FEATURE ARTICLE

Engaging History of Biology: Why Teachers Care and How One Succeeds

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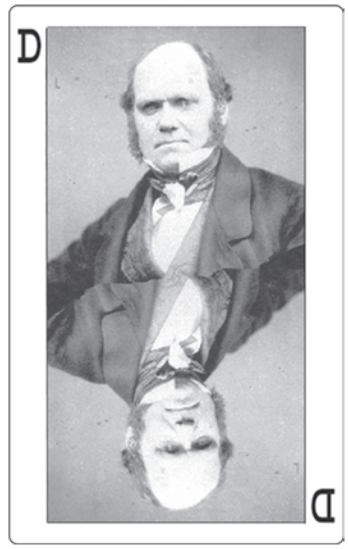

Abstract

American Biology Teacher *has published over seven dozen articles relevant to the history of biology in biology teaching. They are cataloged here and indexed by topic. As reflected in this archive, teachers adopt a historical approach for many pragmatic motivations: (1) to engage students, by contextualizing science culturally; (2) to foster student interest through storytelling; (3) to promote the human dimension of science and offer role models; (4) to exemplify and nurture scientific reasoning; and (5) to convey the ever elusive "nature of science." Here, I summarize and comment on those aims and their relation to the Next Generation Science Standards, and consider briefly some of the practical dimensions for teachers who have not yet engaged with historical approaches.*

Key Words: *history of science; narrative; motivation; nature of science; role models; NGSS.*

Into the classroom walked Gregor Mendel. Although he looked strangely like their regular biology teacher. And he began to share stories from his life and his experiments on hybridization in pea plants, inviting students to help him interpret his data. . . .

Some themes percolate through the *American Biology Teacher* (*ABT*) for years, perhaps unnoticed by many readers. Browsing through my collection of past issues, I was impressed by the recurrent "discovery" of the value of history as a tool in teaching biology. I was also deeply impressed by the enthusiasm of the reports from authors, eager to share their insights. At the same time, there was little cross-referencing between these accounts. Little synthesis. Hence, this review: a history of the history of biology in biology teaching (or "H.O.B.Bi.T.," if you would like a nod to the theme of storytelling). Namely, *what can we learn from our peers' many first-hand reports about how historical perspectives have enriched their classrooms?*

> ABT *authors over several decades have concurred on the virtues of history as a tool for enriching science education.*

I have endeavored to be comprehensive, consolidating dozens of articles. At the same time, I hope to have distilled the most common threads and culled the most valuable insights, while intermittently quoting the authors—the key information for teachers who may yet have no affinity for using history. As detailed in the first section below, biology teachers adopt a historical approach for many pragmatic motivations. History is not for its own sake, to displace the biology. Rather, historical perspectives are both a vehicle for engaging students and an indispensable lens for appreciating many *ideas about* science. Next, I present a synoptic summary of some of the resources to be found within the pages of this journal (and elsewhere). I then address the relevance of history to the omnipresent Next Generation Science Standards (NGSS). Finally, I offer some practical advice for how inexperienced teachers may confidently step into history, and fit it comfortably into their existing curriculum.

○ Why Do Biology Teachers Value History?

Over six decades, ABT has published nearly eight dozen articles engaging historical perspectives, cataloged in Table 1. (Note that I will be citing references from this list using bracketed numbers.)

Among the many authors, there is no one single reason for tapping into history in the biology classroom. And most decidedly, the view is *not* to try to wedge history into an already crowded curriculum, or to eclipse biology as the primary focus. Rather, history is regarded *as a tool* for more effective biology lessons, especially concerning scientific practices (see section on the NGSS below) and other difficult topics. For example, Philip Eichman [48] noted, "I do not mean here the 'history of science,' which is an academic discipline in itself. 'Historical background material' is a better description of what I am talking about. This could include persons, places, events, ideas and experiments of the past" (p. 200; see also [23, 57]).

From scanning *ABT*'s historical collection, several themes on profiting from the history of biology emerge. Each theme offers a

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Table 1. Articles in *American Biology Teacher* addressing the history of science.

[1] Allchin, D. (1999). The tragedy and triumph of Minamata. 61, 413-419.
[2] Allchin, D. (2005). William Harvey and capillaries. 67, 56-59.
[3] Allchin, D. (2007). Was Darwin a Social Darwinist? 69, 49-51.
[4] Allchin, D. (2008). Marxism and cell biology. 70, 303-305.
[5] Allchin, D. (2008). Nobel ideals and noble errors. 70, 389-392.
[6] Allchin, D. (2008). Monsters and the tyranny of normality. 70, 117-119.
[7] Allchin, D. (2011). The domesticated gene. 74, 120-123.
[8] Allchin, D. (2012). A comedy of scientific errors. 74, 530-531.
[9] Allchin, D. (2012). To be human. 75, 132-135.
[10] Allchin, D. (2013). Ahead of the curve. 75, 72-74.
[11] Allchin, D. (2013). Deciphering how cells make energy: an acid test. 75, 598-601.
[12] Allchin, D. (2014). On genius and happenstance in scientific discovery. 76, 145-148.
[13] Allchin, D. (2014). Out of balance. 76, 286-290.
[14] Allchin, D. (2015). Hooks, lines, & sinkers. 77, 718-720.
[15] Allchin, D. (2015). Listening to whales. 77, 220-222.
[16] Allchin, D. (2016). Is science self-correcting? 78, 695-698.
[17] Allchin, D. (2017). Does the evidence speak for itself?: Archibald Garrod & inborn errors of metabolism. 79, 335-337.
[18] Allchin, D. (2017). From snakebites to serpentariums. 79, 428-430.
[19] Allchin, D. (2018). The politics of biodiversity speak. 80, 397-400.
[20] Allchin, D. (2019). From Leopold's land ethic to ecological hubris. 81, 291-93.
[21] Allchin, D. (2019). Science without shiny labs. 81, 61-64.
[22] Allchin, D. (2020). The counter-roll in science. 82, 188-191.
[23] Allchin, D. (2020). Role models and real people. 82, 365-365.
[24] Allchin, D. (2021). The vaccine skeptics of 1731. 84, 53-54
[25] Allen, G.E. (1970). Intellectual history as an organizing principle. 32, 277-280.
[26] Aulie, R.P. (1970). On the idea of the nitrogen cycle. 32, 461-471.
[27] Aydin, S.O. (2015). Considering the role and nature of the scientist: The case of Darwin and evolution. 77, 94-97.
[28] Bajema, C.J. (1985). Charles Darwin and selection as a cause of adaptive evolution, 1837-1859. 47, 226-232.
[29] Baumel, H.B. & Berger, J.J. (1976). Increasing student understanding of the scientific enterprise. 38, 302-303.
[30] Berry, J.M., Jr. (1971). Great men, paradigms and scientific revolutions. 33, 345-347,354.
[31] Bicak, L.J. & Bicak, C.J. (1988). Scientific method: historical and contemporary perspectives. 50, 348-353.
[32] Bierema, A.M.-K. & Rudge, D.W. (2014). Using David Lack's observations of finch beak size to teach natural selection & the nature of science. 76, 312-317.
[33] Biermann, C.A. & Grinstein, L.S. (1994). Despite the odds: Women biologists who succeed. 56, 468-475.
[34] Brandiss, T. (1999), Heroes for our students. 61, 108-115.
[35] Brown, W.E., Jr. & Williams, R.P. (1990). Ignaz Semmelweis & the importance of washing your hands. 52, 291-294.
[36] Byington, S. (2001). Spontaneously generating life in your classroom? Pasteur, Spallanzani & science process. 63, 340-345.
[37] Carroll, S.B. (2018). The power and place of stories in biology class. 80, 557-559.
[38] Charney, S. (1961). A method for recent proposals. 23, 135-136.
[39] Clary, R.M. & Wandersee, J.H. (2006). Mary Anning: She's more than "seller of sea shells at the seashore." 68, 153-157.
[40] Clopon, J.R. (2010). Narrative accounts of research for teaching the processes of science. 73, 8-14.
[41] Crenshaw, N. (1979). Teaching the history of science through inquiry. 41, 564-565.
[42] Dai, P. & Rudge, D. (2018). Using the discovery of the structure of DNA to illustrate cultural aspects of science. 80, 256-262.
[43] Daisey, P. (1996). Promoting interest in plant biology with biographies of plant-hunters. 58, 396-406.
[44] De Beer, J. & Whitlock, E. (2009). Indigenous knowledge in the life sciences classroom: put on your De Bono hats! 71, 209–216.
[45] De Beer, J. van Wyk, B.E. (2011). Doing an ethnobotanical survery in the biology classroom. 73, 90-97.
[46] DeMarco, L. & Jungck, J.R. (1985). Rosalyn S. Yalow: "Opening new vistas." 47, 137, 141.
[47] Dennison, R. (1993). Using Darwin's expermental work to teach the nature of science. 55, 50-52.
[48] Eichman, P. (1996). Using history to teach biology. 58, 200-204.
[49] Emani, C. (2010). Using the "DNA story" to inculcate a scientific thought process in the classroom. 72, 410-413.
[50] Evans, J.P. (2020). Still learning from Gregor Mendel after 200 years. 84, 8-13.
[51] Farber, P. (2003). Teaching evolution and the nature of science. 65, 347-54.
[52] Flannery, M. (1992). Lives in science. 54, 375-378.
[53] Flannery, M. (1998). Aldo Leopold reconsidered. 60,148-151.
[54] Flannery, M. (2000). Nothing was easy. 62, 520-524.
[55] Gauld, C. (1992). Wilberforce, Huxley and the use of history in teaching about evolution. 54, 406-410.
[56] Harley, S.M. (2010).Charles Darwin's botanical investigations. 72, 77-81.
[57] Hendrick, R. (1991). Biology, history and Louis Pasteur: A new approach to teaching science. 53, 467-477.
[58] Hoh, Y.K. (2009). Using biographies of outstanding women in bioengineering to dispel biology teachers' u misperceptions of engineers. 71, 458-463.
[59] Howe, E.M. (2007). Addressing nature-of-science core tenets with the historyof science: an example with sickle-cell anemia &malaria. 68, 467-472.

Continued

Table 1. *Continued.*

[60] Howe, E.M. (2009). Henry David Thoreau, forest succession & the nature of science: a method for curriculum development. 71, 397-404.	[84] Walsh, J.A. (2014). The jealousy of scientific men. 76, 23-27.
[61] Jensen, M.S. & Finley, F.N. (1997). Teaching evoluton using a historically rich curriculum & paired problem solving instructional strategy. 59, 208-212.	[85] Wayne, R. & Staves, M.P. (1998). Connecting undergraduate plant cell biology students to the bioloigsts about whom they learn: A bibliography. 60, 501-512.
[62] Jungck, J.R. (1984). Rosalind Franklin: "Bold experimentalist." 46, 430, 472.	[86] Wieder, W. (2006). Science as story: Communicating the nature of science through historical perspectives on science, 68, 200-205.
[63] Jungck, J.R. & Bybee, R. (1984). Rachel Carson: human ecologist. 46, 302-303.	[87] Williams, C.T. & Rudge, D. (2015). Mendel and the nature of science. 77, 492-499.
[64] Krupa, J.J. (2014). Scientific methods & evolutionary theory elucidated by the ivory-billed woodpecker story. 76, 160-16.	[88] Witucki, A., Seals, L. & Rudge, D. (2018). Typhoid Mary: A story-based approach to the teaching of epidemiological concepts. 80, 477-482.
[65] Lenning, E. & Rudge, D. (2023). Using the discovery of penicillin resistance to teach nature of science and natural selection. 85, 135-140.	[89] Young, C.C. (2000). A textbook history: Use of the Kaibab lesson in teaching biology. 62, 559-564.
[66] Love, A.C. (2010). Darwin's "imaginary illustrations": Creatively teaching evolutionary concepts & the nature of science. 72, 82-89.	[90] Zaitsev, I.V. (2009). Prions: Introducing a complex scientific controversy to a biology classroom. 71, 525-530.
[67] McComas, W.F. (1997). The discovery & nature of evoluton by natural selection: Misconceptions & lessons fom the history of science. 59, 492-500.	[91] Zevenhuizen, E. (2022). Recognizing Mendel: Rediscovery, discovery, or neither? 84, 14-15.
[68] McComas, W.F. (2012). Darwin's error: Using the story of pangenesis to illustrate aspects of nature of science in the classroom. 74, 151-156.	[92] Mysliwiec. T.H. (2003) The genetic blues: Understanding genetic principles using a practial approach and a historical perspective. 65, 41-46.
[69] Morton, E.A. & Talyor, M.B. (2022). Teaching molecular biology with the historical accounts in *The Eighth Day of Creation*. 84, 45-49.	[93] Allchin, D. (2009). Celebrating Darwin's errors. 71, 116-119.
[70] Posner, H.B. (1996). Teacbing introductory cell & molecular biology: A historical & empirical approach. 58, 272-274.	--
[71] Quinlan, C.L. (2020). Expanding the science capital in K–12 science textbooks: A notable doctor's insights into biology & other accomplishments of African American scientists. 82, 381-388.	[A] Allchin, D. (2010). Debating Rachel Carson's *Silent Spring*. SHiPS Resource Center. http://pesticides1963.net
[72] Randak, S. (1990). Historic role-playing. 52, 439-442.	[B] Clough, M. (Ed.) (2010). *The Story Behind the Science*. http://StoryBehindTheScience.org
[73] Shodell, M. (2010). Using a 17th-century experiment as a gateway to critical assessment of scientific reports. 72, 16-19.	[C] Friedman, A. (2010). Alfred Russel Wallace & the origin of species. SHiPS Resource Center.
[74] Shotwell, M. (2021). The misuse of pedigree analysis in the eugenics movement. 83, 80-88.	[D] Gabel, K. & Allchin, D. (2017). Archibold Garrod & the black urine disease. SHiPS Resource Center.
[75] Simon, S.E. (1985). Jane Goodall: Living with close relatives. 47, 267-269.	[E] Gros, P.P. (2010). Carlton Gajdusek & kuru. SHiPS Resource Center.
[76] Small, P.A., Jr. & Small, N.S. (1996). Mankind's magnificant milestone: Smallpox eradication. 58, 264-271.	[F] Hagen, J., Allchin, D. & Singer, F. (1996). *Doing Biology.* Glenview, IL: Harper-Collins. http://doingbiology.net
[77] Stansfield, W.D. (2012). The discovery of insulin: A case study of scientific methodology. 74,10-14.	[G] Klopfer, L. (Ed.) (1964). *History of Science Cases*. Chicago: Science Research Associates. http://shipseducation.net/hosc
[78] Stansfield, W.D. (2013). Teaching evolution & the nature of selection via the history of debates about levels at which natural selection operates. 75, 96-100.	[H] Leaf, J. (2010). Charles Keeting & measuaring atmospheric carbon dioxide. SHiPS Resource Center.
[79] Steglich, C.S. (2000). A writing assigment that changes attitudes in biology classes. 62, 98-100.	[I] Leland, T. (2007). Interpreting Native American herbalism. SHiPS Resource Center.
[80] Swab, J.C. (2010). Introducing students to Charles Darwin via the voyage of *HMS Beagle*. 72, 281-286.	[J] National Library of Medicine. (2023). Charles R. Drew – educational resources. https://profiles.nlm.nih.gov/spotlight/bg/feature/educator
[81] Vigue, C.L. (1976). A short history of the discovery of gene function.38, 537-541.	[K] Remillard-Hagen, E. (2007). Lady Mary Wortley Montagu & smallpox inoculation in 18th-century England. SHiPS Resource Center.
[82] Vigue, C.L. (1984). Oswald Avery and DNA. 46, 207-211.	
[83] Voltchow, J. (2017). Traveling with Charlie: The voyage of the *Beagle* as an introduction to the natural history of South America. 79, 151-155.	

separate motivation, variously emphasized in different lessons. Collectively, however, they provide potent reasons for venturing into history (echoed in other views from the classroom—for example, Allchin, Andersen & Nielsen, 2014; Seker & Welsh, 2003; for more academic reviews, see Allchin, 2013; McComas, 2020a). In a complementary paper (Allchin, 2024), I discuss a framework for combining and integrating these benefits.

1. Motivating Students: Contextualizing Science

Teachers generally readily acknowledge that their primary challenge is motivating students. Why should anyone care about learning this particular topic in biology? *History provides cultural and human context.* Why did this topic matter socially, such that anyone would fund studying it? What motivated a particular scientist to research it? What biographical background—perspectives and resources—did that person bring to the task? Namely, history (in the classroom teacher's jargon) is a powerful "hook."

Teachers often talk about hooks, the strategies used to garner attention and engage students in the forthcoming lesson. For all their importance in classroom practice, they are generally disregarded by academic educators. But they are critical to the primary challenge of motivating students (Allchin, 2015). "Education is not the filling of a pail, but the lighting of a fire" [64, quoting Yeats, p. 160]. Hooks come in a variety of forms. One popular strategy is to secure attention through sheer *spectacle* or *wonder*: an "ooh-aah" moment (or perhaps even an "ew-gross!"). These command attention. But, alas, often all too briefly, for just that moment. The segue to the lesson may be tenuous. The initial enthusiasm quickly wanes.

Another common tactic is to tap into a contemporary socio-scientific issue. Here, the hook exudes here-now *relevance*. This has more staying power because students want to learn something personal (that might help them navigate an active controversy) or collect information that is potentially valuable currency in their social networking. The risk, however, is that student focus will be superficial, waiting only for quick fixes, rather than delving into the biology conceptually.

History, by contrast, provides (in a sense) the *ultimate relevance*. What motivated someone to pursue this topic originally? History provides two layers of context—both of which simultaneously contribute to broader lessons in the nature of science. First, why did the knowledge matter culturally? How was it meaningful to society—to health, to farming, to the environment, to understanding who we are, or perhaps merely to making a profit or securing more power? Second, why did it matter personally? Why did an individual care about the "abstract" knowledge? All this humanizes the science. It tends to tap into a sense of curiosity, which can be sustained throughout an entire lesson. The historical discovery will eventually lead to the current applications (a satisfying capstone at the end of the lesson?).

As a measure of the increased motivation based on history, teachers report that students listen better; they ask more questions; they talk about biology outside of class; they report more enthusiasm and are eager for the next occasion; and some enroll in subsequent classes or change their major.

2. Engaging Students: Storytelling & Narratives

Another motivational challenge is *sustaining* student engagement. Here, teachers who draw on history frequently allude to *the power of narrative*. Namely, we fill our lives with stories, from gossip to sharing "how-to" videos on YouTube to great sagas in entertainment. Junior college instructor Joe Clopon observed, "Stories, seemingly, are everywhere. We construct them to explain daily events, pass them about in conversation, tell them to our children, and enjoy them in books and films. Even our sense of self, that internal monologue that pervades our consciousness, is a story—one we constantly update" [40, p. 8]. HHMI and NABT luminary Sean Carroll echoed that sentiment. "Stories typically embed content into vivid imagery and characters that inspire our imagination and arouse our emotions." Namely, stories are more memorable. "Good stories," he contends, "make for good pedagogy" [37, pp. 557, 558].

Indeed, "thinking in terms of stories is deeply ingrained, perhaps innately in the circuitry of the brain" [40, p. 8]. Carroll speculates that it may be an evolutionary adaptation for learning cause and effect, or stimulus and appropriate response (see also Hadzigeorgiou, 2016; Newkirk, 2014). It is "a form [of explanation] that shows how and why things happen" [40, p. 8]. Humans are deeply social animals and social learning is integral to our make-up (Mercier & Spencer, 2017; Sharot, 2017). We typically share our knowledge via stories (outside schools, at least!). As biologists, perhaps we should heed the implications of the very science of storytelling (Gopnik, 2012)? *ABT* authors certainly repeatedly attest to the power of stories to engage students.

Here, a story is more than a brief anecdote or amusing vignette. It is an extended plotline that carries the students along. Narratives provide *lines* that thread lessons together, contextualize the abstract concepts, and give them coherence [14]. History can also structure a learning sequence across an entire semester (e.g., [69, 70]). Namely, stories are not diversions, for entertainment value. Appropriately framed, they help students focus on the biology itself.

Stories of scientific investigations can also render scientific practices in an authentic context. They "give the student an idea of how scientists work and how it really feels to be engaged in scientific endeavor" [38, p. 135]. They implicitly *explain* how science works. Psychologist Jerome Bruner regards science as "narratives in problem solving" (quoted in [37]). At the same time, stories link science-in-action to human emotion, or the passion that motivates the researchers themselves [69]. That is, the story format helps convey the process of science (as elaborated below), but (as noted above) in a vivid human and cultural context.

Attuned to stories, one may first consider briefly the properties that make the narrative format so effective. One is the familiar human framework. It makes sense to students. Educational professionals are generally committed to intellectual perspectives. They can easily forget how students think—embedded in their TikTok posts and Instagram feeds, and managing their status in a social network. Abstract ideas are inherently foreign (however fascinating to teachers). Stories, with human agents and emotions, help situate biology in everyday terms.

Second, teachers may be alert to the role of narrative tension (Klassen & Froese Klassen, 2013). As any mystery or novel reader knows, a good plot generates expectations and unfinished events, which engage the reader in anticipation. Turns of the plot—unexpected scientific results, failed experiments, skeptical colleagues—all help students connect with the scientific enterprise and the fate of conceptual content-in-the-making. (The history of science rarely wants for drama!) Teachers should thus not shy away from dramatizing the data and the uncertainty.

In the end, the discovery, when ultimately revealed, helps resolve the plot tension. Good narratives, having begun with a "hook" and followed a story "line," end with a satisfying "sinker" [14]. Sinkers bring closure. The resolution helps root the concept, the endpoint of the story, in student memory. Ironically, perhaps then, *historical* narratives are tools to promote better *biological* learning.

Finally, one should not overlook the social role of stories. As noted by conservationist Terry Tempest Williams, "Stories bind. They are connective tissues. They are basic to who we are" (quoted by [40]). Psychologically, the very act of storytelling helps link storyteller and listener *socially* (Gilovich, 1993, pp. 91–94). Accordingly, the stories may become interactive. Teachers, as storytellers, may interrupt their narrative to invite comment or ask what students think will come next (e.g., [39]). Stories help nurture the *teacher-student relationship*, which is integral to establishing the personal trust upon which effective education depends (Allchin & Dittmer, 2019).

3. Inspiring Students: Celebrating Science, Humanizing Scientists

For biology teachers, biology is thrilling. For students, typically less so. Years later, students tend to remember foremost trudging through Punnett squares, suffering through traumatic dissections, or labeling the parts of a cell or the stages of mitosis. Boooor-ing!

Of course, most biology teachers hope to convey otherwise. Here, history is a valuable resource. "Science is no longer a 'dry body of facts,' but rather an active, developing human endeavor. Scientists become real persons and discoveries, experiments and abstract thoughts become linked to real human beings" [48, p. 201]. Even Charles Darwin [27, 80]. "It is this human dimension that is generally missing in science instruction. We have traded people for facts. Nature does not do biology, people do. However, our students will come to know this only when we reinvigorate biology education by restoring the human dimension of science in an engaging and accurate fashion." [67, p. 499]. "Historical perspectives allow students to identify with, learn about, and empathize with scientists who made important contributions to our understanding about the world, thus increasing student motivation" [86, p. 203]. That is, when they encountered history, "students identified with the *people* involved in science, not the traditionally communicated *product* of science" (p. 202; see also [85]). Some teachers even make the biology "alive" by appearing in class as a historical scientist (see opening above; cover photo or Eakin, 1975). "Role-playing a Darwin or a Mendel makes these historic figures appear as real people with all the hopes and doubts of real people. It helps to make their science real. It will excite your students and rejuvenate you. Quite simply, it is fun" [72, p. 442]. History is a tested route to the oft-cited aim of humanizing science, or portraying its human dimensions.

In this way, perhaps, history is not a stranger to the biology classroom. Most teachers celebrate the discoveries of Darwin, Mendel, and Watson & Crick (e.g., [28, 49, 50, 80, 86, 87]). Pasteur, too [57]. It is an occasion to celebrate scientific achievements, and to reinforce the value of the scientific enterprise in our culture. And to convey the thrill of doing science (e.g., [52, 69]). So, one way to raise interest in plants is by contextualizing them in the adventures of plant collectors [43], see also Flannery, 2024, and book review, 2024.

It is also an occasion to honor the discoverers themselves. Alexander Fleming, Barbara McClintock, Gerty Cori, or Ernest Everett Just, among others. In this way, historical figures become potential role models [34]. And that usually involves learning more about the scientists' personal lives, not just the raw facts of their discoveries [58, 79]. As Sean Carroll noted, "By offering students glimpses into the hearts and lives of scientists—their passions, aspirations, struggles, setbacks, and the price many willingly pay to do what they love—stories offer one of the most precious gifts any student may receive—inspiration" [37, p. 559]. "Nothing was easy" [54].

That can be especially important to addressing the disparities in participation in science based on gender, race, ethnicity, or other political factors. History offers an opportunity to celebrate women scientists, such as Mary Anning [39], Rosalind Franklin [42, 62, 84], Rachel Carson [63], Jane Goodall [75], Mary Leakey [37], Rita Levi-Montalcini [52], Rosalyn Yalow [46], Maria Sibylla Merian, and many others [33, 58]. And African American scientists too, such as Charles Drew, pioneer in blood preservation and blood banks [71]. Or indigenous scientists (mostly unnamed) [21, 44, 45]. Of course, one might equally celebrate even the less heroic scientists, the lab technicians and assistants—some anonymous—and those who helped nudge "normal science" along in small increments ([30]; Conner, 2005). Fruitful contributions to science occur at many levels. If we do not make their history explicit, they remain invisible. Namely, portraits from the past can be a tool for promoting social justice and inclusiveness today.

4. Modeling and Nurturing Scientific Thinking

Many teachers strive to go beyond conceptual content and help students appreciate the process of science and develop skills in scientific reasoning. For example, the NGSS underscores the significance of learning scientific practices. The aim is twofold: (1) to develop individual skills in investigation and problem-solving, and (2) through meta-reflection, to learn how science justifies its claims. Such abilities obviously help those who will ultimately pursue careers in science. But they are also regarded as critical to citizens and consumers in evaluating scientific claims relevant to social policy or personal lifestyle choices.

Here, history can again be a valuable tool (e.g., [31, 40, 49, 77]; see also Boston Working Group, 2013). Namely, history of science is also a "how story" of science. One approach is to have students read about how scientists in the past reasoned — about framing questions, developing hypotheses, designing experiments, interpreting data, responding to criticism, and so forth. With additional analysis and questions as prompts, students may learn to understand and adopt those patterns of reasoning themselves (one hopes) [e.g., 29, 49, 66, 69]. Popular books are frequently available. For example, past favorites of biology teachers have included: Richard Preston's *The Hot Zone,* Jonathan Weiner's *The Beak of the Finch*, and Rebecca Skloots' *The Immortal Cells of Henrietta Lacks* (for lists in *ABT*, see [40] and [71]). A recent collection of short stories is Carroll's et al. (2018) *The Story of Life*. Other collections, with embedded questions, include Hagen et al.'s *Doing Biology* (1996, now available free online) and the *Story Behind the Science* website (see Clough, 2024). Optionally, stories may be supplemented with labs (e.g., [33, 35, 36, 87, 88, G]).

Currently, however, the most commonly recommended method for teaching scientific thinking seems to be student inquiry—investigations led by students, ideally on questions posed by students. This approach certainly promotes "ownership." Yet it also requires an immense investment of time. It may also be limited by the current reasoning tools of the students themselves. An alternative, therefore, is to use history to structure and guide inquiry (e.g., [41, 60]). "Historical perspectives without investigative activities fail to convey the nature and process of science.... These pitfalls may be avoided by synthesizing inquiry-based learning opportunities with historical perspectives that contextualize science and make it relevant to students' lives" [86, p. 201]. For example, one can situate questions in historical scenarios—perhaps in the spirit of peering over the shoulders of notable historical scientists, and being invited to participate on occasions (e.g., [24, 47, 59, F, G]). Using history, one can condense a vast scope of research into the scale of the classroom by focusing on key moments for inquiry, linked by narrative. Again, this pedagogical approach is hardly new. In 1961, Sol Charney advised *ABT* readers, "This method actually enables the student to be engaged in studying basic research by going to primary source material of great biologists, repeating original experiments, and reforming basic concepts and theories" [38, p. 135]. The challenges of weaving inquiry into a historical narrative, punctuated by interruptions, is addressed more fully in a complementary article (this issue, pp. 599–604; see also Allchin, 2017, 2020).

Note, however, that adapting history for inquiry involves a significant transformation in the style of narrative: from a story of the past, whose endpoint is already known, to an unfolding present-tense narrative, blind to the outcome. Historical science needs to be restored to its original context, as "science-in-the-making" (e.g., Flower, 1995). Namely, no spoilers! Accordingly, the narrative that provides a storyline, or underlying structure, is likely to become more a lineage of *questions* than a predictable string of successive discoveries (Allchin, 2015, 2017, 2020; Farber, 2003). This reorientation is essential to learning how to reason *from* evidence *to* conclusions, rather than to starting with a "conclusion" and rationalizing it with cherry-picked evidence and selective arguments. In today's climate of disinformation, we desperately need to teach that true scientific thinking is based on the former, not the latter.

5. Understanding the Nature of Science

In addition to helping students develop scientific ways of approaching problems and appraising scientific arguments, a major goal of many teachers is to convey *ideas about* science. How does science work? (How does it occasionally fail?) This topic seems especially important now, in light of the apparent crisis in trust about science. Namely, how might we bolster trust in science through historical stories and understanding?

The nature of science, or NOS, can be a rather contentious topic among academics. But the basic pedagogical notion is that nonscientists, as well as scientists themselves, need to have a meta-appreciation of "scientific practices" and science in context. This is where teachers most consistently turn to history. That is, "the history of science shows how discoveries are made, how theories grow and develop, how scientific change is brought about." History illustrates "the way in which the questions are posed, the kind of evidence sought in answer to them, and the ways in which the same information can lead to different answers—all give the student some sense of the many factors (some of them subjective) that are involved in scientific research" [25, p. 277].

Many *ABT* authors seem to have developed their appreciation of history and NOS intuitively, through informal practice and their own encounters with history. However, more disciplined analysis tends to confirm this. In addition, formal research on NOS education across all science subjects indicates that history proves an effective approach, besides inquiry (e.g., see Deng et al., 2011 for a synoptic review of NOS studies published between 1992 and 2010, and a further summary in Allchin et al., 2014).

Three features of the nature of science regularly appear in historically based lessons in *ABT*. First: *conceptual change*. In oft-used language, science is "tentative"—although a better term might be *provisional*. Namely, with more evidence later, scientists can find errors. History helps render those occasions as "reasonable." That is, even when scientific knowledge is upended, it should not threaten its status as being the most trustworthy source of knowledge [e.g., 5, 59, 68, 87, 89, 93].

The second common NOS feature in historical lessons is *uncertainty* and contingency. Knowledge is not pre-established, awaiting "discovery." Rather, science is *constructed*. Debate is common. It requires work to resolve disagreement between alternatives. Most notably, that sense of science-in-the-making applies to contemporary science [e.g., 16, 60, 69, 90].

Third, history helps delineate the *limits of science*. Science addresses empirical and causal questions only, not issues related to ethics, religiosity, or values. Historical cases help illustrate and articulate these boundaries [e.g., 19, 20, 55, 61, 68, 74, 88].

All three of these ideas about science seem especially relevant in addressing questions about the trustworthiness of scientific claims—a topic made more urgent recently by widespread disinformation about vaccines, the COVID pandemic, climate change and other topics.

"The" nature of science is not one thing. It is an ensemble of ideas. Thus, NOS lessons from history are hardly limited to these major, recurring themes. One finds *ABT* authors discussing many ideas:

- the role of criticism and debate [e.g., 55, 78, 90]
- the role of chance [e.g., 77]
- the role of framing empirical questions [e.g., 47]
- the role of argumentation [e.g., 73]
- the role of personality [e.g., 49, 57, 84]
- scientific trends vs. revolutions [e.g., 30]
- cultural source of scientific ideas [e.g., 9, 19, 57, 74]
- emotions and research style [e.g., 69]

These further insights help contribute to a complex, well informed view of the nature of science. Further, the diversity of features—as highlighted by practicing teachers—may indicate that fruitful NOS lessons are not limited to a predetermined "consensus list." Rather, any historical episode, rendered with enough context and detail, is likely to reveal something important about NOS. Accordingly, teachers should feel free to venture into and use historical perspectives unconstrained by prescribed lists about NOS.

Finally, one should note that striving for NOS lessons from history does place a modest burden on the teacher. If the history is ill informed, the NOS lessons will be distorted or misleading. Accurate history from well informed sources is essential (e.g., [2, 67]; Barnes, 2017).

Synergy

Overall, *ABT* authors regularly report finding historical approaches "*rewarding*." That is, students respond favorably, creating a more congenial classroom atmosphere. Their other verdict is: historical approaches are effective. Teachers observe not only stronger student interest, but also stronger performance, whether about biology content or NOS understanding. Students sometimes comment on this spontaneously. There is something about history beyond just avoiding another dry lecture. Equally remarkable, perhaps, all these benefits—motivation, engagement, role model inspiration, and hard-to-secure lessons in scientific thinking and NOS—emerge from adopting just one approach. A historical orientation comfortably integrates them, through the "naturalness" of human stories. For a model synthesizing these various virtues see the complementary paper in this issue (pp. 599-604).

Table 2 presents the repertoire of lessons published in *ABT*. They are organized by topic (paralleling common textbook outlines) to facilitate finding something for any particular occasion. The lessons encompass all aspects of a standard curriculum (core concepts are listed in column 1). (Note, too, the special "Scientific Practices" section at the end.) Important NOS features for each case are noted (column 3). Also indicated are lessons in inquiry mode (I), with original data or observations, or quotes (O), and labs (L). Many of these resources are classroom-ready, having been developed through classroom use. Others need only minimal adaptation to local needs or contexts. The articles are all available through the online archive (free to NABT members). The final column identifies relevant lessons in other prominent online collections.

Table 2. Historical lessons in American Biology Teacher and online collections, organized by biological topic. (Column headings include: L=Lab; I=Inquiry; O=Original data, observations or quote).

Topic	*Central Character*	*Nature of Science Themes*	*L*	*I*	*O*	*ABT Reference*	*Other*
EVOLUTION							
natural selection, adaptation	Georges Cuvier, Jean-Baptiste Lamarck, William Paley, Charles Darwin	teleology		+		[28, 61]	[B]
natural selection, speciation	Charles Darwin	historical misconceptions				[67]	
natural selection, biogeography	Alfred Russel Wallace	simultaneous discoveries; "genius" & intellectual context		+		[12]	[B, C]
natural selection: competition	David Lack	field work vs. laboratory experiments	+	+	+	[32]	
natural selection: antibiotic resistance	Edward Abraham & Ernst Chain	evidence vs. creativity		+	+	[65])	
natural selection	Charles Darwin	limited evidence; thought experiments			+	[66]	
adaptation: animal coloration	Abbott Thayer; Theodore Roosevelt	field observation vs. experiment				[57]	
evidence for evolution	Samuel Wilberforce	criticism & debate; cultural contexts				[55]	
natural selection: peppered moth	Bernard Kettlewell	experimental design & controls		+			[F]
phylogeny, sexual selection, biogeography: ivory-billed woodpecker		hypothesis generation; evidence		+		[64]	
fossils	Mary Anning; Henry de la Beche	women scientists		+		[39]	
pangenesis	Charles Darwin	errors; subjectivity; empiricism			+	[68]	
sickle cell anemia & malaria	Anthony Allison and others	conceptual change; cultural contexts; subjectivity; creativity		+	+	[59]	
levels of selection	(multiple)	debates; confirmation bias				[78]	
biogeography	George Gaylord Simpson	alternative theories		+			[F]

GENETICS & DEVELOPMENT							
basic (Mendelian) genetics	Gregor Mendel	biographical & cultural contexts; conceptual change	+	+	+	[50, 87]	[B]
basic genetics	Gregor Mendel	quantification; prematurity				[50]	
basic genetics	Hugo de Vries; Carl Correns; Erich von Tschermak	priority of discovery; delayed acceptance				[91]	
pedigree analysis: methemoglobinemia	Martin Fugate; Cathy Trost	cultural contexts	+		+	[92])	
pedigrees	Charles Davenport	eugenics; errors				[16, 75]	
sex-linked inheritance	Thomas Hunt Morgan	model organisms; chance; conceptual change					[F]
population genetics	J.B.S.Haldane						[F]
insect metamorphosis	Maria Sibylla Merian	women scientists	+			[33]	
teratology	Etienne Serrres; Isidore Geoffroy Saint-Hilaire	naturalizing error				[6]	
MOLECULAR BIOLOGY							
DNA	Oswald Avery	premature theories				[82]	[F]
structure of DNA	Erwin Chargaff; Watson & Crick			+	+	[86]	
structure of DNA	Rosalind Franklin	women scientists		+		[42,62]	[B]
structure of DNA	many	intuition, personality, collaboration, luck				[49]	
DNA to central dogma	many	cultural contexts; errors; conceptual change; research styles; emotions			+	[69]	
one gene, one protein	Archibold Garrod	"premature" theories; conceptual contexts & biases				[17]	[D]
gene function	George Beadle & Edward Tatum; others	piecemeal growth of knowledge				[81]	
sex chromosomes	Nettie Stevens						[F]
MICROBIOLOGY							
handwashing	Ignaz Semmelweis	cultural contexts	+			[35]	
vaccines, pasteurization, fermentation, sterilization	Louis Pasteur	personality; cultural, political and economic contexts of science				[57]	
epidemiology; Koch's postulates	Mary Mallon ("Typhoid Mary")	cultural contexts	+	+		[88]	

Table 2. *Continued*

CELLULAR BIOLOGY							
cell theory	Robert Hooke; Anton van Leeuwenhoek; Robert Brown; Matthias Schleiden; Theordor Schwann	cultural contexts; error; instruments; assumptions; preconceptions; scientific communication; scientific societies	+	+	+		[G]
cells							
organelles	Alex Novikoff	political perspectivies (Marxism)				[4]	
chemiosmosis	Andre Jagendorf	crucial experiments				[11]	
chemiosmosis	Peter Mitchell	paradigm shift/debate		+			[F]
endosymbiosis	Lynn Margulis			+			[F]
citric acid cycle	Hans Krebs			+			[F]
PHYSIOLOGY							
circulation	William Harvey	historical myths				[2]	
blood preservation	Charles Drew	African-American scientists; racial bias				[71]	[J]
immunization / smallpox variolation	Lady Mary Wortley Montagu	credibility; gender bias; cultural bias; research ethics		+		[24]	[K]
vaccines: smallpox	Edward Jenner	cultural contexts; technology				[76]	
prions	Carlton Gajdusek	research ethics		+		[23]	[E]
prions	Stanley Prusiner	scientific debate; uncertainty		+		[90]	
nutrition / vitamin deficiencies: pellagra	Goldberger	uncertainty & debate; error correction				[16]	
nutrition / vitamin deficiencies: beriberi	Christian Eijkman	confirmation bias		+		[20]	[F]
hormones: insulin	Frederick Banting & Charles Best	trial and error				[77]	
immunology /specificity of antigen-antibody response	Vital Brazil	research instruments & tools				[18]	
antibodies: radioimmune assays	Rosalyn Yalow	scientific careers; measurement				[46]	
antibodies: clonal selection theory	Frank Mcfarlane Burnet			+			[F]
homeostasis	Cannon	research ethics (animal experimentation)		+			[F]
pain	acupuncture	cultural contexts & biases		+	+		[F]

PLANTS							
plant hunting & collecting	many	human context; emotions				[43]	
photosynthesis	Joseph Priestley	replication & error				[8][54]	
nitrogen; nitrogen fixation	Jean-Baptiste Boussingault	[see also nitrogen cycle]			+	[26]	
plant sexes	Nehemiah Grew; Linnaeus; and others		+	+	+		[G]
pollination, heterostyly, carnivorous plants	Charles Darwin	copmleteness of observations;				[56]	
ethnobotany	indigenous cultures	cultural contexts; ethics; experience vs. experimentation; relevant variables; publication vs. oral tradition	+			[21][44][45]	[I]
TAXONOMY & DIVERSITY							
Plants v. animals	Abraham Trembley					[54]	
human classification & evolution		naturalizing error				[9]	
biodiversity / conservation	E.O.Wilson	ideological contexts				[19]	
5-kingdom view	Robert Whitaker	creativity					[F]
BEHAVIOR							
bioacoustics (whales)	Roger Payne	chance; environmental ethics; aesthetics				[15]	
eusociality	E.O. Wilson	naturalizing error				[7]	
cooperation	Charles Darwin	assumptions, bias				[3]	
primates	Jane Goodall	careers in science; funding				[75]	
stickleback mating	Niko Tinbergen						[F]
ECOLOGY							
nitrogen cycle	Jean-Baptiste Boussingnault	biographical context; quantification/measurement			+	[26]	
succession	Henry David Thoreau	social context; biographical context		+		[60]	
predator-prey	Aldo Leopold	sampling; errors; preconceptions				[89]	
bioamplification in food chains	Minamata, Japan	sociocultural contexts			+	[1]	
biomes	Charles Darwin	curiosity, record-keeping		+	+	[83]	

Continued

Table 2. *Continued*

ECOLOGY (continued)							
global warming/ Keeling Curve	Dave Keeling	instrumentation, calibration,		+	+	[10]	[B][H]
pesticides, "balance of nature"	Rachel Carson	teleology		+		[13][63]	[A][F]
conservation; "land ethic"	Aldo Leopold	environmental ethics				[20][53]	
biophilia	E.O. Wilson	naturalizing error				[19]	
SCIENTIFIC PRACTICES							
experimentaion	Charles Darwin	experimental questions		+	+	[47]	
controlled experiments	Charles Darwin; Francisco Redi; James Lind; John Snow; Christian Eijkman	comparative nature of controls				[22]	
spontaneous generation	Lazzaro Spallanani; Louis Pasteur	testability; experimental design	+	+		[36]	[B]
scientific discourse	Charles Darwin; Carl Correns; James Watson	competition for credit				[84]	
argumentation	Accademia del Cimento	critical reading; assumptions; controls			+	[73]	
errors	Charles Darwin	errors; bias				[93]	
errors	16 Nobel Prize winners	errors				[5]	

Again, history is not an exclusive approach to teaching NOS (e.g., McComas, 2020b, pp. 75–83). However, it appears again and again (at least among *ABT* authors). As noted above, student-initiated investigation is also a strategy, as is authentic research experiences or the use of contemporary cases, highlighting socioscientific issues. Each approach has its merits, as well as its limits or deficits. These are noted in Table 3 (reproduced from Allchin et al., 2014).

○ History of Science & the NGSS

Adopting history-infused approaches aligns with the NGSS, at least in part. It also helps to expose some of NGSS's shortcomings, if one regards these standards as an exhaustive benchmark. (Here, I situate NGSS among the enduring educational objectives of years past—and likely years to come.)

Using history to model scientific reasoning (#4) certainly reflects NGSS's major focus on "scientific practices." Using history to motivate and engage students (#1, #2) further fosters the end goal of learning both practices and core ideas (the other major focus).

Notably, the NGSS is completely silent on pedagogical methods. Peripheral comments tend to tout student-initiated inquiry as optimal. But the experience of *ABT* authors indicates that historical approaches can be equally, if not more effective, especially in introducing new skills and ways of thinking. NGSS's implicit indifference about teaching method reflects their narrow institutional role. That is, they focus on student performance as a measurable *product*. They do not embody a broader educational philosophy of respect for the student as a whole person. In particular, the image they convey is one of enculturating scientists-in-the-making. They are not oriented to educating citizens or consumers—the majority of K–12 students.

The context of the NGSS is further indicated in how NOS is treated, perhaps the foremost lessons emerging from delving into historical perspectives (#5). For example, the lessons of provisionality, uncertainty, and the limits of science are duly noted within NGSS's scientific practices. So they may seem to be well aligned. At the same time, one finds the NOS features buried in the detailed specifications of NGSS competencies, not highlighted as a significant theme on their own. Ironically, NOS is treated instrumentally—as a practical skill *within* science, rather than as a form of understanding *about* science. Again, NGSS seems to focus narrowly on measurable performance, not a deep understanding of the scientific enterprise or its cultural context. History provides that context (#1, 3). This may further be viewed with regard to the challenge of misinformation and trust in science, also not squarely addressed by the NGSS.

Finally, one may consider the role of celebrating science and inspiring students (#3). These goals are explicitly addressed in NGSS's parent document, the *Framework*:

Table 3. Merits and deficits of different approaches to NOS instruction, as identified by teachers: inquiry, history, contemporary cases (from Allchin, Anderson & Nielson, 2014).

Approach	*Merits*	*Deficits*
Inquiry	• helps motivate engagement through personal involvement • fosters personal integration of lessons • supports understanding of constucted interpretations, models, forms of evidence, and model revision • develops experimental competences: framing hypotheses, designing investigations, handling data, evaluating results • relates NOSK to inquiry skills and methods • develops understanding of how scientific claims can be defended or criticized in contemporary SSI cases	• difficult to motivate all students, especially as a group • may be viewed as artificial exercise or school "game," not as genuine science • when investigations "fail," can prompt negative emotions, alienating student from NOS lessons • typically shuttered off from cultural, social, or political contexts • hard to model role of "chance," or contingency requires substantive amounts of time and resources
Historical Case	• helps motivate engagement through cultural and human contexts and through narrative format • can support understanding of long-scale and large-context NOS features: esp. conceptual change, and cultural/biographical/economic contexts of research problems and interpretive biases • can support understanding of investigative NOS: problem-posing, problem-solving, persuasion, debate • can support understanding of complexity of scientific practice, as well as historical contingency • supports analysis of process and product, since ultimate outcomes are known • when framed in inquiry mode, can develop scientific thinking skills — more efficiently than with hands-on inquiry • can foster understanding of error and revision — without risking emotions of personal failure	• may seem "old" and irrelevant • difficult or time-consuming for teachers to learn background or historical perspective • if text-based only, limits development of hands-on experimental competences • if rationally reconstructed only or presented as final-form content, does not support understanding of "science-in-the-making"
Contemporary Case	• helps motivate engagement through authenticity and "here-now" relevance • can support understanding of cultural, political and economic contexts of science • can support understanding of how science and values relate • develops scientific literacy skills in analyzing SSI	• cannot be fully resolved, leaving uncertainty and incomplete NOS lessons • cannot exhibit details of process which are not yet public or are culturally obscured

> Discussions involving the history of scientific and engineering ideas, of individual practitioners' contributions, and of the applications of these endeavors are important components of a science and engineering curriculum. For many students, these aspects are the pathways that capture their interest in these fields and build their identities as engaged and capable learners of science and engineering. (National Research Council et al., 2012, p. 249)

Yet the NGSS document explicitly relegates these goals to "the affective domain" (p. xviii). Namely, it disavows responsibility for them. This is a further indication that teachers should regard the NGSS as incomplete, even if they provide helpful guidance regarding core ideas and scientific practices. The blind spot of the NGSS is certainly laid bare by the spirited views of *ABT* authors. History, well used, taps into emotions and personal meaning (#1, 2, 3).

By comparison, history was prominently and explicitly featured in NGSS's predecessor, the National Science Education Standards (National Research Council, 1996). Historical perspectives remain a pillar in AAAS's Project 2061 (Rutherford & Ahlgren, 1989) and in BSCS's (1993) well informed profile of biological literacy. *ABT* authors have generally regarded history as a tool more than an endpoint, yet it provides a humanistic context that seems essential for students. Their responses may be a reminder to respect students as citizens and consumers, not merely as future workers. Historical

Figure 1. The author (1982) teaching as Thomas Hunt Morgan (1916).

cases, appropriately formatted, are effective vehicles for motivating, engaging, and inspiring students, while helping them develop an appreciation for scientific ways of thinking and other aspects of the nature of science and its cultural and humanistic contexts.

○ Pragmatically Speaking

OK, using history in biology teaching may seem *reasonable*. Even *desirable*. But is it *practical*? How is a biology teacher, untrained in history, to proceed? As historian Robert Hendrick noted, "Science teachers rarely know enough history to feel comfortable including it in their courses, even if they feel it is of value " [57, p. 469]. Gar Allen, a historian who *also* co-authored a biology textbook(!), echoed the sense of challenge: "How is it possible to teach active, current science, with all its demands for time, while at the same time pursuing the historical and cultural side of its development?" [25, p. 278]. Fair question.

First, consider small steps. Start with the familiar. Play to your strengths—perhaps use a favorite episode to begin, one you feel passionate about [e.g., 64]. Find more opportunities gradually, adding cases stepwise. Play the long game. Few of the *ABT* authors started with an expertise in history.

Second, borrow from others. (One strength of great teachers, I think, is how well they exploit—er, um … *capitalize on*—the experience of their peers.) Table 2 was assembled precisely as a resource for teachers, to help in locating prepared materials, where the history is already organized for the biology classroom. All are available online (free for NABT members through the *ABT* archive).

Third, listen to your students (of course?). They will let you know what works. And you will find the reward more immediately. Adopt your own, distinctive narrative style. Everybody tells stories, even you. Find your own "voice."

Fourth, learn alongside your students? One of the key features of inquiry learning is that there is no master Answer Key. Questions are open-ended. Reasoning toward an acceptable answer collectively (rather than judging a response against a predetermined "right" answer) is the very essence of the learning strategy, as is true of science itself. So, it matters far less that the teacher knows everything in advance. Rather, the teacher is the expert in the *process*. She knows the investigative tools: how to evaluate experimental design, how to assess evidence, and how to negotiate the critical discourse among alternative interpretations. Indeed, being blind to the outcome is central to the teaching method. Some teachers may well find the uncertainty intimidating. But a more fruitful posture is to embrace the excitement of science-in-the-making, and share the mystery of the unknown with the students. Of course, this is as much a challenge in inquiry teaching as it is about venturing into an unfamiliar history. Teachers may well find confidence in their ability to negotiate their way through new cases, adopting the perspective of the historical scientists involved. "Sometimes student comments and suggestions considered irrelevant by the teacher may not be so irrelevant after they are considered carefully. Students can be surprising" [41, p. 565]. Learning with the students is an exceptional opportunity for teachers to share an experience with them and thereby relate to them more closely. A bonus, not a weakness.

That said, some caveats about history may be in order. Short anecdotes are easy. And they may be familiar. But they rarely delve deeply into the intended lessons described above. Namely, as noted earlier, beware using history as a casual aside—inevitably, a caricature of science, not a window of insights for students [55].

Also, popular histories may easily drift into melodrama and thereby misrepresent the process of science. So, be careful to find historically well informed sources. For example, James Watson's tale of *The Double Helix* is popular among ABT authors. It is a gripping *story*. But it is biased and less effective as history for portraying how science happens. Teachers should accordingly be aware the dangers inherent in the psychology of storytelling. As noted by Thomas Gilovich (1993), in the social context of sharing stories, the storyteller tends to sharpen and level—distortions that amplify the drama and increase impressions of informativeness. But they are artifacts of the act of telling and retelling stories. In summary, ill-informed histories can promote *myth*-conceptions, rather than the intended lessons about the nature of science (Allchin, 2013).

In the same way, the teacher should resist the temptation to "idealize" the history to "correct" the process of science. Understanding the nature of science involves acknowledging the way science *really* happens. Teachers should avoid shoehorning the past into some favorite philosophical model, whether it be the hypothetico-deductive method, or falsification, or other ideal methodology (Allchin, 2000). These few caveats should help the novice from going astray en route to an enriching use of historical perspectives.

○ Envoi

ABT authors over several decades have concurred on the virtues of history as a tool for enriching science education (Table 1). And they have shared their experience and the resources they have developed in the pages of this journal (Table 2). They complement situating scientific practices in student inquiry or contemporary socioscientific issues (Table 3).

In my experience, most teachers already dabble in history. Darwin, Mendel, and Watson and Crick provide stock stories, typically with moralizing commentary. The implicit challenge posed by *ABT* authors is twofold. First, *is the use of history well focused? Does it achieve concrete educational aims? Are we engaging students in explicit reflection about the nature of science, as exhibited in the history?* As noted above, anecdotes and casual asides may need to yield to more mindful lessons and to active inquiry. We also need to ensure that the history (and thus the story of science it presents) is well informed (Barnes, 2017; [67]). Second, *why should we not expand beyond these familiar cases across the curriculum* (Table 2)? These are the questions that challenge us now.

I vividly recall the first day I walked into my biology class as Gregor Mendel, prepared to teach a genetics lesson in a historical context. I was incredibly nervous. Fearful, really. Would the students buy into the facile charade? Would the historical context help engage them in the sense of inquiry and the process of science? Well, it all worked fabulously well. So that led to a later guest visit from Thomas Hunt Morgan, who asked the students to help him interpret his anomalous results breeding a white-eyed fruit fly mutant (Figure 1; Hagen et al., 1996, pp. 48–59).

References

Allchin, D. (2000). How not to teach historical case studies in science. *Journal of College Science Teaching*, *30*, 33–37.

Allchin, D. (2013). *Teaching the nature of science: Perspectives & resources*. SHiPS Education.

Allchin, D. (2015). Hooks, lines, and sinkers. *American Biology Teacher*, *77*, 718–720.

Allchin, D. (2017). Historical inquiry cases for nature of science learning. *Cadernos da História da Ciencia*, *13*(2). http://ojs.butantan.gov.br/index.php/chcib/article/ view/276/263

Allchin, D. (2020). Using historical inquiry cases to learn nature of science skills. In W. F. McComas (Ed.), *The nature of science in science education: Rationales and strategies* (rev. ed., 595–607). Springer.

Allchin, D. (2024). Transforming history into scientific inquiry. *American Biology Teacher*, 86(9), 597–601.

Allchin, D., & Dittmer, A. (2019). The heart of biology teaching [guest commentary]. *American Biology Teacher*, *81*, 609.

Allchin, D., Andersen, H. M., & Nielsen, K. (2014). Complementary approaches to teaching nature of science: Integrating student inquiry, contemporary cases and historical cases in classroom practice. *Science Education*, *98*(3), 461–486.

Barnes, W. S. (2017). History of science is good unless it's bad. *American Biology Teacher*, *79*(5), 341.

Boston Working Group. (2013). How can history and philosophy of science contribute to understanding the nature of science for scientific literacy?: Mapping research needs. *Report from the Conference on How Can the HPS Contribute to Contemporary U.S. Science Teaching, Boston University*, December 7–8, 2012.

BSCS. (1993). *Developing biological literacy*. Kendall Hunt.

Carroll, S. B., Brewer, R., Scudellari, M., Malone, C., Houtman, A. (2018). *The story of life: Great discoveries in biology*. W.W. Norton.

Clough, M. (2024). The story behind the biology: Bring biology and biologists to life. *American Biology Teacher*, 86(9), 587–592.

Conner, C. D. (2005). *A people's history of science*. Bold Type Books.

Deng, F., Victor Chen, D.-T., Tsai, C.-C., & Chai, C. S. (2011). Students' views of the nature of science: A critical review of research. *Science Education*, *95*(6), 961–999.

Eakin, R. M. (1975). *Great scientists speak again*. University of California Press.

Flannery, M. (2024). Herbaria: From history into the digital age. *American Biology Teacher*, 86(9), 567–571.

Flower, M. (1995). Conceiving science education as a practice of technoscientific practice. In F. Finley, D. Allchin, D. Rhees & S. Fifield (Eds.), *Proceedings of the third international history, philosophy, and science teaching conference* (pp. 389–409). University of Minnesota Office of Continuing Education.

Gilovich, T. (1993). *How we know what isn't so*. Free.

Gopnik, A. (2012, May 18). Can science explain why we tell stories? *The New Yorker*. Retrieved October 16, 2024 from http://www.newyorker.com/books/page-turner/can-science-explain-why-we-tell-stories

Hadzigeorgiou, Y. (2016). Narrative thinking and storytelling in science. In Y. *Hadzigeorgiou* (Ed.), *Imaginative science education* (pp. 83–119). Springer International.

Hagen, J. B., Allchin, D., & Singer, F. (1996). *Doing biology*. Harper-Collins. http://doingbiology.net

Klassen, S., & Froese Klassen, C. (2013). Science teaching with historically based stories: Theoretical and practical perspectives. In M. R. Matthews (Ed.), *International handbook of research in history and philosophy for science and mathematics education* (pp. 1503–1529). Springer.

McComas, W. F. (2020a). A typology of approaches for the use of history of science in science instruction. In W. F. McComas (Ed.), *Nature of science in science instruction: Rationales & strategies* (pp. 527–550). Springer.

McComas, W. F. (Ed.) (2020b). *Nature of science in science instruction: Rationales & strategies*. Springer.

Mercier, H., & Sperber, D. (2017). *The enigma of reason*. Harvard University Press.

National Research Council, (1996). *National Science Education Standards*. National Academy Press.

National Research Council., Committee on a Conceptual Framework for New K-12 Science Education Standards., Board on Science Education., Division of Behavioral and Social Sciences and Education. (2012). *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas*. The National Academies.

Newkirk, T. (2014). *Minds made for stories*. Heinemann Educational Books.

Rutherford, J. F., & Ahlgren, A. (1989). *Science for all Americans*. Oxford University.

Seker, H., & Welsh, L. (2003). The differentiation of contexts provided by history of science. In D. Metz (Ed.), *Proceedings of the 7th international history, philosophy of science and science teaching conference*. University of Winnipeg.

Sharot, T. (2017). *The influential mind*. Little Brown.

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