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The Case for Explicit Instruction

of the Nature of Science in Secondary Science Education
through the Incorporation of the History and Philosophy of Science

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Abstract: *Richard Feynman, the celebrated physicist, is frequently attributed as saying that "philosophy of science is about as useful to scientists as ornithology is to birds."*

Professor Feynman taught at the California Institute of Technology for many years, but perhaps this experience did not afford him the best view of the general level scientific literacy of most people.

The inventive Feynman would likely be disappointed in the rigid nature of much pre-college science instruction, and he would definitely be disappointed in the lack of student understanding of the nature of science.

The Next Generation Science Standards emphasize the nature of science as one of their standards, but currently most pre-college science instructors do not address this learning target or only do so through the indirect approach of using inquiry lessons.

There is strong evidential support for including the explicit instruction of the philosophy of science and the history of science in pre-college science classrooms as a way of augmenting scientific literacy and enhancing student views on the nature of science.

The Scientific Method is taught in almost every science class from elementary grades through high school. From a pedagogic standpoint this repetition is desirable – reiteration will aid student memory and familiarity. The most frequently emphasized ideas about the scientific method are Francis Bacon's inductive method, originally proposed in the 1600s, and Karl Popper's falsifiability, tracing back to the 1960s (Lederman et al., 2002, p. 501). For many years, though, scientists and philosophers of science alike have recognized there is no set scientific method (Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002, p. 501). The instruction of these views of the scientific method would not be problematic if they were taught as conflicting views about the nature of science (NOS), each with weaknesses and strengths, but they generally are not – they are presented as procedures that scientists follow when they practice science. This rigid interpretation of NOS leads students down false pathways in their conceptualization of science.

Understanding the Nature of Science

Misinformed views of NOS have many negative consequences. Two recent related concerns are the decline in scientific literacy and the dearth of young adults pursuing STEM degrees in the United States (Hossain & Robinson 444). These issues may be linked to a fragmented understanding of NOS and correlated to misconceptions about the tentative state of scientific knowledge. These fallacies can be readily evinced through student (and teacher) misunderstandings of basic ideas like hypotheses, theories and laws (Abd-El-Khalick & Lederman, 2000, p.1076). Poorly developed understandings of the cautious nature of scientific language have contributed to alarming societal trends. Fad diets are espoused by nutritionists; vaccines are condemned by celebrities and shunned by parents for fear of their inefficacy and "potential" link to autism; and homeopathic remedies garner followers because they are phrased in terms of absolutes, whereas doctors and scientists couch their descriptions in probabilities. The fact that students graduating from high school and college (even with science degrees) do not understand the tentative nature of scientific knowledge makes it difficult for them to navigate through the sensationalized science and pseudoscience presented by the media.

The Future of STEM

STEM fields are likely having difficulties recruiting and retaining qualified candidates for related reasons. According to the National Math & Science Initiative, in 2013 only 36% of high school graduates in the U.S. were ready for college science ("STEM Education Statistics"). Even some of these "prepared" students potentially avoid pursuing STEM degrees because they see science as staid, logical, and fixed – the antithesis of the collaborative, creative, and evolving process that it truly is. Others who do originally pursue these degrees expecting this inventive process find themselves wading through rigid, stagnant introductory college classes in which there is also little NOS instruction. Students initially enrolled in STEM programs have an alarming attrition rate – a recent study found that "a total of 48 percent of bachelor's degree students and 69 percent of associate's degree students who entered STEM fields between 2003 and 2009 had left these fields by spring 2009" (Chen & Soldner, 2013). There are different causative factors of these disturbing trends, but it is a reasonable speculation that a lack of a developed sense about NOS and the intricacies of the scientific process contribute significantly.

Since scientists, educational leaders, and pedagogic organizations have long recognized that it is desirable to help students "develop informed conceptions of science," it is surprising that so little instruction about NOS seems to take place (Lederman et al., 2002, p. 498). Even though guidelines like the Next Generation Science Standards emphasize its importance, popular curricula like the Common Core do not (NGSS, 2013, Appendix H). There also seems to be a disconnect with science teachers. Claims that a majority of these pre-college instructors view science merely as an "established body of knowledge and techniques that require minimal justification" (Monk & Osborne, 1997, p. 407) may not sound particularly generous to educators, but multiple studies have reached these conclusions. The recent emphases on teacher accountability and standardized tests used to evaluate teacher effectiveness have likely exacerbated this problem, as these exams generally are not designed to assess NOS. Creating a valid assessment to gauge students' conceptions about NOS has been an issue in education for decades, but the instruction is critical even if there is disagreement over how, or if, to evaluate it.

Using History & Philosophy in Science

Not all science teachers have eschewed the instruction of NOS, but many who do address it approach it indirectly. Some science educators have even suggested that NOS "cannot be taught directly, rather it is learned, like language, by being part of a culture" (Abd-El-Khalick, 2012, p. 2089). This has led many to assume that just using inquiry methods helps students develop NOS understandings, but Sandoval and Morrison found that inquiry has little impact on comprehension of NOS without explicit attention being concentrated on epistemological ideas (2003, p. 384). Exacerbating the issue is that "even when they (teachers) hold clear and coherent views about science and scientific inquiry, teachers do not plan laboratory-based lessons consistently or carefully in relation to those views" (Monk & Osborne, 1997, p. 407).

This is not to contend the importance of inquiry lessons. These lessons lend themselves to helping students understand some of the processes of science. However, they must be carefully planned and include guided reflection about how they relate to NOS. Even then, they are limited in their possible impacts on student comprehension. The explicit teaching of NOS should also be employed through the inclusion of the history and philosophy of science (HPS). Many studies have found this to be "an effective way to reach the goal of enhancing science literacy for all citizens" (Wang & Schmidt, 2001, p. 52). Using the history of science as an instructional tool has been promoted since William Whewell published "History of the Inductive Sciences, from the Earliest to the Present Times" in 1855 (Niaz, 2015, p. 176). Some history has traditionally been taught in science classes, though there is little evidence that this instruction has been well-designed or appropriately connected to NOS concepts. Gallagher found in a 1992 study that when teachers did try to include the history of science, that it was merely to "humanize science" and "foster positive attitudes" rather than enhancing an understanding of NOS (Monk & Osborne, 1997, p. 407).

Employing HPS as an Instructional Tool

This stance needs to be addressed. Michael Matthews, an education professor at the University of New South Wales, has long been a proponent of teaching HPS and sees tremendous opportunities in using it (Yalaki & Cakmakci, 2010, p. 291). Physicist and Nobel laureate Kenneth Wilson and his collaborator Constance Barsky have conducted over ten years of research and argue that "exposure to the history of science helps students consider science as a career to think, ask questions, and explore the concepts and ramifications of broad topics, enabling them to grasp what science is about and how it is concluded" (Gooday, Lynch, Wilson, & Barsky, 2008, p. 323). While the resultant evidence from the few studies that have been conducted into an HPS approach is ambiguous or inconclusive, this is likely because there have been so few investigations and those generally have been conducted over short time periods and with small sample sizes.

Wandersee has found that many student misconceptions are similar to past societal views; students "often harbor misconceptions which were similar to views held at one time or another during historical development of that science concept – thus making the history of science a useful heuristic device for anticipating some students' conceptual difficulties" (Monk & Osborne, 1997, p. 413). Employing HPS as an instructional tool allows students to see how scientists disagree with each other and how they interpret their evidence, thus giving a more appropriate view of science as a creative, collaborative, and, at times, combative practice. Students can also see how scientific ideas change over time with new evidence, shifting paradigms, and developing technologies. HPS can also convey the important interrelationship between culture and science (Lederman et al., 2002, p. 501).

Developing Critical & Evaluative Skills

Even past concerns about using history of science would now seem to be mollified. Steven G. Brush, a noted physicist and historian of science writing mostly in the 1960s and 1970s, supported the use of the history of science toward increasing the understanding of science and scientists' roles in society, but also warned that this history could be construed as subversive since it might undermine the notion of objective truth (Monk & Osborne, 1997, p. 414). In current times this might be seen as a positive - not because of the relativism that Brush was opposed to, but because it might convey the ever-evolving state of scientific knowledge. Teaching the philosophy of science along with the history is critical as it could help students understand this tentative nature and should aid in the development of critical and evaluative skills. Matthews stresses that it is key to pair the philosophy and history of science as the combination can lead to "higher-order understanding and valuation of science" (Yalaki & Cakmakci, 2010, p. 291).

The possible benefits for inclusion of HPS towards addressing NOS are considerable, but research is still in its germinal stage and many obstacles to HPS implementation exist. The aforementioned belief that science is simply "a body of knowledge" poses a difficulty in convincing educators to emphasize NOS at all. Overcrowded curricula provide additional hurdles, as teachers struggle to efficiently allocate the necessary time. Standardized tests and established curricula that do not emphasize NOS shift the focus of teachers to other content. Professional learning communities (PLCs) are a new collaborative trend in education, but they may provide obstructions to change – participating teachers may not feel comfortable re-focusing their practices unless everyone in their PLC agrees to do so. Teachers concentrating on classroom management in over-crowded conditions may be loath to head in new directions for fear of losing control (Abd-El-Khalick, 2012, p. 2098). Additionally, it would not be surprising if the research supporting the explicit approach to teaching NOS has not reached many pre-college teachers. Unfortunately, academic research seems to take an inordinate amount of time to get molded into practical applications in schools.

Change Starts with Teacher in Training

Most likely the largest impediment to the use of HPS is the lack of teacher knowledge. Recently, Denmark and Spain have begun to require pre-teachers to take coursework in HPS (Matthews, 1998, p. 984). Some programs in the United States have also started including this training, but a quick survey of programs throughout the U.S. still shows little employment (Matthews, 1998, p. 984). Without this formal training and with little curricular support, teachers likely will not make the systemic switch. Teachers-in-training should take mandated philosophy of science and history of science courses. Incorporating this into their training would enable teachers to be more confident in employing HPS and would deepen their own understandings of NOS. To achieve these ends, though, would require colleges to embrace a major change in their pedagogic philosophies.

Calls for Reforms in Science Education

Calls for reforms in science education are nothing new. Student misconceptions about NOS have been a target of these calls for over a century. Recent initiatives like the American Association for the Advancement of Science's Project 2061 and curriculum development like the Next Generation Science Standards have helped sharpen instructional focus and learning goals in science education.

Inquiry experiences have been touted for a number of years as an authentic way of providing some of this instruction and they should continue to be employed, but they are not sufficient by themselves. One heretofore underutilized methodology that shows great promise is the practice of using the history and philosophy of science.

A knowledgeable and enthusiastic teacher employing explicit instruction of NOS through HPS can have a tremendously positive impact on student perceptions and understanding. This means that pre-service teachers will also need overt training in HPS before they can bring this educational practice into their high school classrooms. Employing direct instruction on the philosophy and history of science will not be a panacea to fix all of the issues in science education, but it can be a valuable tool for helping students to develop scientific literacy and addressing NOS conceptions.

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