Chapter 2
From Nature of Science to Social Justice: The Political Power of Epistemic Lessons

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2.1 Introduction: From Social Justice to Nature of Science

In pursuing social justice, one usually looks to social workers, charitable programs, or political activists. Not scientists. Still, science can have a significant role in shaping and justifying public policy by documenting injustice and by validating effective solutions. Political rhetoric cannot substitute for the trustworthiness of evidence-based claims. Students should thus learn about the crucial *epistemic* dimension of science. What makes scientific claims reliable? Most current approaches to teaching about how science works, however, are idealized and decontextualized. In this chapter, I describe an alternative approach that incorporates "Whole Science" (Allchin 2011, 2013, 2017a) and conveys fully and concretely the connection between epistemics and science in society. Notably, that includes (as addressed in separate sections below) the roles of science communication, expertise and credibility, uncertainty, and conflicts of interest. Special attention is given to the naturalizing error and to scientific errors rooted in cultural ideology (gender, race and class biases)—and how such errors are mitigated and remedied. That is, students should appreciate how the epistemic practices of science, in conjunction with standard moral principles, can help us expose and resolve the problems that arise from the pursuit of disproportionate privilege, profit or power.

At first, 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

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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; the role of needle-swap programs in reducing disease transmission among drug-users, 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 either justify or challenge the disparities in privilege, profit, and power. *My analysis here builds on this philosophical dimension of science in promoting social justice: through broad epistemic understanding* (see also Kolstø, Chap. 10).[1]

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 et al. 2014; Hodson 2008; NGSS Lead States 2013; 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 a 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; Rutherford and Ahlgren 1991).[2]

[1] 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.

[2] This widespread institutional orientation thus situates NOS education solidly within basic citizenship goals. Epistemic lessons contribute in personal, social, political and economic contexts precisely because they support the assessment of evidence and arguments, and promote informed decision-making (contrast to Vilanova and Martins, Chap. 7).

Historically, of course, many scientific claims have later proven unreliable. All scientific knowledge is "tentative," or provisional (e.g., McIntrye 2019; Oreskes 2019; Zimring 2019). 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 §2.3 and cases in table below, §2.2). 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 (Allchin 2012a). 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 or are not informed by scientific work (McGarity and Wagner 2008; Mooney 2005b; Nestle 2015, 2018; Oreskes and Conway 2010; Rampton and 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 2017a, b, 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 accommodates these issues at the social level. *We need to shift from nature of science to nature of science-in-society* (Allchin forthcoming; Höttecke and Allchin 2020; Kelly et al. 1993; Raveendran and 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 and Wong 2017; see also Bazzul, Chap. 5). 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. NOS needs to address a broader set of questions (see also Bazzul, Chap. 5). 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, from field site to website, from lab book to Facebook—or "*Whole Science*" (Allchin 2010, 2011, 2012b, 2013, 2017a; Höttecke and Allchin 2020).

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 missing in conventional approaches to NOS, but which are integral to pursuing social justice effectively (see table below, §2.2). 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.

2.2 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* (Höttecke and Allchin 2020). 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 and Norris 2001; Norris 1995, 1997; Zemplén 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 2005a; Oreskes and 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.

Expertise does not always align with authority or political leadership. For example, in the early 2000s, while AIDS ravaged South Africa, Dr. Manto Tshabalala-Msimang, the Public Health Minister, adopted a policy that denied the connection between HIV and AIDS. Appealing to anti-Colonial sentiment, she claimed instead that traditional African values and knowledge of nutrition could effectively deal with the "alien" disease (Goldacre 2010; Voude 2007). Yet she was not an expert. Nor did she heed the global consensus of medical science. As a result, hundreds of thousands of people—mostly those already impoverished and modestly educated—died prematurely. All because her power and appeal to cultural values trumped expertise.

As another example of expertise and nationalistic cultural values, 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 2.1).

Table 2.1 Features of NOS relevant to social justice, with some example cases

	Example cases
Epistemic dependence; scientific expertise, credibility, and credentials	Purported role of vitamins or nutrition in preventing AIDS (South Africa) (Goldacre 2010)
	Contagiousness of AIDS (USA) (Toumey 1996)
Role of science communication, including conflicts of interest	Nationalistic promotion of Ayurvedic medicines (India)
	Recruiting poorly educated women for cervical cancer research (India)
	Lack of public disclosure of fracking chemicals (USA)
Scientific uncertainty	Dam safety (Uttarakhand, India; Attapeu, Laos; Burmadinho, Brazil)
	False image of uncertainty about safety of fire-retardants or workplace chemicals (USA)
	Precautionary Principle: nuclear power plants (Japan, India, Brazil)
Scientific errors: gender, race and class bias	Historical IQ testing and immigration (USA) (Gould 1983)
	Davenport's historical view of pellagra as genetic, not nutritional (Allchin 2016)
	Historical craniology and women (Fee 1979)
Scientific errors: the naturalizing error (values masquerading as facts)	Genes as determinants affecting cultural potentials or social class
	Natural selection as a socioeconomic process affecting social status and cultural privilege
	Dichotomy of sexes, gender identity, and transgender rights
Sources of research funding and their biases	Agricultural biotechnology as biased towards mechanization & large-scale monocrops
	Ethnobotanical remedies – research & intellectual property vs. availability & distribution
	Energy research on large-scale (industrial) vs. small-scale (household) sources (Terrapon-Pfaff et al. 2014)

2.3 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 (McIntrye 2019; Oreskes 2019; Zimring 2019).

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 2010; Michaels 2008; Oreskes and 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 1990, 2001; 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 and Werth 2017, in press; Raveendran and 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 et al. 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 2.1; Allchin 2012a, 2013, pp. 165–183).

2.4 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 6000 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 or openness 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. Later, similar events led to major dam collapses in Laos (Ives 2018) and (twice) in Brazil (Douglas 2015; New York Times 2019). Nor is the commercial neglect of safeguards in these episodes that much different from the classic case of building residential communities on top of toxic waste dumps in Love Canal or Times Beach in the U.S. (Newton and 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

(Shrader-Frechette 1990). 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 and Cameron 1994; World Commission on the Ethics of Scientific Knowledge and Technology 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 2.1).

2.5 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 (Allchin 2019; Levidow 1998). 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 shaped by funding. The bias in research choices is also a core epistemic concept, again not included in conventional NOS (see also Dagher, Chap. 3).[3]

[3] Here, I underscore the epistemic dimension of funding. That leaves open the cultural question of who funds science, and how. Some advocates (e.g., Kitcher 2001) propose a public, community-based and democratic ideal. Yet the majority of research is funded by commercial interests. Roughly 40% of all geologists are employed by the petroleum industry. Even the majority of government-sponsored research is typically oriented to national defense and the military. The complex mixture of public and private funding renders deeply problematic the question of how one might regulate which research topics are supported.

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 and Wagner 2008; Wagner and Steinzor 2006). 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, 2018a). 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 credible. 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 (see also Benzce and Carter, Chap. 4). However, if social interests endeavor to "bend" science, the appropriate response seems not to disparage all science as inherently flawed, but to "unbend" the problematic cases. One should use a keen understanding of epistemics to leverage awareness, and thereby forestall or remedy any distorting bias (as in the case of social epistemology discussed above, §2.3).

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 and Uhruh 2008); orphans in an interventive experiment on stuttering (Reynolds 2003), 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 2.1).

2.6 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 2017a, b, pp. 141–145). Nor are the categories of male and female strictly dichotomous (Allchin 2017b, 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 2017b, pp. 37–64). All are examples of the naturalizing error (§2.3). 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. We should recognize that science is not inherently a "weapon of oppression" (see Ogunniyi, Chap. 9) or co-conspirator of coercive capitalism (see Benzce and Carter, Chap. 4), but can sometimes be a tool for liberation and justice. Epistemic lessons can be politically quite powerful.

Achieving social justice often 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 (§2.2). 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 empowered to defend good science and to expose any flaws or pretenses in unjustified claims. This requires understanding how science works, not just ideally or superficially, 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 (§2.3)? What are the genuine uncertainties and where is the burden of proof (§2.4)? Who is a credible expert (§2.2)? Who exhibits conflict of interest (§2.5)? 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 2.1) epitomize the aim of functional scientific literacy for citizenship. It is not enough to know the scientific concepts, nor simply to be able to reason scientifically about evidence. The role of epistemic dependence (§2.2), cultural bias and error in science (§2.3), uncertainties and the precautionary principle (§2.4), and the potential for conflicts of interest and bias in social arguments appealing to science (§2.5) 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, from field site to website, from lab book to Facebook. Accordingly, science teachers should actively introduce and discuss appropriate cases, such as those in Table 2.1, in the classroom.

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