methods by which we avoid such errors in the future. Especially contextualized in history, cases or error in science are valuable contributions to healthy epistemic lessons (Table 1; Allchin, 2012a; 2013, pp.165-183).

#### **4      Uncertainty and the Precautionary Principle**

Another challenge for science in social contexts is not susceptibility to error, but *uncertainty*. That is, in some cases, the science is admittedly incomplete. Conclusions are not yet possible, even “tentative” ones. That applies to many contemporary cases of technological risk. Acknowledging the full range of scientific uncertainty matters. Consider the case of installing hydroelectric dams in Uttarakhand province in India in the early 2000s. Construction proceeded heedless of possible adverse effects. That led to disaster in 2013. As a result of 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 by industry 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 (and profit) from the dams. The risk of the projects was not borne by those who benefitted most, but by those with marginal economic status. With a deficit 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 respect for environmental science was eclipsed in building the projects, in retrospect the disaster may seem “unexpected”: the builders can thus easily frame it as an “accident” triggered by heavy rainfall, a “natural” event for which no one can bear responsibility. Appeal to scientific uncertainty becomes a political escape clause. But many of

the inherent risks were known in advance. The disaster could well have been avoided if the dam-makers had fully addressed the environmental risks and concerns of the engineers at the outset. The social injustice in the disaster ultimately resulted from a disregard for “known” science uncertainties. Many years later, similar events led to a major dam collapse in Laos (Ives, 2018). Nor is the commercial neglect of safeguards in these episodes that much different from the classic case of building a residential community on top of a toxic waste dump in Love Canal in the U.S. (Newton & Dillingham, 1994, pp. 7-28). 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 and related cases underscore the importance of articulating how scientific uncertainty is addressed differently in social versus scientific contexts. 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 precisely predict the consequences. That might be an appropriate idealized epistemic posture, aptly reflecting the NOS tenet of “tentativeness.” But in a social setting, that posture becomes grossly irresponsible. 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 and achieving the absence of significant risk. Socially, scientific uncertainty indicates the need for preventative safeguards, using an ethical guiding principle of “first, do no harm.” That is the philosophical origin of the Precautionary Principle (Foster, et al., 2000; Harremoës et al., 2001; Ivone, 2015; O’Riordan & Cameron, 1994; World Commission..., 2005) and its close relation to science. Epistemic and policy postures under scientific uncertainty differ. The relevance of that difference and of the Precautionary Principle is precisely why students need a Whole Science approach to learning NOS (Table 1).

## **5 Funding and Conflict of Interest**

Bias in science, with corresponding implications for social justice, 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. For example, agricultural biotechnology is based on conceptualizing crops as genes or 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; Allchin, 2019). That view favors property owners who can increase the productivity of their land and wealthy farmers who can invest in capital equipment. In both ways, viewing biotech as central peripheralizes the roles of laborers and the unequal social distribution of wealth.

Biotechnological research yields 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 effective 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 concept, again not included in 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 the real world. Science underwrites power and scientific claims and authority are often contested. Accordingly, no one should be surprised that monied and ideological interests inevitably endeavor to “bend” science where government regulation of risks to workplace and environmental safety are concerned (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, 2017b, pp.104-113; 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 combined with conflict of interest can easily amplify rather than solve social injustice. Of course, historically, other vulnerable groups have been unjustly subjected to the risks in medical investigations. One may consider the cases of prisoners in a malaria study at the Stateville Penitentiary (Comfort, 2009); mentally ill patients in studies on a hepatitis vaccine (Robinson & Uhrh, 2008); orphans in an interventive experiment on stuttering (Reynolds, 2011), prostitutes, prisoners, mental patients and soldiers in a U.S. study of syphilis in Guatemala (Reverby, 2012), as well as the more renowned study of Southern blacks in the Tuskegee syphilis experiment (Jones, 1981). Funding and conflict of interest are further dimensions that shape the reliability of scientific practice and that should be included in NOS curriculum (Table 1).

## **6 Conclusion**

In some cases, social justice is served by lessons in plain old scientific content. Biology, for one, can provide a deeper understanding of the properties that are commonly but inappropriately used



to “justify” many prejudicial categories. For example, the genetics of skin color, so emblematic of race in the public consciousness, are not closely correlated with either distinct ancestral groups or geographic regions (Allchin, 2018b). Indeed, the whole concept of race is biologically unsound. As are the more fundamental widespread beliefs about genes as identity (Allchin, 2017, pp. 141-145). Nor are the categories of male and female strictly dichotomous (Allchin, 2017, pp. 117-124). That has implications for the status of transgender individuals and for biases based on gender stereotypes. The presumption that the cultural status quo, with all its political and economic inequities, reflects “survival of the fittest,” is based on erroneous understanding of natural selection (Allchin 2017, pp. 37-64). Science is a potent resource for informing and challenging many of the prejudices that shape social injustice.

In other cases, science can challenge cultural myths about science, scientists, and scientific reasoning that help perpetuate injustice. For example, eyewitness testimony was once considered by most jurists (and juries) as the gold standard for evidence in pursuit of justice. Yet such testimony proves to be strongly biased by preconceptions and memories that have been reconstructed by suggestion. Hence, in a judicial settings, cultural prejudices, rather than be corrected by such testimony, tend to be ironically reinforced. It has taken rigorous science, led largely by Elizabeth Loftus (1996), to begin to remedy the legal perspectives. By the same token, science can also help produce the evidence that exposes injustice. DNA evidence has helped to exonerate over 350 victims of wrongful conviction, over 70% of them originally involving eyewitness misidentification (Innocence Project, 2017). Some people seem eager to blame science for social injustice, without considering the many roles of science in actually helping to remedy it.

Yet the more powerful route to achieving social justice hinges on proper justification of scientific facts in arguments about privilege, profit, and power. Injustices, in many cases, are sustained by appeals to scientific claims that are deliberately misleading 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 well informed citizen or consumer, vulnerable to such tactics, should ideally be positioned to defend good science and to expose any flaws or pretenses in unjustified 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? What are the genuine uncertainties and where is the burden of proof? Who is a credible expert? Who exhibits conflict of interest? A Whole Science approach is needed to replace the current internalist and decontextualized approaches to the nature of science. To contribute to social justice, students need a full understanding of epistemics through lessons in the nature of science.

That approach, in turn, should guide concrete classroom practice. All the examples discussed here (summarized in Table 1) epitomize the aim of functional scientific literacy. It is not enough to know the scientific concepts, nor simply to be able to reason scientifically about evidence. The role of epistemic dependence (Section 2), cultural bias and error in science (Section 3), uncertainties and the precautionary principles (Section 4), and the potential for conflicts of interest and bias in social arguments appealing to science (Section 5) all underscore the need for more complete understanding of the nature of Whole Science — from test tubes to YouTube, from the lab bench to the judicial bench. Accordingly, science teachers should actively introduce and discuss appropriate cases, such as those in Table 1, in the classroom.

**Acknowledgments.** My deep appreciation to the Editors for their invitation and encouragement in completing this work, to my colleagues in Brazil and India for helping me understand local social justice issues there, and to two anonymous reviewers.

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**Table 1.** Features of NOS relevant to social justice.

	<i>Example Cases</i>
epistemic dependence; scientific expertise, credibility, and credentials	<ul style="list-style-type: none"><li>• purported role of vitamins in preventing AIDS (South Africa) (Goldacre, 2010)</li><li>• contagiousness of AIDS (USA) (Toumey, 1996)</li></ul>
role of science communication, including conflicts of interest	<ul style="list-style-type: none"><li>• nationalistic promotion of Ayurvedic medicines (India);</li><li>• recruiting poorly educated women for cervical cancer research (India);</li><li>• lack of public disclosure of fracking chemicals (USA)</li></ul>
scientific uncertainty	<ul style="list-style-type: none"><li>• dam safety (Uttarakhand, India; Attapeu, Laos);</li><li>• false image of uncertainty about safety of fire-retardants or workplace chemicals (USA)</li><li>• Precautionary Principle: nuclear power plants (Japan, India, Brazil);</li></ul>
scientific errors: gender, race and class bias	<ul style="list-style-type: none"><li>• historical IQ testing and immigration (USA) (Gould, 1983);</li><li>• Davenport's historical view of pellagra as genetic, not nutritional (Allchin, 2016)</li><li>• historical craniology and women (Fee, 1979)</li></ul>
scientific errors: the naturalizing error (values masquerading as facts)	<ul style="list-style-type: none"><li>• genes as determinants affecting cultural potentials or social class;</li><li>• natural selection as a socioeconomic process affecting social status and cultural privilege;</li><li>• dichotomy of sexes, gender identity, and transgender rights</li></ul>
sources of research funding and their biases	<ul style="list-style-type: none"><li>• agricultural biotechnology as biased towards mechanization &amp; large-scale monocrops</li><li>• ethnobotanical remedies -- research &amp; intellectual property vs. availability &amp; distribution</li><li>• energy research on large-scale (industrial) vs. small-scale (household) sources (Terrapon-Pfaff et al., 2014)</li></ul>