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Toward Clarity on Whole Science and KNOWS

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I am pleased to have an opportunity to clarify my proposals for teaching Whole Science and assessing knowledge of the nature of science through seeking a well-informed analysis of case studies in the news (Allchin, 2011; assumed in page references below). In this, I echoed similar earlier proposals by Norris and Phillips (1994), Glynn and Muth (1994), Korpan, Bisanz, Bisanz and Henderson (1997), Murcia and Schibeci (1999), Philips and Norris (1999), Norris, Phillips, and Korpan (2003), and Ford (2008). I hope to address here the concerns of Schwartz, Lederman, and Abd-El-Khalick (2012) and to profile where they have misrepresented published comments, lest others be misled.

My purpose, again, was to "profile . . . a prospective method for assessing nature of science (NOS) knowledge, as an alternative to VNOS and similar approaches." A major objective was to address the widely adopted goal of *authentic assessment* (pp. 520, 529) (National Research Council, 1996, Chap. 5; Newmann, 1996; Newmann, Bryk, & Nagaoka, 2001; Shannon, 1999, Chap. 3; also see Wiggins, 1990). That is, educators ultimately want to know how students understand NOS and apply their knowledge in authentic, common-life contexts. The U.S. National Research Council's Board on Science Education (BOSE) recently reaffirmed this goal:

> to ensure that by the end of 12th grade, *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 2011, p. ES-1)

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This aim parallels similar policy statements by the American Association for the Advancement of Science (2009) and OECD (2009). Thus, in opening my paper, I cited several benchmark examples: Climategate, revised mammogram recommendations, autism and the measles vaccine, and facilitated communication of coma patients. One could add from just the past year controversies over estimating fish populations in the seas off New England (Goodnough, 2011; Rosenberg, 2011); new recommendations on prostate cancer screening (Brownlee & Lenzer, 2011; Harris, 2011); debates about the safety of fracking as a means of oil and gas extraction (Associated Press, 2011; Griswold, 2011); or the retraction of a much publicized study linking chronic fatigue syndrome to a virus (Alberts, 2011; Cohen & Esnerink, 2011; Ritter, 2012). The crux of these socioscientific issues is not evaluating scientific evidence directly, but interpreting the nature of the claims as purported scientific knowledge. They entail practical, concrete epistemic analysis. For example, how does one interpret changes in medical consensus? What is the nature of uncertainty in sampling wild fish populations? Is systematic scientific study or anecdotal local knowledge more reliable? In what ways might economic context bias industry claims about environmental safety or health of fracking methods? What is the nature of the credibility of various sources on such scientific information? What is the nature of scientific error? Citizens or consumers may need to assess the reliability of the claims, but to do so they must understand the epistemic structure of scientific practice (*not* just the raw evidence or arguments). Such cases are central to the established goal of scientific/NOS literacy. The questions they raise seem utmost for considering appropriate assessment formats, as well as the characterizations of NOS on which they are based.

In their spirited defense of VNOS and VOSI, Schwartz et al. (2012) fail to address the challenges of authentic assessment or of contextual performance-based assessment. It is telling, I think, that they do not cite any educational research documenting a link between results on VNOS (or VOSI) and either the ability to engage in public discussion on socioscientific issues or the ability to exhibit care (or critical NOS acumen) in assessing scientific information related to our everyday lives. I know of no such findings. Without such research, claims about the relevance of VNOS or VOSI to practical scientific literacy must remain tenuous and peripheral (van Dijk, 2011).

Authenticity also relates closely to two other major elements in my discussion: the role of assessing student competence and characterizing NOS in terms of all the dimensions that prove relevant in socioscientific issues, namely, Whole Science. By disregarding these important links as well, Schwartz et al. misconstrue my proposals.

In aiming “toward promoting discussion on how to effectively assess practical, culturally functional knowledge of NOS,” (p. 518) I considered previous assessments, chiefly to explore the space for alternatives. Schwartz et al. seem keenly concerned about perceived criticisms of VNOS. Any such comments, however, I regard as secondary. Readers who are interested in detailed and well-documented criticism of the relevant deficits of VNOS may consult Rudolph (2000), Elby and Hammer (2001); Settlage, Southerland, Johnston, and Sowell (2005), Chen (2006), Clough (2007), Clough and Olson (2008); Ford (2008); van Eijck, Hsu, and Roth (2009); Rudge and Howe (2009, in press); Deng, Chen, Tsai, and Tsai (2011); and van Dijk (2011). These suffice, I think, without further comment from me, to warrant a search for alternatives. In their defense of VNOS as the exclusive valid instrument, however, Schwartz et al. also raise several concerns relevant to understanding KNOWS (Knowledge of the Nature of Whole Science). Often I agree with their views. Yet by mistaking my claims, their criticisms are generally misplaced. Addressing their mischaracterizations will help clarify how KNOWS offers an important alternative.

1. *Is NOS a form of knowledge and/or a skill?*

Knowledge of NOS is a form a knowledge. Here we all agree.[1]

Where we differ—and significantly so—is on how to *assess* that knowledge. As noted above, I respect the benchmark of authentic assessment. As expressed in the U.S. National Research Council's *Knowing What Students Know: The Science and Design of Educational Assessment,* knowledge should be interpreted *functionally*:

> Competence, not knowledge per se, is the target (Pellegrino, Chudowsky, & Glaser, 2001, pp. 6, 8)

Competence is expressed through KNOWS in the form of a "*well-informed analysis*." Such an analysis is not possible without foundational knowledge. But the knowledge alone, expressed in a declarative or even explanatory way, is not sufficient (Ford, 2008; van Dijk, 2011). It is not as important to demonstrate that one *knows that* science is influenced by its social and cultural milieu as to demonstrate that one *can discern how these influences may be expressed* in any particular case encountered in one's daily life (Rudge & Howe, 2009). Alleging that global warming is a political conspiracy is quite different from analyzing the concrete political roots of climate change critics (Oreskes & Conway, 2010).

A few concrete examples may help illustrate further the essential role of competences. Consider this letter to the editor of a large city newspaper:

> Perhaps the wisest science teacher I know told his class that science proves nothing true; it can only prove things false. Until something is proven false, we can only assume it to be true until further notice. Science has proven wrong in the past. Remember Pluto? When I was in primary school, everyone knew it was a planet. Now, kids are taught that it's not. Science is constantly updating itself, and things that we knew for certain 20, 50, 100 years ago will eventually be refuted. (Juel, 2011)

Ironically, this was presented to justify taking issue with Richard Dawkin's published comment that "Evolution is a fact, as securely established as any in science." Namely, since all science is tentative, one is entitled to dismiss evolution, too. Consider next another letter:

> Medical personnel and journalists are scratching their heads wondering why parents don't believe the experts when they say vaccines don't cause autism. For insight into this skepticism, just turn the newspaper page to the article "Further study of food dyes is urged." For years, experts have assured us that there is no link between food dye and childhood hyperactivity, but now the FDA says that "hyperactivity and other behavioral problems may be exacerbated by food dyes." (Johnson, 2011)

Ironically, the single study that might have supported this reader's views had itself been prominently retracted. Both these individuals express the basic NOS "knowledge" that scientific knowledge is tentative and even include an explanation and an example. But their NOS knowledge is surely superficial and misapplied. It is this type of particular and contextual application of NOS knowledge—a competence—that is relevant to scientific

[1] This is reflected prominently in the title of my paper and in the name for my assessment: *Knowledge* of the Nature of Whole Science (p. 531). Indeed, I further noted that "NOS knowledge has both breadth and depth (completeness and proficiency)" (p. 524). A reminder appears in the running head at the top of each page. Schwartz et al.'s assertion that instead I view "NOS as a set of skills"—especially *as opposed to* knowledge—is a stark misreading of my text.

literacy. *In the context of assessment*, then, functional NOS knowledge may be properly *demonstrated* through an *analytical skill* (pp. 521, 522, 527, 528, 529, 534, 535), with emphasis on the keyword "analytical" (Rudge & Howe, in press). The letter writers may have general NOS knowledge that science is tentative, but they do not exhibit NOS competence, as reflected in a *well-informed analysis*.

The competences that KNOWS addresses concern the nature of scientific knowledge and scientific practice, or "how science works" to yield reliable claims. They are decidedly *not* skills in scientific inquiry.[2] One prototype KNOWS question asks students to analyze several articles on the new mammogram recommendations issued in late 2009. Students are *not* asked (in the mode of inquiry) to conduct such research themselves, nor to conceive such research. Nor are they asked to evaluate the evidence themselves, another inquiry skill. Indeed, no one expects the typical citizen to evaluate the voluminous and highly technical evidence directly. That was the specialized role of the expert task force. Rather, the important understandings—in the realm of NOS—involve the nature of that expertise and the grounds for the panel's credibility. It involves NOS knowledge of how scientists may shift their consensus on such issues, as well as the significance of more data, larger sample size, or metastudies. It involves assessing how politics and gender may potentially bias conclusions. No one should expect students to have the relevant expertise, which is why regarding this or similar cases as an example of inquiry skills is misguided. For this reason, KNOWS asks students to provide a "well-informed analysis" of the claims *rather than* develop their own conclusions or argument. The aim is to learn what students know about how scientific claims develop and how science works—and how this shapes its conclusions—*not* to do the science themselves.

Schwartz et al. seem adamant about distinguishing nature of scientific knowledge (VNOS) from nature of scientific inquiry (VOSI), while acknowledging their close relationship. They thus fault KNOWS for conflating them. In science, however, process and product are virtually inseparable. Scientific papers typically include a methods section for good reason: The *methods* are integral to the *epistemic* structure of interpreting the results. Scientific practice and epistemology are intertwined. Recent work in science studies has underscored the performative dimensions of science, the material dimensions of epistemology, and the "mangle of practice" (Crease, 1993; Latour, 1987; Latour & Woolgar, 1979; Pickering, 1995; Rheinburger, 1997, 2010; Rouse, 1996). As articulated in Bachelard's concept of *phenomenotechnique*, even instruments that we regard as tools for inquiry embody theory and justification. A spectrophotometer, for example, has an *epistemology* (Rothbart & Slayden, 1994). Debating how to classify scientific inquiry—currently contentious among a handful of science educators—seems to pit splitters against lumpers without truly informing effective teaching and assessment. Ultimately, should we want two separate assessment instruments, where one unified probe with adequate resolving power may suffice? In the context of decision making in authentic cultural contexts, in particular, such distinctions seem academic.

2. *Should NOS be characterized as a short consensus list or as an open-ended "Whole Science" inventory?*

The question of characterizing NOS is itself central, of course. Schwartz et al. believe that my approach is both too broad (hence, impractical) and fundamentally ill conceived. They appeal instead to the consensus among educators in the mid-1990s about what NOS should be taught (McComas & Olson, 1998). The consensus seems to justify itself.

[2] Schwartz et al. wrongly attribute this view to me repeatedly.

Historically, however, this consensus seems more a political common ground than a well-reasoned or properly justified conclusion. Policy documents advocating NOS do not include any clear rationales or analysis for *how* to envision NOS nor *how* to establish its relevant features. They do not articulate *why* the various NOS features were selected or justified, nor how they relate to scientifically literate performance. Our public NOS educational goals should be based on more than mere impressions. The absence of a clear rationale and criteria for what is included in NOS and what is peripheral should, I contend, be addressed. Schwartz et al. fail to fully acknowledge this challenge, appealing only to the authority of the consensus.

The approach I advocate explicitly grounds itself in the authentic context of scientific literacy. It underscores the importance of evaluating the reliability, or trustworthiness, of scientific claims in everyday life (p. 521). This thematic focus echoes the central role of epistemology that Lederman has, on occasions, suggested is foundational to NOS. What is the epistemic structure of scientific conclusions in a public sphere (not just their "arguments" or evidence)? The benchmark for NOS is thus determined empirically: from the relevant NOS dimensions in cases of socioscientific issues in our contemporary culture—the very ones that we intend NOS education to address. This yields an inclusive and open-ended NOS inventory, not a short, exclusive list. (For similar empirically derived inventories, see Millar, 2000, Table 3; Kolstø, 2001; Ryder, 2001.) An inventory-based perspective, in explicit contrast to the familiar but truncated consensus list, I have called a Whole Science approach. "Whole Science" is not, as Schwartz et al. seem to imagine, a loose phrase or mandate to teach everything or anything. It concerns the open-ended versus limited (inclusive versus exclusive) approach to NOS. Cultural relevance as a benchmark guides us to be inclusive.

Consider, for example, the case of "Climategate," involving hacked e-mails by a leading climate change researcher (p. 536). The relevant dimensions of NOS knowledge for an informed analysis include informal scientific communication, the internal politics of science, the nature of graphs, and the public disposition of data. All these are part of scientific practice—and their cultural relevance became vividly clear in this case. Yet, these NOS features do not appear on the consensus list. A student who had mastered its concepts (VNOS), even supplemented by a healthy knowledge of scientific inquiry (VOSI), would not thereby be competent to address this case. That is, the current consensus list as a benchmark will not guide students to scientific literacy (van Dijk, 2011).

An approach using a Whole Science NOS inventory does introduce challenges, as Schwartz et al. rightly observe. First, how can one possibly teach everything that is relevant? Isn't it appropriate, they contend, to identify the most important NOS features and focus just on those? Simplification, as an educational strategy, however, has potentially adverse consequences, especially for NOS (Allchin, 2001, 2003a, 2007). As an effective alternative, however, one might *sample* NOS features exhibited in different historical or contemporary cases. Sampling differs from simplification. Reducing NOS instruction to a few standardized features prevents a full appreciation of the spectrum of scientific practice and fails to fully prepare students for cultural applications. Prominent NOS features will naturally recur across multiple cases, thus ensuring an essential foundation. Every student does not need to learn exactly the same (core) thing for NOS education to be effective. No one expects to teach the whole of NOS in a single lesson (for one such ill-conceived list-inspired effort, see Westerlund & Fairbanks, 2010).

The constraint of time, so vividly recognized by practicing teachers, does indeed provide an occasion for deep reflection about NOS education. Reducing the scope of NOS concepts hardly solves, but rather only amplifies the residual problem: How do students cope with their resulting NOS "ignorance"? If indeed the education system cannot prepare students for fully mature NOS analysis, then it must prepare students to be lifelong *NOS* learners. Teachers must shift emphasis from NOS tenets or views to more powerful abilities in *NOS metareflection*. They must instruct and perhaps habituate students in *posing appropriate NOS questions*. A reduced list, as a benchmark, renders NOS as limited. While Schwartz et al. acknowledge that there is NOS beyond the consensus list, they present no educational strategy to address that further realm or to assess abilities to develop further knowledge of NOS. A Whole Science NOS inventory helps students appreciate the breadth of the NOS landscape, even if only part of that territory can be covered in detail in a school setting. Furthermore, from a teacher's perspective, any case may become an occasion for reflecting explicitly on and learning about NOS. One need not wait for specific "target" NOS elements. This can liberate teachers substantially in planning and organizing NOS lessons.

Finally, for a glimpse of the problematic real-world consequences of the consensus-list approach, consult a recent historical lesson explicitly motivated by and guided by the NOS list (Westerlund & Fairbanks, 2010). Here, the authority of the list (to be learned, just like the parts of a cell) upstages the role of reflection, while biasing the history, resulting in deeply distorted NOS lessons (Allchin, 2002, 2003b). Yet, the authors seem to treat the consensus list as *justification* for their short-circuited approach, which they present as a model for others. Such a false impression of effective NOS education is an inherent danger I see in a tidy NOS list.

3. *Has the KNOWS assessment demonstrated validity or construct validity?*

No. *Not yet*. KNOWS is a *prototype.* It is a *prospective* method for assessing NOS knowledge. Nowhere do I claim or imply that any research has been done on this assessment. Schwartz et al.'s bold allegation that as a scholar I have *misrepresented* the validity of KNOWS is patently false. However, such misleading assertions need not preemptively forestall any fruitful investigation on it or discussion of it as a model. With further research, we may know soon if the KNOWS prototypes meet the standards of validity (as well as relevance), or whether the framework needs further refinement. In the meanwhile, it can certainly provide an occasion for discussing a Whole Science/inclusive NOS approach and authentic NOS assessment.

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