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Some Reflections on "Going Beyond the Consensus View" of the Nature of Science in K–12 Science Education

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ABSTRACT

Hodson and Wong (2017, this issue) argue that, though the nature of science (NOS) is now an established focus of school science education and a key element in defining scientific literacy, "the consensus view" of NOS misrepresents contemporary scientific practice. They then propose a number of alternative approaches to science curriculum building. I agree with Hodson and Wong's criticism of the consensus view of NOS. I also like many aspects of their proposals and believe that they would enrich the curriculum and present students with a much more realistic picture of science. But I have an important reservation about these proposals. Hodson and Wong's view of NOS is largely ahistorical in that they seem to focus only on contemporary science. Such a focus may lead to a distorted picture of science and its history, portraying science as little more than a mirror image of contemporary science. In order to understand the nature of science, it is vital to learn its history. I conclude by briefly commenting on the role that the history, philosophy, and sociology of science should play in shaping a vision for science education that would inspire creativity, open-mindedness, critical thinking, and respect for different cultures and conceptions of the world.

RÉSUMÉ

Hodson et Wong affirment que, bien que la nature des sciences/nature of science (NOS) soit maintenant un aspect reconnu de l'enseignement des sciences à l'école et un élément clé dans la définition de la culture scientifique, le consensus dominant en NOS donne une fausse représentation des pratiques scientifiques contemporaines. Les auteurs proposent donc d'autres approches pour le développement des curriculums. Je suis d'accord avec leur critique du consensus. J'apprécie de nombreux éléments de leurs propositions, qui à mon avis pourraient enrichir le curriculum et présenter aux étudiants une vision beaucoup plus réaliste des sciences. Cela dit, j'ai aussi de sérieux doutes, car la conception qu'ont Hodson et Wong de la nature des sciences est en grande partie non-historique, centrée principalement sur les sciences contemporaines. Cela risque de donner une vision déformée des sciences et de l'histoire des sciences, dont le portrait ne serait ici que le miroir des sciences contemporaines. Afin de comprendre la « nature des sciences », il est essentiel d'en connaître l'histoire. Je termine par un bref commentaire sur le rôle que devraient jouer l'histoire, la philosophie et la sociologie des sciences dans une conception de l'enseignement des sciences capable de favoriser la créativité, l'ouverture d'esprit, la pensée critique et le respect des différentes cultures et visions du monde.

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Hodson and Wong (2017, this issue) argue that, though "nature of science (NOS) is now a well established focus of science education and a key element in defining scientific literacy," the consensus view of NOS, which has become very influential in many countries as a template for curriculum building and evaluating students' understanding, misrepresents contemporary scientific practice. I am an outsider to the field of science education and not familiar with the literature and controversy about NOS in K–12 science education. Thus, in what follows, I will take at face value the authors' description of the consensus view. In the following sections, I review Hodson and Wong's critique of the consensus view and their proposed revisions. Though I agree with many of Hodson and Wong's proposals, I also have some important reservations, which I discuss later. I conclude by briefly commenting on the role that the history, philosophy, sociology, and anthropology of science should play in a new vision for K–12 science education.

Hodson and Wong's critique of "the consensus view" of the nature of science

Hodson and Wong (2017, this issue) argue that the consensus view fails to reflect contemporary science and includes overly simplified, confused, misleading, and philosophically naïve views about science.

First, Hodson and Wong note that the consensus view tends to focus on scientific knowledge and overlooks the nature of scientific inquiry, and they object that this is problematic given that "the status, validity, and reliability of scientific knowledge are inextricably linked with the design, conduct, and reporting of the scientific investigations that generate it" (Hodson & Wong, 2017, this issue, p. 7). They maintain that both the process and product of scientific inquiry are inextricably linked and any definition of NOS that excludes the methods of science is seriously deficient (Hodson & Wong, 2017, this issue).

A second concern that Hodson and Wong have with the consensus view is that it "neglects crucial issues relating to the structure and form of scientific language." This is problematic given that scientific language shapes our ideas, provides means for constructing scientific understanding and explanations, and is essential in communicating the aims, processes and products of science (Hodson & Wong, 2017, this issue). Hodson and Wong maintain that gaining familiarity with the language of science is a central aspect of learning about NOS and "should be a priority throughout school science education" (2017, this issue, p. 8).

Hodson and Wong also complain that several aspects of the consensus view are a gross distortion of scientific practice. They focus on two such aspects. The first is the "naïve proposition that there is a crucial distinction between observation and inference," which overlooks the heavy reliance of contemporary science on theory and technology. Hodson and Wong remark that "when theories are not in dispute … the language of observation is infused with theoretical assumptions" (2017, this issue, p. 8). One may add that this is also the case when theories are disputed. The second distortion is the too-literal interpretation of statements about the tentative character of science that leads "students to regard *all* science as no more than temporary" (Hodson & Wong, 2017, this issue, p. 8), whereas an important element of scientific education is the ability to distinguish between controversial ideas and those that are no longer in doubt.

Further, Hodson and Wong remark that several aspects of the consensus view are unclear. For example, it is not clear whether the consensus view takes a realist or instrumentalist position. For another example, though the consensus view recognizes the social and cultural embeddedness of science, it is unclear whether students are expected to regard sociocultural influences as internal or external to science and whether they are beneficial or detrimental. Hodson and Wong disagree with the tendency of some of the supporters of the consensus view to dismiss the above questions as irrelevant for the K–12 classroom. They maintain that the status of scientific knowledge and the extent to which it is socially constructed are among the most interesting and important features of science (Hodson & Wong, 2017, this issue).

Next, Hodson and Wong object to the tendency of the consensus view to characterize NOS in general and overlook "the complexities and diverse practices of generating knowledge across the subdisciplines" while regarding physics as the standard for all sciences. They maintain that such a perspective is neither valid nor productive for science education and that "teachers should acknowledge the context dependency of scientific practice and knowledge generation" (Hodson & Wong, 2017, this issue, p. 9). Hodson and Wong also object to the idea that the differences across scientific domains are not important for K–12 education. Yet, as we shall see later, they contend that science as a whole does have certain characteristics.

Finally, Hodson and Wong (2017, this issue) warn that

> a disarmingly simple specification of NOS items, especially when allied to a purpose-built assessment protocol (the VNOS instruments), can quickly become established as the norm for building a curriculum and designing teaching and learning materials. The great danger is that items in the approved list become oversimplified by busy teachers and taught as truths about NOS, with consequent narrowing of the curriculum. (p. 11)

Alternative views of NOS

Hodson and Wong discuss alternative perspectives to the consensus view of NOS. Following are the main ones.

One proposal, due to Sandoval (2005), is to replace the consensus view by an approach that is based on four key ideas. First, science is constructed rather than discovered and knowledge claims gain their authority through their ability to pursuade. Here an interesting question is whether such a constructive approach, which is common among many current historians of science (Golinski 2005), is compatible with realist positions. Second, there are substantial differences between scientific disciplines and, accordingly, the criteria for evaluating scientific claims are not the same in different disciplines. Third, "there are different forms of scientific knowledge that vary in explanatory or predictive power" (Hodson & Wong, 2017, this issue, p. 11). Fourth, though we can never be absolutely sure of scientific claims, we should not regard all of scientific knowledge as tentative.

A second proposal, due to Matthews (2012, p. 4), is that we should consider NOS "not as some list of necessary and sufficient conditions for a practice to be scientific, but rather as something that, following Wittgenstein's terminology, identifies a 'family resemblenace' of features that warrant different enterprises being called scientific." The idea is to shift from the consensus view to "a more relaxed, contextual and heterogeneous 'Features of Science,'" which "would be elaborated, refined, and discussed, not simply learned and assessed" (Hodson & Wong, 2017, this issue, p. 12).

Another approach that appeals to the idea of family resemblance among sciences is due to Irzik and Nola (2011), who propose to organize the cognitive aspects of science into four categories: activities; aims and values; methodologies and methodological rules; and products. Irzik and Nola (2014) refine their approach by drawing a distinction between "science as a cognitive–epistemic system of thought and practice" and "science as a social–institutional system." Hodson and Wong believe that the stregth of Irzik and Nola's approach is that they provide a natural framework for accounting for the diversity and similarity among different sciences. One may wonder, however, whether such a distinction is in line with Hodson and Wong's aim to highlight science as a social activity.

Complementing the previous proposals, Hodson and Wong (2017, this issue) suggest that school science curriculum should pay close attention to the distinctive language of science, the characteristics of scientific inquiry, the role and status of scientific knowledge, the modeling involved in constructing scientific theory, the social and intellectual circumstances of significant scientific achievements, the social dynamics of groups of scientists, the values and conventions that underpin scientific practice, and the ways in which science impacts and is impacted by social contexts.

Hodson and Wong also recommend various media for learning about NOS. For example, they advocate using historical and contemporary case studies, biographies and autobiographies, textbooks, movies, magazines and newspapers, accounts of respected commentators on scientific practice, instructions and demonstrations, hands-on investigative activities, and visits to research laboratories and other sites of real-world science. In particular, Hodson and Wong emphasize the importance of careful consideration of the views of scientists at the front of scientific research for building a broader, richer, and more functional understanding of NOS. They propose three ways in which this could be achieved: (a) learning about scientists, which includes views of science, scientists, and scientific practice, as seen by historians, philosophers, and sociologists; (b) learning from scientists, which includes attending lectures and seminars by scientists, reading academic papers, scientists' autobiographies, etc.; and (c) learning with scientists, which includes observing, interviewing, and working alongside scientists. Hodson and Wong note that the last type of activity would expose the students first-hand to the realities of day-to-day scientific practice.

On the importance of the history of science for science curriculum building

I agree with Hodson and Wong's criticism of the consensus view of NOS. I also like many aspects of the alternative approaches that they discuss and propose. I believe that these approaches would enrich the curriculum and present students with a more realistic picture of science. But I also have some reservations about these proposals.

A role for the history

Though Hodson and Wong advocate the study of the history of science, their vision of NOS is, in fact, largely ahistorical in that they seem to focus only on contemporary science. This is displayed in various aspects of their proposed revisions. Here are some examples.

After criticizing the tendency of the consensus view to characterize NOS in general and overlook the complexities and diverse practices of generating scientific knowledge, Hodson and Wong argue that, although there is clearly no *one* scientific method, science as a whole does have certain characteristics. Among these characteristics are "particular styles of reasoning, including experimental exploration; measurement; hypothetical modeling and use of mathematics; the search for theories with broad scope, extensive explanatory power, and high predictive capability" (Hodson & Wong, 2017, this issue, p. 9). Some of these characteristics, like the empirical nature of science, do indeed constitute the hallmark of modern science, but less so of the science before the "scientific revolution."[1] Other characteristics, such as the importance of mathematics and explanatory power, may be common to science in different phases of its history, but these commonalities disguise important differences.

Consider the role of mathematics in science. Henry (1997, p. 8) commented that the "mathematization of nature," which has been seen as an important element in the scientific revolution, saw the replacement of a predominantly instrumentalist attitude to mathematical analysis with a more realist outlook. Mathematics became an essential part of natural philosophy, playing a central role in characterizing and explaining the nature of the physical universe rather than finding use as a convenient descriptive tool. Here one may recall Galileo's (1623/1960) famous statement that nature is written in mathematical and geometrical language. This important shift was related to a change in the status of both mathematics and mathematicians (Henry, 1997, pp. 15–24).

Next, consider scientific explanation. Hodson and Wong are right to maintain that science aims toward producing explanatory theories. This commonality, however, disguises a sea of differences between the present and the past. For example, current scientific explanations do not involve God or "intelligent design," but things were very different three centuries ago. Consider the famous and fascinating correspondence in 1715–1716 between Leibniz and Clarke, a natural philosopher who was a close friend and disciple of Newton (Alexander, 1956/1998). Therein God and intelligent design play central roles in explanations of the physical realm. Leibniz maintained that God used the principle of sufficient reason and the principle of the identity of the indiscernibles (which Leibniz seems to deduce from the principle of sufficient reason) in creating the universe, and he argued that these principles imply various conclusions about the physical nature of the universe; for instance, that space and time are relational (rather than absolute as Newton argued) and that matter is continuous (rather than discrete as Newtonian mechanics postulates). Clarke agreed with Leibniz that God used the principle of sufficient reason in creating the universe, though he had a very different reading of this principle and accordingly of the way God created the universe. Based upon his understanding of the nature of God and physical considerations, he argued for a different picture of matter and space-time.

The empirical nature of science also changed substantially during the history of science. Within the Scholastic–Aristotelian tradition, which predominated medieval universities, claims of natural philosophy were based upon what were held to be evident, undeniable truths of experience (Henry, 1997, p. 24). Natural philosophers deferred to the authority of texts, whether the seminal works of Aristotle or the corpus of commentaries on these works. Though the Scholastic tradition never totally ignored observations and experiments, positions that could be maintaned by recourse to authorative texts had a privileged status over empirical data (Gascoigne, 2006, p. 859). Thus, the nature of experimental exploration was very different from that of current science. Moreover, according to current historiography, the change in the attitude toward the experimental method was influenced by the strong interest in alchemy, astrology, and natural magic,[2] which are now considered pseudosciences.

Another important change in the history of science is in the attitude of scientists toward philosophy. For example, until the 19th century, a sharp distinction between science and philosophy did not really exist. Thus, for instance, Newton and Leibniz were natural philosophers, not physicists. The change from natural philosophy to physics was associated with important changes in the physical sciences and their practitioners, including changes in the nature of scientific explanations and styles of reasoning.

The upshot is that the search for certain characteristics of "science as a whole" may lead to a distorted picture of science and its history and is likely to end up with a characterization of science that amounts to little more than a mirror image of contemporary science. Indeed, even if we conceive science along the family resemblenace approach, where one looks for features that warrant different enterprises being called scientific, the term *nature of science* is highly misleading when it is applied to the history of science. That is not to deny, of course, that sciences at different periods could have common characteristics. Rather, it is to argue that one should look for a curriculum that would do justice to the important differences between scientific thinking and practices at different periods.

Science and pseudoscience

Hodson and Wong (2017, this issue) remark that, given their "discussion of disunity among the sciences, it may seem contradictory to raise issues relating to demarcation criteria for science" (p. 14). Nevertheless, they see the question of the demarcation between science, nonscience, and pseudoscience as an important issue for students to address. As they point out, the "designation of a field of study as scientific is a much-sought-after and jealously guarded status, carrying with it a subtext of rationality, dependability, trustworthiness, rigor, and stability" (p. 14). Thus, Hodson and Wong (2017, this issue) maintain that it is crucial that

> students are equipped with the capacity to distinguish science from nonscience and pseudoscience. Without this capacity, they are vulnerable to the lure of pseudoscientific beliefs such as telepathy, precognition, psychokinesis, extraterrestrial visitation, clairvoyance, and astrology; the enticements of "New Age" beliefs such as the healing power of crystals, reflexology, aromatherapy and iridology; and the claims of all manner of snake oil salesmen, hucksters, and unscrupulous advertisers who use spurious scientific arguments to sell their products and services. Without clarity on demarcation issues, they have no defence against those who advocate the inclusion of creationism in the school science curriculum, especially in its contemporary manifestation as "intelligent design." (p. 14)

Hodson and Wong consider some characterizations of pseudoscience. They also mention Smith and Scharmann's (1999) recommendation for teachers "not to seek a clear distinction between science and nonscience but rather to generate a set of predictors that can be used to judge which fields of study are *more* scientific or *less* scientific than others" (Hodson & Wong, 2017, this issue, p. 14). Finally, Hodson and Wong briefly discuss some evidence for the success of teaching about pseudosciences.

Mastery of current science implies the capacity to understand the differences between intelligent design and natural selection and, correspondingly, between creationism and evolutionary biology, and to recognize that the latter but not the former is part of contemporary science. Yet, I believe that the K–12 science curriculum should not be *directed* to developing such a capacity because of the risk of promoting a distorted and anachronstic view of the history of science and, accordingly, a misguided view of science. The question of the distinction between science, pseudoscience, and nonscience is both complicated and controversial. Attempts to set the capacity to distinguish between them as a measurable goal for an educational system, one populated by overworked teachers and increasingly looking for fast and easy measures of success, is likely to lead to simplistic views about these matters. The capacity to develop such a distinction should be a byproduct of a proper study of the relevant sciences and their history rather than an explicit goal. That way, students could both understand the distinctions between evolutionary biology and creationism and contextualize these distinctions within the history of science.

The language of science

Hodson and Wong argue that gaining familiarity with the language of science should be a priority of science education and that school "science curriculum should pay close attention to the distinctive language of science (especially the linguistic conventions for reporting, scrutinizing and validating knowledge claims)" (Hodson & Wong, 2017, this issue, p. 13). Though I agree that to know a scientific discipline it is important to learn its language, it is misleading to speak about "the language of science." Indeed, given the authors' emphasis on the disunity among the sciences and the discussion above, it should be clear that there is not any single language of science and that the languages of the various scientific disciplines have changed substantially over their histories.

Learning from scientists

A central aspect of Hodson and Wong's proposal for revising the current K–12 science curriculum is the emphasis on careful consideration of the views of scientists at the fore of scientific research. As they note, lessoning, meeting, observing, interviewing, and working along scientists would expose students first-hand to the realities of day-to-day scientific practice and would complement, elaborate, and sometimes challenge the NOS views of historians, philosophers, and sociologists of science. Yet, in addition to providing exciting opportunities for learning about real-life science, such encounters embody potential risks. Scientists work with numerous implicit assumptions that are often reflected neither in their articulation of their practices nor in their opinions on science. Scientists are rarely educated to reflect on the science they practice, its implicit presuppositions and dogmas, its foundational difficulties, and its historical development. Accordingly, scientists' articulations of the nature of science are frequently misleading and out of sync with their actual practice.

Indeed, Hodson and Wong mention the importance of learning about scientists and scientific practices from historians, philosophers, and sociologists of science. However given their authority, scientists, and especially leading scientists, could exert a very significant influence on students (and teachers)—an influence that may be difficult to balance by simply learning about scientists. Thus, though Hodson and Wong's proposals hold promise, I think that one needs to reflect carefully on how to design the proposed encounters to avoid undesirable outcomes. Perhaps a way to balance possible undesirable consequences associated with learning about science from scientists may be to complement the authors' proposals with encounters with historians, philosophers, sociologists, and anthropologists of science.

A vision for K–12 science education

Science education should provide students with the tools to understand modern science and its history; inspire them to develop creativity, open-mindedness, and critical thinking; and promote tolerance and respect for different cultures and conceptions of the world. Any vision for K–12 science education should strive to achieve these goals. In the previous section, I argued that in order to understand the endeavour we call science, it is vital to learn its history. I believe that teaching science through teaching its history, philosophy, sociology, and anthropology is also an effective way to achieve the above goals.

The study of the history of science, which is involved with the study of philosophy, sociology, and antropology of science, is important for a better understanding of the way in which science is socially and culturally situated and how this situatedness reflects on its content, practice and its evolution, as well as how we evaluate it. As Ludwik Fleck taught us, knowledge of the history of science is important for a better understanding of contemporary science.

> [W]hether we like it or not, we can never sever our links with the past...It survives in accepted concepts, in the presentation of problems, in the syllabus of formal education, in everyday life, as well as in language and institutions. Concepts are not spontaneously created but are determined by their "ancestors." (Fleck 1935/1979, p. 20)

This may sound counterintuitive, because past ideas may strike us with their far-reaching incomprehensibility.

> A book of alchemy appears to us a tangled muddle of fantastic pictures, empirical observatons and distorted views of earlier centuries. We find symbols in it which are dealt with as things, and things possessing features of symbols, mystical correlations between phenomena which we consider to be distant from one another, a strange mood of bombastic mysteriousness, a clumsy manner of argumentation and expression of thoughts, and curious confrontations. No picture of our own reality can replace the descriptions found there, no problem corresponds to present-day one, no solution can be reproduced exactly. (Fleck, 1936/1986, p. 89)

Yet, argues Fleck (1935/1979), a closer study shows that these archaic ideas contain elements from which our present-day notions and views developed. Many established scientific facts are "linked in their development, to prescientific, somewhat hazy, related proto-ideas or pre-ideas" (Fleck 1935/1979, p. 23). These proto-ideas are neither right nor wrong, because they are too vague to be true or false. They are plastic and malleable and should be "regarded as developmental rudiments of modern theories," which originated from a socio-cogitative foundation (Fleck, 1935/1979, p. 25). They emerge from a chaotic mixtures of ideas, over many epochs, and become more and more substantial and precise (Fleck, 1935/1979, p. 23). For the members of the collective[3] that upholds a proto-idea, the idea appears both obvious and natural, and it suggests its own indispenability. A proto-idea retains this quality of seeming obvious even after the differentiation and the transformation of the notions which comprise it. It "becomes then a subconscious guiding principle for the development of notions" (Fleck 1936/1986, p. 93).

Fleck gives various examples of proto-ideas and their expressions in modern theory. For example, the so-called Wasserman reaction, which was used to redefine syphilis, expresses a proto-idea—the idea of syphilitic blood. For another example, the notion of organism as a closed unit and the hostile causative agents invading it, which is the basis for the concept of infectious disease, originated in the myth of disease-causing demons that attack man. The "evil spirits became the causative agents; and the idea of ensuing conflict, culminating in a victory construed as the defeat of that 'cause' of disease, is still taught today" (Fleck, 1935/1979, pp. 59–60). It might be disputed that, although this notion of organism as a closed unit originated from the myth of the disease-causing demon, it was accepted because of experimental reasons. However, Fleck argued that not a single experimental proof existed that could force an unbiased observer to adopt such an idea. In particular, he pointed out that "an organism can no longer be construed as a self-contained, independent unit with fixed boundaries" (Fleck, 1935/1979, p. 60). The upshot is that by studying the history of a contemporary scientific fact (model or theory), we could see how a proto-idea that guided the "discovery" of this fact has been developed and substantiated in that fact and that the transformation and substantiation of the proto-idea into a scientific fact was not necessitated by observation or logic: it was the result of a historical process, which was influenced by cultural and social factors.

The study of the history, philosophy, sociology, and anthropology of science could also promote tolerance and respect for different cultures and conceptions of the world. The traditional "Whiggish" conception of the history of science portrays the discoveries of modern science as the culmination of a long process of advancing knowledge and civilization. This view of the history of science has been the subject of heavy criticism in the second part of the 20th century and the 21st century. Yet, it is deeply entrenched among scientists and the wider public, and it naturally cultivates attitudes that do not pay due respect to past science or contemporary conceptions that are substantially different from those of modern science. By contrast, a study of the history of science along recent historiographies that recognize the social–historical situatedness of scientific knowledge promotes respect for past science and, more generally, for other conceptions of the world.

Finally, studying science through studying the history, philosophy, sociology, and anthropology of science could inspire students to develop creativity, open-mindness, and critical thinking. According to Kuhn (1962/1970), science does not normally aim at major substantial novelties but rather "puzzle solving." Scientists are educated not to challenge the paradigm that governs normal periods of science (i.e., periods of science between scientific revolutions). They are indoctrinated to follow this paradigm and not to engage with its historical or philosophical foundations. Science education is mainly based on training in solving puzzles that the ruling paradigm deems central, and theories are learned through this training. Such training is certainly very important, and Kuhn's portrayal of normal science and its education seems to capture adequately some central aspects of contemporary sciences, especially natural sciences. It does not, however, do justice to the history of science. In the past, an important group of natural inquirers were natural philosophers, and their reflections on the philosophical foundations of their science were part and parcel of their scientific engagment. I believe that K–12 science education could and should contribute to the development of future scientists and citizens that are engaged not only in training and puzzle solving but also with the philosophical and historical foundations of science. Educating students to think like natural philosophers, who are engaged in both puzzle solving and philosophical reflections on the foundations of sciences, would be instrumental to the development of creative and critical thinking.

Notes

1. As Henry (1997, p. 1) notes, the "scientific revolution" is primarily a historian's conceptual category. It is the name given by historians of science to the period in European history when, arguably, the conceptual, methodological, and institutional foundations of modern science were first established. For a criticism of this conceptual category, see, for example, Shapin (1996). Whether the important changes that occur during this period should be called a revolution is not essential for what follows.
2. See, for example, Smith (2009) and references therein.
3. In Fleck's terminology, a "collective of thinking" (*denkkollektiv*).

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References

Alexander, H. G. (Ed.). (1998). *The Leibniz-Clarke correspondence: Together with extracts from Newton's Principia and Optiks*. Manchester, England: Manchester University Press. (Original work published 1956).

Fleck, L. (1979). *Genesis and development of a scientific fact* (T. J. Trenn & R. K. Merton, eds., F. Bradley & T. J. Trenn, trans.). Chicago, IL: University of Chicago Press. (Original work published 1935).

Fleck, L. (1986). The problem of epistemology. In R. S. Cohen & T. Schnelle (Eds.), *Cognition and fact: Materials on Ludwik Fleck* (pp. 79–112). Dordrecht, The Netherlands: D. Reidel. (Original work published 1936).

Galilei, G. (1960). *Il saggiatore, (the assayer)*. In *The controversy of the comets of 1618* (S. Drake, trans.). Philadelphia, PA: University of Pennsylvania Press. (Original work published 1623).

Gascoigne, J. (2006). The nature of study. In K. Haakonssen (Ed.), *The Cambridge history of eighteenth-century philosophy* (pp. 854–872). Cambridge: Cambridge University Press.

Golinski, J. (2005). *Making natural knowledge: Constructivism and the history of science* (2nd ed.). Chicago, IL: Chicago University Press.

Henry, J. (1997). *The scientific revolution and the origins of modern science*. Palgrave: MacMillan.

Hodson, D., & Wong, S. L. (2017). Going beyond the consensus view: Broadening and enriching the scope of NOS-oriented curricula. *Canadian Journal of Science, Mathematics and Technology Education*, *17*(1), 3–17.

Irzik, G., & Nola, R. (2011). A family resemblance approach to the nature of science for science education. *Science & Education*, *20*(7–8), 591–607.

Irzik, G., & Nola, R. (2014). New directions for nature of science research. In M. R. Matthews (Ed.), *International handbook of research in history, philosophy and science teaching* (pp. 999–1021). Dordrecht, The Netherlands: Springer.

Kuhn, T. (1970). *The structure of scientific revolutions* (2nd ed.). Chicago, IL: University of Chicago Press. (Original work published 1962).

Matthews, M. R. (2012). Changing the focus: From nature of science (NOS) to features of science (FOS). In M.S. Khine (Ed.), *Advances in nature of science research: Concepts and methodologies* (pp. 3–26). Dordrecht, The Netherlands: Springer.

Sandoval, W. (2005). Understanding students' practical epistemologies and their influence on learning through inquiry. *Science Education*, *89*(4), 634–656.
Shapin, S. (1996). *The scientific revolution*. Chicago, IL: Chicago University Press.
Smith, M. U., & Scharmann, L. C. (1999). Defining versus describing the nature of science: A pragmatic analysis for classroom teachers and science educators. *Science Education, 83*(4), 493–509.
Smith, P. (2009). Science on the move: Recent trends in the history of early modern science. *Renaissance Quarterly*, *62*(2), 345–375.