FROM TEST TUBES TO YOU TUBE: NATURE OF SCIENCE IN SOCIOSCIENTIFIC ISSUES AND HISTORY

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In preparing students to address socioscientific issues (SSIs), teachers must go beyond scientific content, and even beyond ordinary scientific reasoning. Citizens and consumers must understand the epistemic structure of science and its subsequent cultural communication. Students must learn how scientific claims are grounded in observations in the lab or field, but also how they are transmitted and transformed in social contexts and the media—from the lab bench to the judicial bench, from test tubes to YouTube. This knowledge guides non-experts in assessing the trustworthiness of scientific claims. In this presentation, I build on previous epiSTEME presentations to describe the essential elements of this understanding—namely, how to conceive the nature of science (NOS), or how science works. Ironically, perhaps, this parallels a list of all the possible errors in science, or ways science can go wrong.

SCIENTIFIC LITERACY AS A GOAL

Do cell phones cause cancer? Are Ayurvedic remedies effective? —Or: *which ones?* Are genetically modified (GM) foods safe to eat? In a public policy sphere, when can much needed development projects—such as the ultimately disastrous one at Utturakand—be considered scientifically well informed enough to earn endorsement? Is climate change real? Is it contributing to worse monsoons? Is nuclear power safe and environmentally sound? These are the challenges that face informed consumers and citizens. They form a framework for science education and for developing what is generally called scientific literacy.

Namely, one may characterize the primary (although perhaps not the only) goal of public science education as developing analytical skills based on understanding the nature of science (NOS):

> *Students should develop a broad understanding of how science works to interpret the reliability of scientific claims in personal and public decision making.*

This is in sharp contrast to, first, an emphasis on conventional conceptual content and, second, the process of science skills important in developing future scientists and engineers. As Rai (2011) noted in an earlier epiSTEME conference, students as future citizens need to have:

> a minimum level of knowledge and understanding of science that enables them to participate in science related discourse at least over those issues that are directly linked to them, personally or socially. (p. 65)

This was echoed by an analysis in the U.S. of the relevant dimensions of functional scientific literacy (Toumey et al., 2010). Namely, today's students need to understand how science works and, as evidenced in some dramatically tragic cases, how science does not work. Epistemic understanding of science, or NOS, is a necessary tool for the contemporary informed citizen.

This view has been largely endorsed in an Indian context—at least among educational professionals. For example, over a decade ago, Popli (1999a, 1999b) advocated that schools address a "common man science," relevant to the typical citizen. More recently, Raveendran & Chunawala (2013) have underscored the central role of socioscientific issues (SSIs) as a benchmark for science education in developing nations. (Ironically, perhaps, their argument seems to extend equally well to developed nations.) They emphasized the intersection of science and values, with the consequent importance for including values and ethics discussion in the curriculum. In the sample issues noted above, however, the chief issue is the reliability of the scientific claims. The core issue is *epistemic*: how do we know whether, or to what degree, one may trust the various claims? What is the empirical evidence? What are the uncertainties? In what ways might the claims be significantly qualified, limited in scope, or open to error? As illustrated by the case of socioscientific issues in India in the opening paragraph, epistemic analysis forms the essential core of NOS understanding.

Rai (2011), also in a previous epiSTEME conference, provided a similar analysis in the context of promoting nature of science as a central curriculum element. He, too, underscored the critical role of the epistemological dimension of science in interpreting socioscientific issues:

> whether an individual can discuss such matters and to what extent his/her participation is successful depends on the individual's capacity to understand not only the issue at hand but also on his/her understanding of NOS. (p. 65)

Again, quite apart from knowing basic concepts or being able to discuss values, students need to understand how scientists develop and substantiate their knowledge claims.

One common sentiment is that our goal is to empower students to evaluate scientific arguments and evidence on their own. That is, we should train them to make scientific judgments independently. As expressed in the OECD/PISA framework (quoted in Rai, 2011, p. 64), we want students to develop:

> ...the capacity to use scientific knowledge, to identify questions and to draw evidence based conclusions in order to understand and make decisions about the natural world and the changes made to it through human activity.

This may seem a natural expression of understanding NOS epistemically. However, this noble aim may be misplaced. Philosopher John Hardwig has prominently noted how in constructing our knowledge as individuals, we inevitably rely on others. We rarely have direct, observational or sensory experience of everything we purport to know. For most facts that we commonly accept, we rarely test or confront all the evidence. Nor do we need to. Simply, we depend on the reports, or testimony, of others. For example, we trust our teachers and textbooks. Hardwig called this *epistemic dependence*. Steve Norris especially has profiled the importance of this concept in conceiving education (Norris, 1995; 1997). Pragmatically, how does this alter our vision of scientific literacy? Students will surely benefit from learning modes of scientific reasoning, but this alone is not sufficient for functional scientific literacy.

Epistemic dependence applies as much to scientists as to everyone else. Building scientific knowledge is made possible because scientists can trust and accept the work of others. Repeatability is a basic principle in science, but it is extraordinarily rare in practice (Broad & Wade, 1982). As sociologist Steve Shapin (1996) has noted**,** science is ironically marked less by skepticism, than by trust. The role of trust can be traced back at least to Robert Boyle and the founding of the Royal Society and his effort to establish a scientific community that would share results. Boyle helped contribute to a new tradition of reporting scientific observations and findings, conceived as virtual witnessing. Trust in scientific publications enables scientists to work from and extend the results of others. But the trust must work.

The role of epistemic dependence introduces another dimension in scientific practice, or NOS. Namely, as claims move further from their empirical and evidential sources, who can one trust? When can testimony be considered credible? Who has sufficient authority to warrant the trust of others? Who is a relevant expert? These questions become especially acute as scientific claims travel into the realm of non-scientists and non-experts who ultimately depend on the knowledge (Goldman, 1999, 2001, 2002). Trustworthiness is a major element of NOS.

Scientific knowledge is thus conveyed, and sometimes transformed, through social networks (Latour, 1987). For socioscientific issues, those networks extend beyond the scientific community to non-scientists, where they function to guide consumers and public policy. Ensuring trust through appropriate social mechanisms, institutional credibility, and other checks and balances becomes even more important. How credibility works, both inside and outside the community of researchers, is thus also an integral element of NOS for functional scientific literacy.

The purpose of exploring epistemic dependence in interpreting socioscientific issues is not merely to justify (yet again) its importance in science education. Rather, the analysis helps contextualize what the rather vague label ‘nature of science’ ultimately means. Just what elements should one include in nature of science education? What should one specify in terms of concrete curricular elements as concepts or competences to learn—and that ultimately can be tested as well?

Three studies are valuable benchmarks. Kolstø (2001) analyzed the needs of citizens interpreting science and discerned eight basic conceptions in four thematic groups. These deep understandings were: knowledge is actively “constructed” and involves consensus (namely, science is a social process); science is one of several social domains; descriptive and normative statements are distinct; claims are linked to their underpinning evidence; and scientific models are bound to certain contexts (all indicate the limits of scientific knowledge); scientists approach claims with a “suspension of belief”; and find authority in empirical evidence (science embodies certain epistemic values); and, finally, scientists adopt a posture of scrutinizing knowledge claims (that is, they exhibit a critical attitude). These are basic orientations thought which science earns its authority. Again, content knowledge is secondary.

Ryder (2001) made a parallel analysis by focusing on 23 cases studied in detail by sociologists of science. What did citizens need to know to interpret the social controversies involving scientific knowledge? Four categories of requisite knowledge were fairly standard: some subject matter knowledge; how scientists collect data and assess their quality; how they interpret those data (including distinguishing correlation from causation and allowing for possible multiple interpretations); and how scientists use models and work with their assumptions and errors. Two additional categories were important. First, a citizen needs to be aware of uncertainty in science, what factors lead to that uncertainty, and what its consequences are. Namely, science is not always complete and this can affect our decisions about SSIs. Second, a citizen needs to understand something about how science is communicated in the public domain. As noted above, understanding sources of information and their relative reliability or biases can deeply influence how one treats particular claims in a social controversy. Ryder's analysis further underscores the need for understanding both internal and external aspects of science.

Finally, a workshop sponsored by the U.S. National Science Foundation articulated the components that characterized "science in the service of citizens and consumers" (SSCC) (Toumey, et al., 2010). Their categories were rather broad, but embraced three very general domains: some basic scientific content knowledge; exposure to the mode of scientific reasoning; and (again) awareness of the institutional structure and political processes of science. Their profile further underscores the broad spectrum of NOS elements in scientific literacy.

CHARACTERIZING HOW SCIENCE WORKS—OR DOESN'T WORK

The context of functional (civic) scientific literacy, including its inevitable epistemic dependence, is a benchmark for the more practical question, "what understanding of the nature of science is important to teach?" Because assessing the reliability of scientific claims is central, students need to learn just how those claims develop and, equally, how they are conveyed from scientists to others. What ensures their trustworthiness or, alternatively, justifies being skeptical of them? Ironically, an understanding of "how science works" parallels an appreciation of how science does *not* work (Allchin, 2012b). To discriminate acceptable from unacceptable claims, one needs to understand both. As cogently profiled by Jonathan Osborne (2011) in epiSTEME 4, "knowing what's wrong matters as much as knowing what's right" (see also Henderson et al., 2015). Here, then, I briefly survey some examples from public discourse as a guide. These cases offer concrete indications about what elements of NOS belong in the classroom.

The concept of sources of error is familiar to experimentalists. Namely, what could go wrong that would disrupt the conduct of an investigation or the effective interpretation of its results? Awareness of these potential errors is critical to protecting against them and to bolstering confidence in one's results and conclusions. Something as simple as a controlled test helps avoid seeing a spurious cause as real. Of course, there are many possible sources of error beyond the laboratory, as well. There are fallacies in reasoning, cognitive biases, errors of reputational trust, and so forth. The concept of sources of error is properly a very broad one. This brief survey samples a wide spectrum of newsworthy errors, from working in the lab to communicating good science (Table 1; Allchin 2013, p. 24). Again, these cases reflect the kind of knowledge of NOS concretely relevant to the scientifically literate citizen or consumer.

For example, in 2011 news of neutrinos traveling faster than the speed of light reached the front page of *The New York Times*. That might have presaged a revolution in physics. Months later, however, it was confirmed that the finding was wrong. Time was mismeasured because of a faulty clock signal between labs in Switzerland and Italy. Quite simply, one transmission cable was not securely connected to its socket (Cartlidge, 2012). Yes, something as apparently trivial as a loose cable on the equipment can matter to media science headlines

In 2009, a study published in the prestigious journal *Science* implicated the XMRV virus as a cause of chronic fatigue syndrome, whose cause had long been unknown. Two years later, after millions of dollars in additional research, it became clear that the samples in the original study had been contaminated (as some critics had suspected). Inactive fragments of the virus were found unexpectedly in a standard commercial reagent used to process the DNA samples (Simmons et al., 2011). Contaminated samples matter, too. Teachers who admonish their students to clean their glassware thoroughly are not being unduly fussy after all; it matters to reliable results.

In 2008, based on promising positive evidence, the U.S. Food and Drug Administration approved the drug Avastin for treating breast cancer. Data continued to be collected, however, and several years later, with larger numbers, the relative safety and effectiveness of the drug came into question, and the drug approval was withdrawn (U.S. Food and Drug Admin., 2011). Earlier, the popular pain killer Vioxx suffered a similar fate, as more evidence accumulated. When statistics are involved, sample size matters to the reliability of the claim.

Once, India and Bangladesh were threatened with disease transmission from surface water. As a result thousands of tube wells were dug in the 1970s intended to provide fresh water more safely. Not until decades later, after severe health problems had emerged, did it become evident that the new wells contained large amounts of arsenic (Chatterjee et al., 1995; Flanagan, Johnston & Zheng, 2012). What went wrong with science? Well, no one had bothered to investigate. Incomplete research can be a significant source of mistakes, in this case with adverse health effects for tens of millions of people. And the problem persists (Guglielmi, 2017).

Decades ago, sociobiology seemed to explain social behavior. Prominent biologist E. O. Wilson promoted genetics, not intentional good will, as the basis for altruism, as exemplified in honeybee colonies and other animal societies with only one reproductive individual. Kin selection seemed to echo and rationalize certain social values about family structure. Recently Wilson has “recanted.” With much more evidence available it now seems that ecology drives social structure and that the unusual genetic patterns follow. The original scientific claims, it now seems clear, were deeply theory-laden and influenced by cultural politics. That kind of bias is a potential source of error in science, too, and important for citizens to understand.

In another case in India, in 2009 aid agencies sponsored clinical trials for vaccines against cervical cancer. Unfortunately, many children experienced adverse side effects, which were not well monitored in the study. Later inquiry documented that participants, including many in impoverished tribal populations, were not duly informed about the nature of the test or the risks. The U.S. drug companies had hoped to ultimately earn approval for—and to profit from—mandatory vaccination programs. One U.S. researcher spoke publicly about Merck’s aggressive marketing and its failure to fully disclose information about risks. Deliberate misrepresentation and fraud can also lead to erroneous or misleading claims (Attkisson, 2009; Bagla, 2013; Chamberlain, 2015).

Sometimes, errors are due to failures in how science is communicated. In 2010 headlines announced the dramatic discovery of bacteria that incorporated arsenic into their DNA. “Scientists said the results, if confirmed, would expand the notion of what life could be and where it could be” (Overbye, 2010a). The results could not be confirmed by others, however, and the bold announcement—ahead of publication in a scientific journal—soon dissolved (Overbye, 2010b). The funding agency had promoted a premature news conference to publicize a finding that had not yet really passed scientific muster. That, too, can be important for students to learn.

At the prestigious Indian Science Congress in 2015, one presentation described ancient Indian aviation technology. According to Vedic texts, it was claimed, pilots thousands of years ago flew from country to country, and planet to planet. Amazing, if true. The claims were denounced, of course, by other scientists. The speaker, Anand Bodas, was a retired head of a flight training facility. He had no background in history of science, nor even in the physics of flight. Expertise matters. That is another NOS dimension relevant to assessing scientific claims.

Finally, is nuclear power safe? The construction of the huge Kudankulam plant in Tamil Nadu has been a flashpoint for debate, especially in the wake of the 2011 Fukushima disaster in Japan. In May, 2014, six workers were severely burned and suffered injuries when a pipe burst. Despite such accidents and fines for negligence in violating operational guidelines, officials continue to maintain the plant is safe—in design, at least. But power and profit are at stake. Interest-laden judgments of evidence are open to question. Conflict of interest matters to scientific claims and in this case independent assessment seems to have been conspicuously missing. That makes any reliable conclusion problematic, at least.

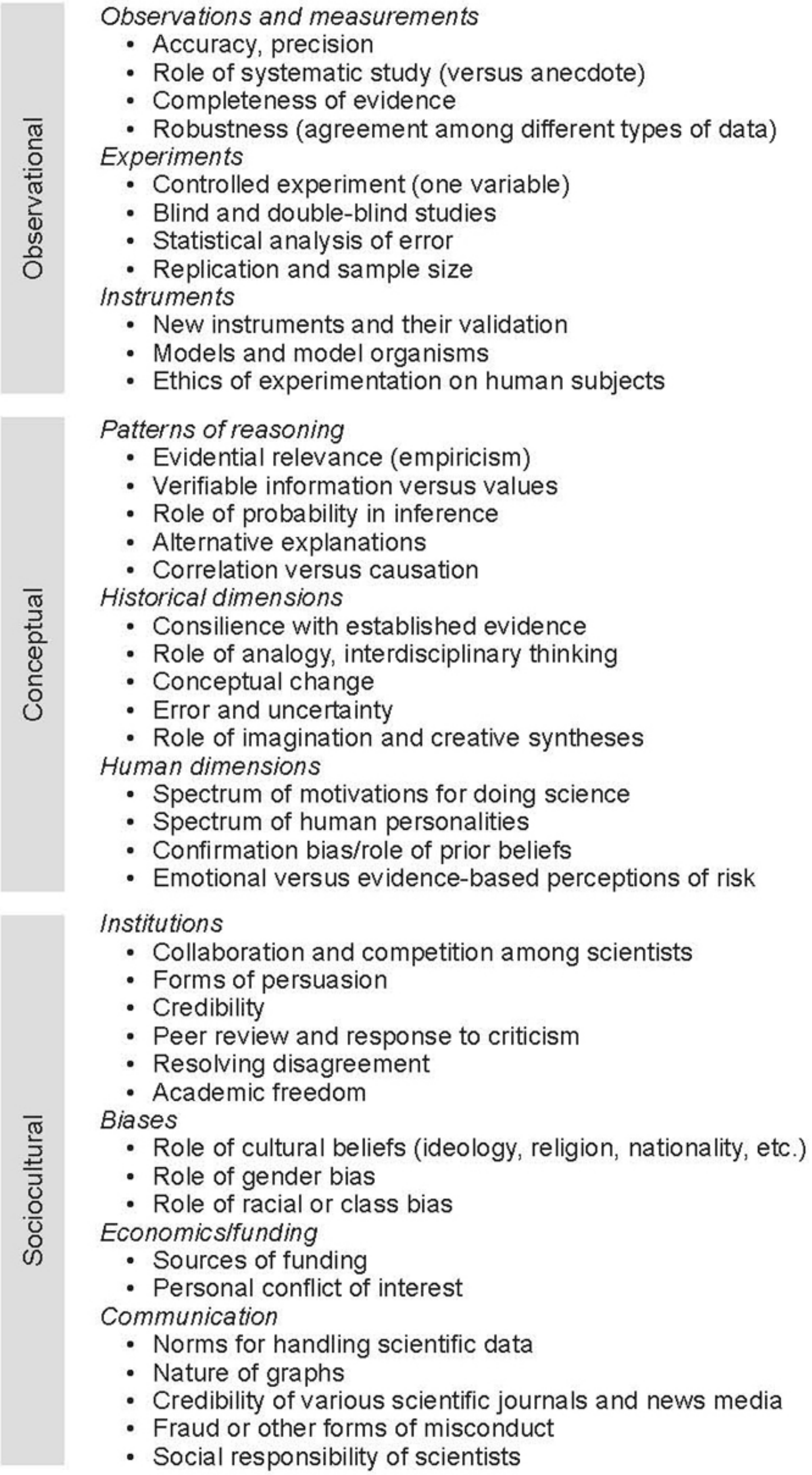
Scientific claims permeate our society. For example, do cell phones cause cancer? A search on YouTube will easily yield a disturbing video that shows cell phones popping popcorn (Lastfools, 2008). If they can do that to popcorn (one might wonder), what will they do to your brain? In Italy a worker sued his employer alleging that his brain cancer was caused by his cell phone use—a case that ultimately was heard by the Supreme Court (who, despite lack of any scientific consensus, decided in his favor in 2012; Owens, 2012). This context establishes the extraordinary reach of epistemic understanding that is needed: from test tubes to YouTube; from the lab bench to the judicial bench. As exemplified in the many actual cases from the news above, students need to learn about the entire process—from loose cables and contaminated samples through sample size and cultural bias, to fraud, expert testimony, and conflict of interest. Elsewhere I have called this view of NOS teaching about *Whole Science* (Allchin, 2013).

Whole Science embraces three broad categories of errors as well as the corresponding methods that tend to guard against them (Table 1). First, one may note observational epistemics. For example, when we use a microscope, how do we know what are we observing? Are the images real? Do we see through a microscope (Hacking, 1981)? Second, there are conceptual epistemics. For example, Linnaeus seems to have named mammals based on his personal conceptions of women and wet nursing (Schiebinger, 1993)—a case where cognitive perspectives inappropriately shaped scientific ideas. Third, there are the sociocultural dimensions of epistemics, involving epistemic dependence, trust, expertise, and communication networks. We see nature through a metaphorical social microscope (Allchin, 1999). These stages all link together. There is a grand chain of transformations from original observations and empirical evidence in a lab to the claims we consider in the context of personal and public decision-making (Latour, 1987). Epistemic analysis applies to each link in that chain. That, again, is Whole Science.

Adopting this synoptic view of how scientific knowledge develops (or how science works), one may articulate the individual factors along that epistemic route/social network, from test tubes to YouTube. This establishes an NOS inventory (Table 1). These are the teachable concepts for NOS.

An NOS inventory based on a Whole Science perspective differs markedly from the "consensus view" once common in discussions of teaching NOS (McComas & Olson, 1998). While the former view selected a few important principles, it developed in an *ad hoc* way, with little systematic reflection. There was never any clear, explicit benchmark — the relevance of interpreting socioscientific issues, for example — for deciding what to teach, what not to teach, and why. Here, assessing the reliability of claims, as they inform decision-making, is central.

The Whole Science view also differs from a focus on argumentation (Osborne et al., 2001). While analyzing arguments offers great benefit in terms of underscoring the importance of



Observational

Observations and measurements
- Accuracy, precision
- Role of systematic study (versus anecdote)
- Completeness of evidence
- Robustness (agreement among different types of data)

Experiments
- Controlled experiment (one variable)
- Blind and double-blind studies
- Statistical analysis of error
- Replication and sample size

Instruments
- New instruments and their validation
- Models and model organisms
- Ethics of experimentation on human subjects

Conceptual

Patterns of reasoning
- Evidential relevance (empiricism)
- Verifiable information versus values
- Role of probability in inference
- Alternative explanations
- Correlation versus causation

Historical dimensions
- Consilience with established evidence
- Role of analogy, interdisciplinary thinking
- Conceptual change
- Error and uncertainty
- Role of imagination and creative syntheses

Human dimensions
- Spectrum of motivations for doing science
- Spectrum of human personalities
- Confirmation bias/role of prior beliefs
- Emotional versus evidence-based perceptions of risk

Sociocultural

Institutions
- Collaboration and competition among scientists
- Forms of persuasion
- Credibility
- Peer review and response to criticism
- Resolving disagreement
- Academic freedom

Biases
- Role of cultural beliefs (ideology, religion, nationality, etc.)
- Role of gender bias
- Role of racial or class bias

Economics/funding
- Sources of funding
- Personal conflict of interest

Communication
- Norms for handling scientific data
- Nature of graphs
- Credibility of various scientific journals and news media
- Fraud or other forms of misconduct
- Social responsibility of scientists

Table 1. A partial inventory of dimensions of reliability in science: a Whole Science view.

justification, the analysis typically remains text-based. A Whole Science view also includes the challenges of measurement and interpreting observations and the very construction of evidence. It also addresses not just the argument, but the person presenting the argument — their expertise, credibility, and potential conflict of interest. The social context and the communication network matter very much in knowing precisely what has been omitted from the argument proper (such as honesty or reputation) but which may nonetheless be relevant in assessing the trustworthiness of a scientific claim.

Another prominent approach to NOS is to teach "scientific practices" (NGSS, 2013). Here, the emphasis is on inquiry — both teaching investigative skills and reflecting on them. While this is an integral part of science education, and can provide simple models about how knowledge is generated, it is critically limited in what it can convey in terms of interpreting the claims one might find in socioscientific controversies. School science activities are simply too limited to model the complexities found in society without additional depth from studying real scientists and real case studies. Relying too heavily on inquiry discounts the lessons of epistemic dependence.

Finally, one should note that a Whole Science perspective highlights science as it is concretely practiced. It does not pretend to present some imagined ideal norms as a substitute (Allchin, 2013, pp. 107-120). It aims to revel in real scientific achievements, as well as lapses, in an effort to learn from them.

HOW TO TEACH WHOLE SCIENCE/NOS

Socioscientific literacy and informed decision-making provides a guiding rationale for highlighting NOS in science education. And Whole Science provides a theoretical framework for knowing what concepts to teach and how to organize them. But the educational vision is still incomplete without concrete strategies for achieving this on a more practical level. What does good NOS education look like in the classroom? How does one teach Whole Science?

Educators now generally recognize three methods for teaching about NOS: student-based inquiry, contemporary cases and historical cases (Allchin, Andersen & Nielsen, 2014). Each has particular merits, and each has deficits (Table 2).

First, students may learn about science by doing it themselves, at least on a small scale. Active participation and the exercising of some autonomy obviously help personalize and strengthen the lessons. Students can learn especially the relevance of demonstrative evidence and the limited nature of models and explanations. Along the way, they learn skills for conducting their own simple investigations later in life. At the same time, such lessons are limited. Personal involvement also amplifies the role of emotions when experiments go "wrong," leaving teachers to manage feelings of failure. Also, the NOS features that students can learn are limited to those that can be modeled in the classroom. Lessons about funding, epistemic dependence and expertise, gender and cultural bias, for example—all critical to robust socioscientific literacy—are not available in a simplified school lab. Moreover, students are cognizant of the lack of depth. Having been enculturated to view science as monumental and impressive, they tend not to view their own modest activities as authentic science. More lessons are needed to connect their experience to real science.

Second, students can study contemporary SSI cases, in all their complexity. The vivid "here-now" relevance is not lost on students, who are eager to engage in something meaningful. And the cases reflect quite directly the very aim of socioscientific literacy. Unfortunately, contemporary controversies are also not resolved. They can underscore the importance of epistemic assessments and indicate where they are needed, but not teach what

Mode	Merits	Deficits
Contemporary case	• helps motivate engagement through authenticity and "here-now" relevance • can support understanding of cultural, political and economic contexts of science • can support understanding of how science and values relate • develops scientific literacy skills in analyzing SSI	• cannot be fully resolved, leaving uncertainty and incomplete NOS lessons • cannot exhibit details of process which are not yet public or are culturally obscured
Inquiry	• helps motivate engagement through personal involvement • fosters personal integration of lessons • supports understanding of constructed interpretations, models, forms of evidence, and model revision • develops experimental competences: framing hypotheses, designing investigations, handling data, evaluating results • relates nature of scientific knowledge to inquiry skills and methods • develops understanding of how scientific claims can be defended or criticized in contemporary SSI cases	• difficult to motivate all students, especially as a group • may be viewed as artificial exercise or school "game," not as genuine science • when investigations "fail," can prompt negative emotions, alienating student from NOS lessons • typically shuttered off from cultural, social, or political contexts • hard to model role of "chance," or contingency • requires substantive amounts of time and resources
Historical case	• helps motivate engagement through cultural and human contexts and through narrative format • can support understanding of long-scale and large-context NOS features: esp. conceptual change, and cultural/biographical/economic contexts of research problems and interpretive biases • can support understanding of investigative NOS: problem-posing, problem-solving, persuasion, debate • can support understanding of complexity of scientific practice, as well as historical contingency • supports analysis of process and product, since ultimate outcomes are known • when framed in inquiry mode, can develop scientific thinking skills—more efficiently than with hands-on inquiry • can foster understanding of error and revision—without risking emotions of personal failure	• may seem "old" and irrelevant • difficult or time-consuming for teachers to learn background or historical perspective • if text-based only, limits development of hands-on experimental competences • if rationally reconstructed only or presented as final-form content, does not support understanding of "science-in-the-making"

Table 2. Merits and deficits of different modes of teaching NOS (from Allchin, Andersen & Nielsen, 2014).

the guiding long-term principles are or should be. That is why they are still controversial. Much of the relevant information is not yet accessible to the public. In addition, the students' own political and ideological perspectives may shape perceptions and filter the intended lessons (already a demonstrated issue in the cases of evolution and climate change). Epistemic analysis is more easily learned from a more neutral vantage point, and with the benefit of retrospect.

That need for conceptual distance and epistemic closure is one compelling reason for turning to historical cases, the third mode of teaching NOS. At first, history may seem remote and irrelevant, buried in the past. But a good historical case begins with the cultural and human context that was once contemporary. The problems and questions inspire engagement and help profile and motivate the role of NOS analysis. As in contemporary cases, students adopt the perspective of uncertainty and science-in-the-making. As in student-based investigations, they participate in inquiry, not yet aware of the historical outcome. They share the problems with great scientists of the past and are challenged to solve them. Participating In the history virtually, students are free to fail, with no cost. The key difference from contemporary and student-based cases is that by continuing through the story, however complex, students eventually learn how the cases were resolved, and what epistemic principles were effective. This can be especially important for critical epistemic issues, such as gender or cultural bias. The NOS elements of epistemic concepts are constructed through active involvement in the issues, rather than learned passively through lecture. Accordingly, historical cases have a pivotal role in NOS education (Allchin, 2013, pp. 28-45). Ironically, perhaps, history may be the best guide for developing the tools to address contemporary socioscientific issues.

The use of history in the classroom brings with it certain challenges. First, there is a strong cultural tendency to render all science as heroic. For example, we are generally not accustomed to scientists making mistakes. But, of course, they do. That is part of the process of science. As prospective role models and characters in inspirational stories, great historical scientists are also often idealized. While these popular views may seem trivial, they easily lead to distorting the true nature of science. The imagery fosters misconceptions of a particular kind: *myth*-conceptions (Allchin, 2013, pp. 46-76). Students — and sometimes teachers themselves — need to "unlearn" some of those powerful prejudices about scientists of the past. Of course, good history in the classroom, rendering scientists in all their humanity and complexity is also the prospective solution.

Another common tendency is to reconstruct history as it *should* have been (ideally), not as it actually was (Allchin, 2013, pp. 77-106). For example, as in the case noted earlier, one may be tempted to generously interpret vague Vedic texts as documenting achievements that occurred only millennia later. One of the great virtues of turning to history is to learn how scientists indeed made their great achievements. Thus, trying to shoehorn their methods into one's personal view of how science is "supposed to" work does little in providing insight into how science truly works. The real history almost always turns out to be more fascinating and more informative than the imaginary or modified tales.

Finally, teachers often aim to simplify lessons, in an effort to make them more accessible or understandable to students (Allchin, 2013, pp. 121-132). When applied to history especially, this too can distort the nature of science. Of course, a students who experiences only a style of streamlined, oversimplified education will be wholly unprepared to deal with complex SSIs. Indeed, complexity is a typical hallmark of such contemporary controversies. In many cases, the science itself is unfinished. Uncertainty is another feature of science-in-the-making, as illustrated through history. Again, good history, well rendered and enriched by retrospect and discussion, is a way to approach the challenges of complexity and uncertainty.

Thus, as much as there is good reason to use historical cases and historical perspectives in teaching NOS, there are equally important ways *not* to teach history in science. One should be wary of heroic myth-conceptions. One should set aside "rational" reconstructions in favor of authentic narratives of discovery, with their unexpected twists and turns and a role for accident, or chance. Lastly, one should embrace complexity and uncertainty and show how scientists negotiated their way through it, rather than succumb to an oversimplified and misleading portrayal of how science works. Good history will ultimately prepare students for analyzing the reliability of scientific claims in personal and public policy contexts and thus for informed participation in discourse on contemporary debates.

Fortunately for teachers, numerous inquiry-style historical case studies are already available (http://shipseducation.net/modules; see also Allchin, 2012a, and 2013, pp. 249–252, for a list of further good exemplars). In addition, in an institutional context, there are new models for assessing student understanding of NOS, aligned with the aim of interpreting contemporary socioscientific issues (Allchin, 2011; 2013, pp. 152–62). In short, the tools for realizing the vision of scientific literacy are in place for those ready to pursue it in daily practice.

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