From History to Teaching Nature of Science

Douglas Allchin
University of Minnesota
2005 Carroll Ave., St. Paul, MN 55104, USA; allch001@umn.edu

Historians know very well that their studies yield valuable insights into the nature of science (NOS), or how science works in practice (Bird, 2013; Larvor, 2000). “History, if viewed as a repository for more than anecdote or chronology,” Thomas Kuhn famously declared, “could produce a decisive transformation in the image of science” (1970, p. 1). The challenge today is how to convey those insights to students in science classes (Allchin, 2014). Over the past two decades, science curricula internationally have adopted an important role for NOS — or, alternatively phrased, “ideas about science,” “how science works,” “the scientific enterprise,” or “scientific practices” — all towards promoting functional scientific literacy and informing personal and public decision-making (Board on Science Education, 2012; Evans & Jennings, 2008; Gormally et al., 2011; Hodson, 2009; Kolstø, 2001; McClune & Jarman, 2010; OECD, 2017; Ryder, 2001; Toumey et al., 2010). This special volume describes a method for teaching NOS based on historical inquiry cases, and presents four field-tested examples, each featuring an important scientific discovery in Brazil.

Conventional historical narratives are, of course, one strategy for conveying the lessons of history. As early as the 1950s, Harvard University professor and political titan James Bryant Conant and his colleague Leonard Nash articulated the goal and assembled a handful of case studies specifically for college science students (Conant, 1947; Conant & Nash, 1957; Nash 1951). Leo Klopfer then did the same for high school students, with measured success (Klopfer, 1964-66; Klopfer & Cooley, 1963). Such stories were accompanied by commentary and study questions to highlight the nature of science elements. The use of narratives, or stories, still contiues today, in Brazil and elsewhere (Klassen, 2009; Metz et al., 2007; Teixeira et al., 2012).

Educators today, however, do not regard simple texts or didactic lectures as the most effective form of learning. Rather, they aim to engage students in their own learning. Educators focus on what students already know — or think they know — and pose questions, problems and anomalies designed to deepen their understanding. The students’ subsequent investigative activity and reflection helps them develop more sophisticated concepts. Just as historians are aware that scientists “construct” knowledge rather than “discover” it passively, educators realize that students “construct” and transform their own knowledge through complex cognitive processes. The contemporary aim, then, is to frame episodes of inquiry. Inquiry is the method whereby students build their own knowledge stepwise through solving intellectual challenges in a collaborative setting. For the instructor, the primary focus shifts from delivering preformed, pre-digested answers to posing open questions and carefully guiding inquiry and reflection.

Accordingly, several science education projects combine historical narratives with embedded questions (Allchin, 2012; Clough, 2011; Hagen et al., 1996; HIPST, 2008). The aim is to highlight certain aspects of scientific practice and prompt students to consider and characterize their role in the case. For example, students might be asked how to compare measurements of atmospheric carbon dioxide from two different instruments hundreds of kilometers apart — ultimately a lesson in standardization and calibration (based on the work of Charles Keeting; Leaf, 2011). They might be asked to consider how well the available evidence supports a method for preventing smallpox and whether it can be considered “proven” — a lesson on underdetermination, potential error, credibility, and the nature and limitations of evidence (based on the efforts of Lady Mary Whortley in the 18th century; Remillard-Hagen, 2010). Or students might be invited to consider how they will fund an expedition to study natural history and collect specimens in an exotic rainforest far away — a lesson in patronage and the need for resources and funding to conduct scientific research (drawn from the life of Alfred Russel Wallace; Friedman, 2010).

Questions about cases from the past could easily drift into what historians might recognize as standard historical analysis. One examines just how the science unfolded, in retrospect, from a secure perspective of having reached a final conclusion. However, a major goal of science education (or scientific literacy) is to inform an assessment of claims from contemporary science. In many cases relevant to consumers and citizens today, the science is incomplete or claims are actively disputed. Students must develop epistemic skills to evaluate the reliability or trustworthiness of alternative claims, even when the science is not considered complete. That skill is ultimately based on historical understanding of how knowledge is created gradually, and how growing confidence in scientific conclusions is secured. The ideal inquiry approach for educators borrows again a concept familiar to professional historians: a historicist perspective, or a view of what Bruno Latour (1987) called “science-in-the-making” (in contrast to “ready-made science”). Accordingly, historical perspectives that render cultural and technological context and uncertainty at a given point in history are indispensable tools for educators in teaching the nature of science through inquiry. The effect is not unlike some immersive participatory activities used to teach history itself: open-ended historical role-play simulations, such as the Reacting to the Past curriculum (Barnard College, 2018; Driscoll et al., 2014; Powers et al., 2010).

The result is that historical inquiry cases in science education ideally situate the student in the historical context and present them with the problems just as they were addressed by the historical scientists. For example, students learn about problems of development, heredity and evolution in 1910, then assume the role of Thomas Hunt Morgan, who encountered an anomalous white-eyed fruit fly mutant: what did it mean? What experiments should one do next? Later, how should one interpret the unexpected results, which fit no known pattern? (Allchin, 1996). Or: as Archibald Garrod in 1909, how should one proceed when others fail to take notice of your claims about several striking cases of inborn errors in metabolism (such as albinism and alkaptonuria, conditions that would later be recognized as vivid evidence for the one gene-one enzyme concept) (Allchin & Gabel, 2017; Allchin, 2017)? Or: as a fellow scientist in the 1960s, how would you evaluate Lynn Margulis’s claims about the endosymbiotic origin of cells, given that the evidence is mixed (Hagen, 1996)? From reflecting on these inquiries and their historical outcomes, students learn about experimental design, critical experiments, revision of theories, cognitive barriers to conceptual change, scientific debates and their resolution, and more. These are the basis of the analytic skills that students will use to assess contemporary scientific claims, such as about links between climate change, deforestation and drought; or about the efficacy of garrafadas as traditional remedies or of phosphoethanolamine as a treatment for cancer; or whether Brazilian policies support sustainable fisheries; or whether a nuclear power plant is sufficiently safe.

This special volume of *Cadernos de História da Ciência* addresses the use of historical inquiry cases to teach nature of science. The first paper describes the method in general. It addresses, in particular, the tension between open-ended inquiry, which is preferred for learning, and the closed nature of history, which has already occurred. If the historical lessons are to be informative, how can students be given the freedom to pursue the problems, essentially creating their own history instead of learning directly from it?

The next four contributions are about particular cases studies. All are based on science in Brazil. The first presents Vital Brazil and his work on snake venom, and how he reached the unexpected conclusion that anti-sera were specific to snake type rather than following a common scale of venom toxicity. The second concerns the ground-breaking work of Carlos Chagas on the cause and transmission of a disease that afflicted railroad workers, and that now bears his name. The third case is about Johanna Döbereiner and her work on nitrogen fixation symbioses in various tropical grasses, a series of discoveries of enormous economic importance to Brazil's soybean industry and other agricultural crops. The fourth concerns the work of world-renowned evolutionary biologist Theodius Dobzhansky, who studied the genetics of fruit fly populations in Brazil, and helped to establish the Genetics Department at the University of São Paulo.

References

Allchin, D. Thomas Hunt Morgan & the white-eyed mutant. In J.B. Hagen, D. Allchin and F. Singer, *Doing Biology*, pp. 48-59. Glenview, IL: Harper Collins; 1996. See also: http://doingbiology.net/morgan.htm

Allchin, D. The Minnesota Case Study Collection: new historical inquiry cases for nature of science education. *Sci & Educ* 2012; 21:1263–1282.

Allchin, D. From science studies to scientific literacy: a view from the classroom. *Sci & Educ* 2014; 23:1911-32.

Allchin, D. Does the evidence speak for itself?: Archibald Garrod & inborn errors of metabolism. *Am Biol Teacher* 2017; 79:335-337.

Barnard College. *Reacting to the Past*. New York: Author; 2018. https://reacting.barnard.edu

Bird, A. The historical turn in the philosophy of science. In S. Psilos & M. Curd (Eds.), *The Routledge Companion to Philosophy of Science*, 2d ed.; 2013, pp. 67-77. London: Routledge.

Board on Science Education, U. S. National Academies of Sciences. *A framework for K- 12 science education*. Washington, DC: National Academies Press; 2012. Retrieved March 14, 2014, from http://www.nap.edu/catalog.php?record_id=13165.

Clough, M. The Story Behind the Science: bringing science and scientists to life in post-secondary science education. *Sci & Educ* 2011; 7:701–17.

Conant, JB. *On Understanding Science: an Historical Approach*. New Haven, CT: Yale University Press; 1947.

Conant, JB, Nash, LK. (Eds.). *Harvard case histories in experimental science* (Vols. 1 and 2). Cambridge, MA: Harvard University Press; 1957.

Driscoll M., Dunn E, Siems D, Swanson K. *Charles Darwin, the Copley Medal, and the rise of naturalism, 1861-1864*. New York, NY: W.W. Norton; 2014.

Evans M, Jennings C. *Ideas about science*. Stevenage, England: Badger; 2008. Also retrieved December 18, 2014, from www.badgerlearning.co.uk/ecommerce/ProductPDFs/IdeasAboutScience.pdf.

Farber P. Teaching evolution and the nature of science. *Am Biol Teacher*; 2003, 65:347-54.

Flower, M. Conceiving science education as a practice of technoscientific practice. In F. Finley, D. Allchin, D. Rhees & S. Fifield (Eds.), *Proc. of the Third International History, Philosophy, and Science Teaching Conf.*, pp. 389-409. Minneapolis, MN: University of Minnesota Office of Continuing Education; 1995.

Friedman, A. Alfred Russel Wallace & the origin of new species. Minneapolis, MN: SHiPS Resource Center; 2010. Retrieved from http://ships.umn.edu/modules/biol/wallace.htm

Gabel, K, Allchin, D. Archibald Garrod & the black urine disease. Minneapolis, MN: SHiPS Resource Center; 2017. http://shipseducation.net/modules/biol/garrod.htm

Gormally, C., Brickman, P., Lutz, M. Developing a test of scientific literacy skills (TOSLS):Measuring undergraduates' evaluation of scientific information and arguments. *CBE—Life Sci Ed;* 2012, 11:364–77.

Hagen, JB. Lynn Margulis & the question of how cells evolved. In J.B. Hagen, D. Allchin and F. Singer, *Doing Biology*, pp. 23-36. Glenview, IL: Harper Collins; 1996. See also: http://doingbiology.net/margulis.htm

Hagen, JB, Allchin, D., Singer, F. *Doing Biology*. Glenview, IL: Harper Collins; 1996. See also http://doingbiology.net.

HIPST [History and Philosophy in Science Teaching Consortium]. (2008). Theoretical basis of the HIPST Project. http://hipst.eled.auth.gr/hipst_htm/theory_complete.htm. Accessed 12 October 2014.

Hodson, D. *Towards scientific literacy: a teachers' guide to the history, philosophy and sociology of science*. Rotterdam, The Netherlands: SensePublishers; 2009.

Klassen, S. The construction and analysis of a science story: A proposed methodology. *Sci & Educ*;2009 18:401–23.

Klopfer, LE. *History of science cases*. Chicago, IL: Science Research Associates; 1964–1966.

Klopfer, LE, Cooley, WW. The *History of Science Cases for High Schools* in the development of student understanding of science and scientists: A report on the HOSC instruction project. *J Res Sci Teach*;1963, 1:33-47.

Kolstø, SD. Scientific literacy for citizenship: Tools for dealing with the science dimension of controversial socioscientific issues. *Sci Ed*; 2001, 85:291–300.

Kuhn, T. S. *The structure of scientific revolutions* (2nd ed.). Chicago, IL: University of Chicago Press;1970.

Larvor, B. History, role in the philosophy of science. In W. H. Newton-Smith (Ed). *A companion to the philosophy of science*, pp. 154–161. Maiden, MA: Blackwell; 2000.

Latour, B. *Science in action: how to follow scientists and engineers through society*. Cambridge, MA: Harvard University Press; 1987.

Leaf, J. Charles Keeling & measuring atmospheric CO_2. Minneapolis, MN: SHiPS Resource Center; 2011. Retrieved from http://ships.umn.edu/modules/earth/keeling.htm

McClune, B., Jarman, R. Critical reading of science-based news reports: Establishing a knowledge, skills and attitudes framework. *Intl J Sci Ed*; 2010 32(6):727 – 752.

Metz, D., Klassen, S., Mcmillan, N., Clough, M., Olson, J. Building a foundation for the use of historical narratives. *Sci & Educ*; 2007 16:313–34.

Nash, LK. An historical approach to the teaching of science. *J Chem Ed*;1951 28:146–51.

OECD. *PISA 2015 assessment and analytical framework: science, reading, mathematic, financial literacy and collaborative problem solving, revised editio.* Paris: PISA, OECD Publishing; 2017. http://dx.doi.org/10.1787/9789264281820-en

Powers, RG., Burney, J., Carnes, M. *Reacting to the Past: a new approach to student engagement and to enhancing general education*. White paper report submitted to the Teagle Foundation; 2010.

Remillard-Hagen, E. Lady Mary Wortley Montagu & smallpox variolation in 18th-century England. Minneapolis, MN: SHiPS Resource Center; 2010. Retrieved from http://ships.umn.edu/modules/biol/smallpox.htm

Ryder, J. Identifying science understanding for functional scientific literacy. St Sci Ed; 2001, 36:1–44.

Teixeira, E. S., Greca, I. M., Friere, O., Jr. The history and philosophy of science in physics teaching: A research synthesis of didactic interventions. Sci & Educ; 2012, 21, 771– 796.

Toumey, C., Besley, J., Blanchard, M., Brown, M., Cobb, M., Ecklund, EH., et al. *Science in the service of citizens and consumers: The NSF workshop on public knowledge of science*, October 2010. Columbia, SC: University of South Carolina Nanocenter; 2010.