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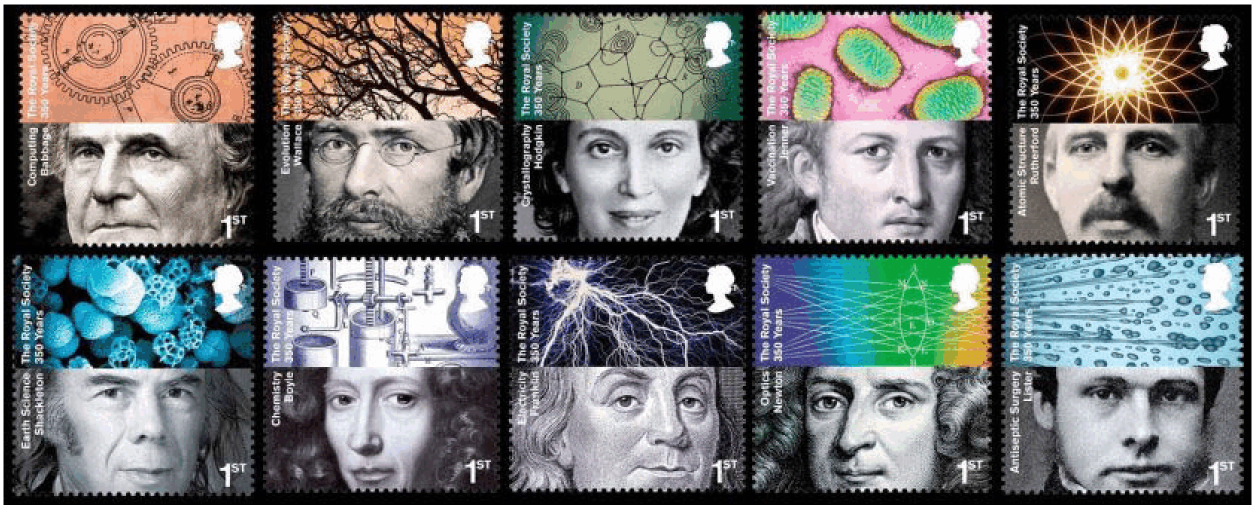

How Can the HPS Contribute to Contemporary U.S. Science Teaching

Report of Working Group 1

How Can History and Philosophy of Science Contribute to Understanding the Nature of Science for Scientific Literacy?

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WHERE DISCOVERIES BEGIN

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The conference on How Can the History and Philosophy of Science Contribute to Contemporary U.S. Science Teaching, was co-hosted by Boston University's School of Education and the Center for Philosophy and History of Science on December 7-8, 2012. It brought together historians, scientists, philosophers, and science educators to discuss and define a research agenda to evaluate the value and use of the history and philosophy of science in the classroom. The conference was sponsored by the National Science Foundation's Division of Research on Learning in Formal and Informal Settings under REESE Grant 1205273.

How Can History and Philosophy of Science Contribute to Understanding the Nature of Science for Scientific Literacy?

Mapping Research Needs

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ABSTRACT

We sketch the research now needed to understand more fully how history and philosophy of science can contribute to students' and pre-service teachers' understanding of the nature of science (NOS), in the context of scientifically literate citizenship. This includes research on effective NOS education, NOS and scientific reasoning skills, NOS and socioscientific decision making, and classroom practices.

History and philosophy of science (HPS) have long been advocated as important contributors to science education, particularly in developing an understanding of the nature of science (NOS) and thus a more functionally literate citizenry (Allchin 2013; Conant 1947; Hodson 2009; Nash 1951). We participated in a one-day workshop reviewing the history and visions of such efforts and, on the following day, considered the concrete prospects for exploring them more fully. This brief paper summarizes our collective perspective on the research now needed to help answer the question:

> *How can history and philosophy of science contribute to students' and pre-service teachers' understanding of the nature of science, in the context of scientifically literate citizenship?*

Our focus is limited. While acknowledging the potential virtues of HPS in other contexts, we do not consider here the role of HPS in teaching conceptual content more clearly, motivating the study of science or the pursuit of scientific careers, developing skills in scientific practice, addressing the ethical and other dimensions of socioscientific decision-making, or fostering an aesthetic appreciation of science and the natural world. Rather, our primary concern is, given what we already know, what research is most immediately needed to articulate and fully realize the value of HPS for teaching NOS in support of functional scientific literacy (Ryder, 2001)?

Our work is situated in current curriculum standards for teaching NOS. Recently the U.S. National Research Council's Board on Science Education recommended that all students:

> possess sufficient knowledge of science and engineering to engage in public discussions on related issues; [and] are careful consumers of scientific and technological information related to their everyday lives. (BOSE 2012, p.1)

Such national documents linking NOS and scientific literacy are found elsewhere, as well (American Association for the Advancement of Science 2009; Andersen 2008, p. 10; Evans & Jennings 2008; and OECD 2009, p. 128; among others). That is, science education aims to prepare students (among other goals) to engage in socioscientific issues (SSIs) (Zeidler et al. 2005; Ekborg, Ideland, & Malmberg 2009; Zeidler, Applebaum, & Sadler 2011).

In 2010, the National Science Foundation sponsored a workshop on "the process of measuring and reporting public knowledge of science" (Toumey et al. 2010, p. 1). They considered how to characterize "how the public examines evidence, reasons about evidence, and uses evidence to make judgments, either as individuals or as communities" (p.1) – what they characterized as "*SSCC*, or 'science in the service of citizens and consumers' "(p. 7). The NSF Workshop identified three broad categories of scientific knowledge: factual knowledge, processes & standards, and institutional knowledge (p. 6). In other words, students need to have, first, some basic knowledge of scientific concepts. (The new Next Generation Science

Standards, or NGSS, in the U.S. address these as "core concepts" and "cross-cutting concepts"; NRC 2013.) Second, they need to understand how science works, how scientists reason, and the benchmarks of naturalistic explanations and empirical evidence that guide those practices (NGSS's "scientific practices"). Third, they need to have some understanding of the sociocultural contexts of science, such as funding and the nature of scientific expertise. The role of HPS in the second and third components of SSCC are addressed here (the first component, science content, was addressed by another working group).

In our discussion, we characterize this body of student understanding in terms of the "nature of science" (NOS), adopting a phrase that has been prevalent in education for at least half a century (Lederman, Wade, & Bell 1998). This corresponds, crudely, to the insights from history of science and philosophy of science and allied disciplines in Science Studies. We acknowledge that the definition or characterization of NOS itself is widely variable and sometimes contentious (Hodson 2009). Our posture here is inclusive, with the aim of incorporating as many useful insights and disciplinary connections as may prove valuable in supporting learning SSCC. As a result, our considerations are meant to include such characterizations as: the "nature of science" (NOS) (AAAS 1989, 2009; NRC 1996; McComas 1998; Lederman 2007), "scientific practices" (BOSE, 2012), "ideas about science" (Evans & Jennings 2008), "identity and methods" of the discipline (Andersen 2008), "science as a way of knowing" (Moore 1999; OECD 2009) or "how science works" (Understanding Science 2012). These are all meant to be included by our use of "nature of science," or NOS, which we regard as implicitly informed by history and philosophy of science. At the same time, we distinguish NOS from a more formal academic or aesthetic appreciation of the philosophy of science for its own sake (for example, Boyd, Gaspar, & Trout 1991; or Okasha 2002). The context of SSCC underscores a particular subset of HPS knowledge: what is relevant to informing social and personal decision-making, or *functional* NOS (Ryder 2001).

We also want to be inclusive in our conceptions of science and science education. That is, we acknowledge that in discussing science, we intend to refer more broadly to science, technology, engineering and mathematics (STEM) education.

Our reflections notably lead us to consider the relevant contributions from well beyond the scholarly work of historians and philosophers of science (HPS). Foremost, we see value for science education in the work of sociologists of science (Kelly, Carlsen & Cunningham 1993; Zemplén 2009). There is also significant and relevant scholarly work in anthropology and ethnography of science, public understanding of science, science communication, cognitive studies of science, cultural studies of science, rhetorical studies, economics of science, and feminist and Marxist critiques—all known collectively under the banner of Science Studies (Hackett et al. 2007). We adopt the label "HPS+" to indicate this broader extension of expertise *about* how science works, which we regard as critical to addressing scientific literacy fully and completely (Allchin 2014).

Our orientation to NOS in the context of scientific literacy, SSIs and SSCC offers a potentially transformative (although also familiar) standard for discussing the role of HPS within science education. Most notably, perhaps, we see the need for science educators to explicitly address public perceptions of science, science communication, and scientific claims—both genuine and bogus—in the public realm, as much as the internal working of the scientific community itself. Such a broader focus enlists HPS+ understanding and contributions regarding such topics as: the sources of funding science and possible conflicts of interest in scientific claims in commerce and public discourse, science journalism, the nature of epistemic trust and scientific expertise, and other aspects of the cultural contexts of science and its institutional structure. Ironically perhaps, such considerations are absent from the new Next Generation Science Standards in the U.S., although ostensibly based on the aims of the NRC's *Framework for K-12 Science Education* (BOSE 2012), cited above.

With this background, we may now explore the status of contributions from HPS+ to NOS learning: in particular, what science education researchers have yet to examine in detail. We survey the challenge in 4 sections. Specific research questions appear indented, in bold italics, and preceded by an arrow (▶). These questions reflect the core of our work. The text serves largely to frame and contextualize and, in a sense, provide a rationale for, those questions.

EFFECTIVE NOS EDUCATION

A substantial body of research now documents many features of effective NOS education. A recent review summarized a large sampling of that research, as reported in 105 studies from 1991 to 2010 (Deng et al. 2011). Of particular interest to our report are a dozen cases involving student engagement with historical cases – following great scientists in their work, or perhaps participating in the historical science vicariously, and reflecting on the process of discovery or debate. Eight classroom interventions showed a positive outcome; however, four studies were one week or less. To these one may add several other studies that have demonstrated NOS learning through historical cases: Clough, Herman and Smith (2011); Faria, Pereira and Chagas (2010); Howe and Rudge (2005); Kruse and Wilcox (2011); Lin and Chen (2002); and Rudge, Cassidy, Fulford and Howe (2012). Indeed, a positive role for historical cases in secondary science education was documented as early as one-half century ago by Leo Klopfer (Klopfer & Cooley 1963). Properly presented, history *can* be a vehicle for learning NOS.

Such lessons are not automatic, however. For example, students who take a history of science course do not thereby enhance their NOS understanding (Abd-El-Khalick & Lederman 2000). As exemplified amply in many studies, NOS learning (perhaps like all learning) must be explicit and involve student reflection about the relevant lessons (Seker & Walsh 2005; Clough 2006; Peters & Kitsantas 2010). Unguided, students may filter their readings of history based on their NOS preconceptions. For example, Tao (2003) noted:

> When studying the science stories, many students selectively attend to certain aspects of the stories that appear to confirm their inadequate views; they are unaware of the overall theme of the stories as intended by the instruction. (p. 168)

Thus, teachers should also actively scaffold students' understandings. (p. 169). For effective learning, someone with NOS knowledge must monitor and guide the NOS reflection by students.

In addition, the nature of science is not one single concept. It encompasses many features or dimensions. NOS lessons are specific. As Rudge et al. (2012) noted, students learn just what a historical story illustrates. Lessons learned on one NOS feature do not necessarily transfer to other NOS features.

The specificity of NOS lessons helps bring into relief a set of unanswered questions important for supporting classroom practice. Namely, educational research has documented that NOS can be taught through several approaches or contexts—student-based inquiry (investigatory experiences), historical cases, contemporary cases, and research apprenticeships. We now need to articulate which aspects of NOS are highlighted in each respective approach (and which not) (Allchin, Andersen and Nielsen, in press):

- ***What are the specific merits and deficits of each NOS instructional approach —student-based investigatory experiences, historical cases, contemporary cases, and research apprenticeships?***

While the overall effectiveness of approaches to NOS instruction are known, more details about the classroom context of each are needed, including consequences for such practical instructional considerations as amount of teacher background needed, teacher preparation time, classroom time, and classroom resources or expenses.

Further, teachers will need to combine the various approaches:

- ***How should teachers integrate the various complementary approaches to NOS instruction, to ensure complete and unified NOS lessons?***

For example, what is the role of highlighting similar versus contrasting cases? Also, NOS perspectives may be taught across a range of examples, from highly contextualized, authentic case studies to quite decontextualized student-based activities (such as "black box" inquiries or mock-forensic scenarios) (Clough 2006). Can research inform how to integrate these approaches? In addition:

- ***What are appropriate ways to integrate history with inquiry?***

History provides the details of how scientists negotiated their way to a discovery. Inquiry provides a context, motivation and framework for student learning. Integrating these seems fruitful, but also challenging given the apparent tension between "science-in-the-making" (historical perspective focusing on process) and "ready-made science" (modern perspective focusing on scientific content as a product) (Flower 1995, HIPST 2008, Latour 1987). How can students be guided through a blind and open-ended process, while leading them unfailingly to a desired endpoint, or along a known historical pathway (Henke & Höttecke 2013)? At the same time, how can we help students appreciate that retrospect tends to prune away ambiguity or uncertainty in our perceptions of the process of science? By highlighting the importance of only certain information, historical accounts may not offer a faithful rendering of the somewhat blind forward-looking process.

Indeed, further research is needed to articulate more precisely why or how historical cases are effective, allowing for the assembly of more effective cases. For example, is it their narrative format, the human or cultural contexts, heroic role models, the scientists' struggles, a broad scope of time, the cultural distance (for showing cultural influences), the resolution of controversial episodes, etc.?

- ***What features of historical case studies promote particular NOS understandings?***

History may be presented in a variety of formats—from short vignettes to extended narratives to multi-week units structured on historical development (McComas 2010). Case stories may be read, presented in videos or films, or narrated and interrupted by questions. They may focus on ideas, individuals, or controversies. They may involve role-play, simulated debates, or group problem-solving scenarios. The pedagogical role of each of these variants is not yet known, but seems important to enhancing the effectiveness of NOS lessons based on history:

- ***What formats of historical cases promote particular NOS understandings, with what other practical classroom consequences?***

In summary, more details about the use of history—beyond its mere effectiveness—are needed to guide the development of curriculum resources and how teachers may use them most effectively.

New research on NOS lessons will require new modes of assessment. There has been a long history of NOS-related assessment instruments, many of them limited in effectiveness (Lederman, Wade, & Bell 1998). For the past decade, most NOS research has relied on the VNOS instrument (Lederman et al. 2002) or variants, such as SUSSI (Liang et al. 2008). However, their limitations have become clearer in recent years and they have been subject to increasing criticism (Rudolph 2000; Elby & Hammer 2001; Settlage, Southerland, Johnston, & Sowell 2005; Chen 2006; Clough 2007; Clough & Olson 2008; Ford 2008; van Eijck, Hsu, & Roth 2009; Rudge & Howe 2009; Deng, Chen, Tsai, & Tsai 2011; van Dijk 2011; Rudge et al. 2012). No clear alternative is yet accepted, although a recent proposal, KNOWS, offers one prospective prototype based on a "well informed analysis" of the NOS in contemporary SSIs (Allchin 2011, 2012b).

- ***What new methods might accurately assess a variety of NOS understandings in a variety of contexts, providing fine-scaled measurements suitable to the research profiled above?***
- ***How might we assess effective teaching besides through pre- and post-testing?***

In other words, new assessment methodologies for NOS educational research seem urgently needed.

Once available, the new modes of assessment will facilitate investigation of a large range of questions about the relationship of learning different aspects of scientific literacy, as characterized broadly above. For example, earlier research indicated that contextualizing scientific concepts in either history or contemporary cases does not appreciably improve student understanding of the conceptual content. (Neither do they diminish such understanding, while using parallel time constraints.) However, such contextualization seems to yield significant gains in attitudes, interest, and other motivational factors (on *Project Physics*, see Walberg & Ahlgren 1973; on *Chemistry in Context*, see Nakhleh 1991; Nakhleh et al. 1995; on *Mindworks*, see Becker 2001). Case-based learning, in general, also tends to greatly reduce if not virtually eliminate the gender and ethnic minority gaps often found in science education achievement. But corresponding research has not been done on NOS understandings:

- ***How might various NOS understandings promote deeper scientific conceptual understandings?***

- ***How might various NOS understandings promote improved (or perhaps diminished) attitudes toward science, motivations to learn, or interests in science careers?***

Similarly:

- ***Are there important correlations among different NOS understandings?***

- ***How might various NOS understandings improve skills in scientific practices? How might stronger performance in scientific practices enhance NOS understanding?***

Research is already beginning to indicate a relationship to NOS knowledge from two important scientific practices: modeling and argumentation. Student work on argumentation seems to enhance some NOS understanding (reviewed by Deng et al. 2011, pp. 975-982, 991) and work on modeling, when accompanied by the requisite student reflection, seems to improve NOS understanding on selected features (Duschl & Grandy 2008; Duschl, Schweingruber, & Shouse 2007; Lehrer, Schauble, & Lucas 2008; Smith, Maclin, Houghton & Hennessey 2000). However, the reverse relationships have yet to be fully explored (Khishfe 2012b). Given the central role of argumentation in SSIs, this one relationship seems to deserve special attention.

The importance of scientific literacy, or SSCC, also underscores the critical importance of establishing relationships which have been long assumed, but not properly investigated or confirmed:

▶ ***In what ways is NOS understanding measurably linked to better personal decision-making? What particular NOS understandings are most prominent?***

▶ ***In what ways is NOS understanding measurably linked to more informed social decision making or discourse on SSIs? What particular NOS understandings are most prominent?***

Namely, educators have generally assumed that better NOS understanding contributes directly to abilities in SSI interpretations and discourse. But this is currently far from established empirically (Zeidler, Walker, Ackett, & Simmons 2002; Sadler & Zeidler 2005; Khishfe 2012a). In particular, basic human perceptual, attentional and cognitive heuristics seem to generate formidable challenges (Grotzer, Miller & Lincoln 2012). Finally:

▶ ***In what ways do students transfer NOS knowledge from historical cases to the contemporary cases they are intended to inform?***

Some anecdotal but nonetheless quite vivid reports suggest that students do spontaneously make such connections. However, these reports also indicate that the transfer is done analogically, from case to case, rather than based on generalized or abstract NOS principles developed from engagement with earlier cases. Understanding more fully the nature of knowledge transfer from history to modern applications is critical to designing the appropriate occasions for HPS+-based student learning in the classroom (Kolstø 2008).

NOS & Scientific Reasoning Skills

A second major concern is the development of scientific reasoning skills as they apply to personal life or socioscientific issues. That is, students should be prepared to conduct simple empirical investigations on their own and, on occasions, evaluate the evidence in policy issues or personal choices that are informed by science (say, about nutrition, health, or the environmental impact of household products). Such skills are highlighted in the NGSS as “scientific practices,” and their concrete specification there helps to clarify such skills for teachers: posing investigative questions, building models, interpreting data, arguing from evidence, etc. (BOSE 2012, p. 3, 41-82). Often, these skills involve appreciating the larger perspectives of empiricism and methodological naturalism that help to distinguish science as a way of knowing, in contrast to other ways of thinking (and echoing again the NSF workshop’s second component of SSCC).

At the same time (due to limited time), we did not discuss in depth the role of HPS+ in the education of reasoning skills. However, one can hardly dismiss such connections and their potentials. Much of the initial challenge, here, lies in the cognitive sciences, in articulating what these skills are and how individuals learn them. Many cognitive scientists have already turned to history and, say, fine-scaled analysis of laboratory notebooks of renowned scientists, to identify and characterize these reasoning skills (Darden 1992; Holmes 1991-1993; Nersessian 2008; Thagard 2012; Tweney 2001). Such work has ongoing value.

HPS+ also seems to offer a wealth of information on how scientists engage in social discourse towards solving problems and resolving disagreement collectively, a potentially fruitful source for modeling similar processes in the classroom (Finkel 1992; Kelly 2011; Kelly, McDonald, & Wickman 2012; Piliouras, Siakas, & Seroglou, 2011).

The other major opportunity for using history is to help profile exemplary scientific reasoning in the classroom and nurture its development among students. Echoing the role of historical cases noted above, historical cases can model fruitful reasoning skills, as well as provide occasions for students to practice such skills in concrete and sometimes complex authentic scenarios. Again, work in developing such curricular material is already underway (for example, Hagen, Allchin & Singer 1996; Allchin 2012a; Höttecke, Henke, & Rieß 2012). At the same time, the reasoning from history can also be reconstructed in ways that do not reflect authentic science and thus do not promote the desired learning aims (Allchin 2013, pp. 77-92). Still, the use of historical cases studies, when framed properly, seems to help foster development of scientific reasoning skills and we should continue to pursue their potential.

NOS & Socioscientific Decision-making

Research to date on NOS education and on applying history to science education seems to have remained relatively remote from SSI applications, even while all these elements have remained prominently together in major policy documents on science education standards and reform (cited above). Some studies have certainly focused on *applying* NOS to SSIs, *learning* NOS through SSIs or other contemporary cases (Kolstø et al. 2006; Wong et al. 2007), and *assessing* NOS through contemporary news accounts (Allchin 2011; Ford 2008; Glynn & Muth 1994; Korpan, Bisanz, & Bisanz 1997; Murcia & Schibeci 1999; Norris & Phillips 1994; Norris, Phillips, & Korpan 2003; and Philips & Norris 1999). But the role of SSIs or contemporary science in the news seems to have had little explicit role in helping to shape how NOS is fundamentally characterized (Sadler, Chambers, & Zeidler 2004), especially in NOS assessment instruments, which might well mirror authentic contexts. This significant lacuna opens a third category of needed research on how NOS relates to socioscientific decision making. First:

- ***Articulate more clearly and concretely, through an enriched HPS+ analysis, the inventory of NOS knowledge, analytical skills, and competences that shape "well informed" engagement in discourse or decision-making on socioscientific issues.***

One such study was conducted by Ryder (2001). He surveyed 31 contemporary cases studied by sociologists of science and catalogued the broad understanding needed by citizens to interpret them. Other models for such an analysis include Kolstø (2001) and Allchin (2012c). This seems a first step in reconnecting the extensive educational research on "nature of science" and "scientific inquiry" with the ultimate aim of informing concrete engagement with

SSIs. Indeed, this strategy seems to provide an empirical benchmark for how to characterize "nature of science," which has exhibited a history of sometimes contentious debate.

Perhaps the central concern of citizens and consumers addressing SSIs is the trustworthiness, or reliability, of scientific claims. In the context of SSCC, the central emphasis of NOS education may thus shift from the current focus on explanation and theory-building (or modeling) to credibility and reliability. This is a potentially transformative reorientation. For example, the context of SSIs foster a shift from *acknowledging that* scientific knowledge *in general* is tentative (or subject to conceptual change) to *interpreting how* any *particular* scientific claim may be subject to error or reflect significant changes in evidence. Similarly, it shifts the focus from the empirical nature of evidence or some abstract nature of experiment to the ultimate soundness of arguments that build upon any such foundation. There has already been a significant increase in science educational research on the relationship of argumentation and NOS understanding (Osborne 2010; Deng et al. 2011).

As noted in the first section above, an SSI analysis underscores the third component identified by the NSF Workshop on science indicators: the institutional and sociocultural dimensions of science. This notably includes understanding how knowledge from the scientific community is reframed and sometimes transformed when presented in public forums. It also includes how citizens or consumers may encounter claims portrayed as "scientific" but lacking credibility among expert scientists (Rampton & Stauber 2002). That is, understanding scientific journalism is significant to NOS in a SSCC context (McClune & Jarman 2010), as is understanding science in the Media, on the Internet, in advertising, or in other cultural settings. In addition, citizens and consumers are not always equipped to assess the highly technical and specialized evidence in modern SSIs on their own. They rely on other experts. So understanding the nature of scientific expertise and credibility is equally important (Norris 1995; Gaon & Norris 2001). All these factors, relevant to the nature of science in a *cultural* realm, extend well beyond knowledge of scientific concepts, or even the scientific arguments and their corresponding evidence, when they are available. The role of SSCC thus underscores the importance of *epistemic analysis*, or assessing reliability based on the context of the research and the testimony:

- ▶ ***In what ways does epistemic analysis differ from evaluation of evidence-based arguments?***

Another dimension of individuals engaging SSIs is not merely "consuming" science, but actively engaging in discourse with researchers or other experts. Here, the goal of NOS understanding would be to foster dialogic skills:

- ▶ ***How do we teach abilities for effective dialogue between non-expert citizens and scientific experts, such as posing well-framed questions about relevant evidence or arguments?***

These dimensions of SSCC, in contrast to conventional approaches to HPS in science education, underscore the importance to scientific literacy of understanding the institutional and cultural contexts of science. Namely, they highlight the "+" in our designation of HPS+.

Addressing the dimensions of NOS that are relevant in a broader cultural context (as specified in the prospective inventory profiled above) cascades through all the questions raised in earlier sections—about the relationships of different NOS understandings, about the relative roles of contemporary, historical, and student case studies, and so forth. Not the least of the new challenges is framing student evaluations that capture the role of expanded NOS in scientific literacy:

▶ ***How can we evaluate NOS knowledge and competences in the situated or authentic contexts of SSIs?***

Such forms of evaluation may be oriented to student achievements or project work, not necessarily mass-testing. Still, there seems a pressing need to address the high-stakes testing common in today's culture of accountability (Allchin 2011; Clough & Olson 2008). What will "the test" look like for NOS that informs scientific literacy, in the sense of SSCC (for one prospective example, see Gormally, Brickman & Lutz 2012)?

Again, an expanded HPS+ focus for SSCC is potentially transformative: establishing an empirical benchmark for how to characterize functional "nature of science," shifting emphasis from explanation to reliability and from simple argumentation to epistemic analysis, and framing new forms of authentic assessment. In all these ways HPS+ can clarify what competences students need to learn, while also profiling authentic examples from which to learn them (Kolstø, 2008).

NOS IN CLASSROOM PRACTICE

Reflections on HPS+ in the service of scientific literacy also include the perspective of teachers and questions relevant to classroom practice. HPS+ can inform not only *what* is to be learned, but also *how*. HPS+ can potentially contribute to teachers' practices, not just the student curriculum. For example:

▶ ***What are the teacher's skills, besides basic understanding of NOS, for scaffolding and facilitating NOS lessons?***

This might include research on how teachers should pose questions or interact with students to effectively promote NOS understandings. For example, as noted above, how should teachers optimally integrate different examples of scientific investigations—historical and contemporary, authentic and scaffolded, contextualized and decontextualized?

Research might well inform the construction of particular curricular material from historical and contemporary cases (Allchin 2012a; Howe 2009; Metz et al. 2007; Wong et al. 2008):

▶ ***What general rules might guide the construction of case studies from history?***

Criteria might well include practical considerations. What is age-appropriate? To what degree can one adapt the history for a classroom setting without undermining the ultimate NOS lessons (Allchin 2013, pp. 77-106)? How much additional teacher background knowledge can be required? Other practical considerations arise:

▶ ***If the NOS lessons themselves are explicit, does it matter whether the history is explicit or implicit (merely guiding the structure of the teacher's lesson)?***

▶ ***Should NOS lessons be different for those likely to continue in careers in research versus those that are not?***

▶ ***Should the variations of dominant methods in different scientific disciplines be emphasized or should commonalities be stressed?***

▶ ***How do teachers promote NOS understanding that is "active" rather than "passive," that is well integrated into beliefs and values that guide real-life decisions, choices, and actions? Namely, how does one instill a critical stance or "skeptical attitude" towards scientific claims?***

Ultimately, the educational research needs to inform classroom practice, not just academic educational theory.

Finally, a thread of current research is beginning to profile appropriate sequences of NOS lessons that can guide long-term learning:

▶ ***Which NOS ideas should be learned first and which should follow (i.e., learning progressions)?***

While such research is already underway (AAAS 2001-2004; Schwarz et al. 2009; Allchin 2012c, pp. 916-919), it needs to continue, to help guide practicing teachers in the classroom.

SUMMARY

Given the high profile of nature of science and SSCC in curriculum standards internationally, there seems to be, ironically, a corresponding deficit of attention among science educators to NOS knowledge *in its intended contextual role*. To begin, most notably, the common characterizations of NOS do not seem well aligned with the concrete needs of citizens or consumers in commonplace matters informed by science. As a fruitful beginning, more empirical analysis of actual SSI cases will help establish a fuller and more accurate inventory of the relevant NOS concepts, skills, and behavioral dispositions. Indeed, some of the common assumptions—such as regarding understanding of scientific argumentation as enabling non-experts to make expert judgments themselves, or expecting NOS issues to be addressed in primarily rational terms—seem to conflict with existing cognitive and sociological studies on public understanding of science. Further studies should help resolve these current tensions in relating NOS understanding to SSCC contexts or applications. Second, new research will depend on more fine-grained analysis—of NOS outcomes and of the dimensions of historical classroom lessons. This new level of research will require new methods or instruments for assessing NOS knowledge and competences in context and at a finer scale of resolution. Third, sociological and cultural studies of science, in particular, need to more fully inform educational perspectives on contextualized NOS. Fourth, the research findings to date need to be transformed into workable solutions for classroom practice, leading to further questions about how to write effective cases studies or lessons, prepare teachers, and assess student performance. We hope our list of questions—on effective NOS education, NOS and scientific reasoning, NOS and socioscientific decision making, and classroom practices—will help motivate and guide the next phase of NOS research and foster more scientifically literate citizenship.

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