Received: 25 November 2021 | Revised: 28 December 2021 | Accepted: 29 December 2021

DOI: 10.1002/sce.21700

ISSUES AND TRENDS

Science Education WILEY

Humanistic science education: The history of science and other relevant contexts

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Abstract

This article offers a retrospective synopsis of 70 years of development of a humanistic approach to science education. Instruction using the history of science, for example, provides a rich context for students to learn not only canonical science content on a need-to-know basis, but also content from the other domains of humanistic science education, including: the nature of science and scientists, cultural studies, and the multifarious interplay between science/scientists and society. The synopsis leads to the conclusion that instructional materials and student assessment tools developed earlier for teaching the history of science are relevant today. Science–technology–society–environment and socioscientific issues, two of the present six domains of humanistic school science, are given special attention. An example of their teaching materials is described, which illustrates in detail how to organize lessons or units particularly suited for the substantial majority of high school students who would not enroll in any current science classes if not required for graduation. Trends suggested for the future are based on shifts in current global economics.

KEYWORDS

assessment, cultural studies, history of science, humanistic, socioscientific issues

1 | CONTEXTS

Reporting on her research study, Hogue (2013) wrote:

> A Blackfoot [Indigenous] student, now a medical doctor, who struggled greatly with the sciences and mathematics, said, “It helps if you show it first with something that makes everyday sense to me so that I can see the relationship for myself then let me do it so I can see how it works first.” *Students need context to make connections* and the more familiar that context is, the easier the connections are. (p. 1, emphasis added)

Conventional high school science curricula today are mainly about the world of abstract categories, laws, theories, models, and calculations (i.e., primarily *decontextualized* knowledge); all focused on preprofessional training in preparation for attending college or university. However, these curricula do not answer two fundamental questions that many learners pose: How is it used? How does it connect with me? (i.e., essentially *contextualized* knowledge).

These two genres of school science were recently delineated in National Science Teaching Association's *The Science Teacher* by Zucker (2021): “We can think of the Next-Generation Science Standards (NGSS), textbooks, and standardized tests as important parts of a science teacher's toolbox. Yet excellent teachers also think outside the standard box” (p. 8). Outside the box was named “*Scientific literacy*” (p. 8). This concept included, for example (p. 8): (a) “Pay attention to the personal and societal contexts of science,” (b) “Include some important events in the history of science [so] students will better understand the nature of science (NOS),” and (c) “Teach about how to find reliable information about science and how to reject junk science.” Thus, on the one hand, this model of school science has two separate boxes: NGSS's decontextualized knowledge and scientific literacy; the latter being an individual teacher's responsibility.

On the other hand, Gallagher, in his 1971 *Science Education* article, A Broader Base for Science Education, introduced the idea of “science, technology, and society” (STS) (p. 337) expressed as a *curricular* addition for the renewal of school science—all one box:

> For future citizens in a democracy, understanding the interrelations of science, technology, and society may be as important as understanding the concepts and process of science. An awareness of the interrelations between science, technology, and society may be a prerequisite to intelligent action on the part of a future electorate and their chosen leaders. (p. 337)

Our model emphasizes the scientific enterprise as a human endeavor grounded in its own culture, values, ideologies, knowledge, and processes; as well as its myriad of interactions with society. This is a one-box unified scientific literacy (Brickhouse, 2007; Hurd, 1975, 1990; Zeidler & Sadler, 2011). The model is developed for the majority of secondary students by expanding on Gallagher's STS; by drawing upon the history of science innovations (Klopfer & Watson, 1957); and by giving emphasis to contextualized scientific knowledge learned on a need-to-know basis. A conventional approach is to give emphasis to *decontextualized* scientific knowledge, on a need-to-know-for-a-test basis.

2 | HUMANISTIC SCIENCE EDUCATION

“The meaning of the term ‘humanism’ has changed according to the successive intellectual movements that have identified with it” (Wikipedia, 2021, website quote). Two solitudes within the academic community were identified and popularized by Snow's (1956) article “The Two Cultures” referring to the sciences and humanities, broadly speaking. He encouraged scholars to build bridges between their diverse worlds.

In education, The Journal of Humanistic Mathematics (2021) explains its territory as: “a broad range of topics; for our purposes, it means ‘the human face of mathematics.’ Thus our emphasis is on the aesthetic, cultural, historical, literary, pedagogical, philosophical, psychological, and sociological aspects as we look at mathematics as a human endeavor" (website quote). An article in this journal "Can we science the poop, too?" by Banting (2021) epitomized humanistic elementary school science, which is not the purview of this article.

Dorce (2020) correctly pointed out that for learners, the history of mathematics "can supply human roots to the subject" (p. 3). We broaden his focus on history to include Snow's (1956) humanities. Slightly broader, we channel Panasuk and Horton (2012) who treated mathematics as a cultural entity, in the sense that it is a human endeavor.

Simply put, our meaning of humanistic, secondary school science is one suited for the context of classrooms. It eschews scientific positivism and more operationally is defined by embracing Snow's wish that we build bridges between the two academic solitudes; which some chapters do in the two handbooks cited just below. The humanistic topics are italicized.

1. Humanistic approaches to teaching science have demonstrated their promise for students who do not see their world through a scientific lens, to varying degrees. They are excellent enrichment for those who do. Some of the evidence for their accomplishments can be found, for example, in two handbooks that holistically serve as a supplement definition of humanistic science education. The humanistic topics are written in italics for the selected chapters. *Handbook of Research on Science Education* (Abell & Lederman, 2007): *Ethnicity, language, culture, and socioeconomic status*, Lee and Luykx (Ch. 7); *Indigenous cultures*, McKinley (Ch. 8); *gender*, Scantlebury and Baker (Ch. 10); *nature of science* (NOS), Lederman (Ch. 28); and *humanistic perspectives*, Aikenhead (Ch. 29). The authors connect these aspects of humanistic science with Western science's ontology, epistemology, and axiology, on the one hand; and with the diverse students' self-identities, on the other.
2. *Handbook of Research on Science Education: Volume II* (Lederman & Abell, 2014) expands on, and updates, the following topics: *culturally responsive science education*, McKinley and Gan (Ch. 15); *nature of science (NOS)*, N. Lederman and J. Lederman (Ch. 30); *the evolving student assessment of NOS*, Abd-El Khalick (Ch. 31); *culturally relevant schooling for Indigenous learners*, Abrams et al. (Ch. 33); and a new topic, *socioscientific issues (SSI)*, Zeidler (Ch. 34).

Besides teaching the history, philosophy, and the sociology of science, other types of humanistic school science include: STS (e.g., Gallagher, 1971; Hurd, 1975, 1998a, 1998b; Solomon & Aikenhead, 1994; Ziman, 1980), cultural studies (e.g., Aikenhead, 1997; McKinley, 1996, 2005; Stewart, 2005), science–technology–society–environment (STSE) (e.g., E. G. Pedretti et al., 2008; E. Pedretti, 2003), SSI (e.g., Zeidler & Sadler, 2011), and the recently proposed civic science education (CSE) (Levy et al., 2021).

One fundamental NOS concept, besides variations on science being a human endeavor, was introduced to science educators by Ogawa (1995): the plurality of culture-based ways of people making sense of nature, of which Western science is but one example. The concept can be taught by yet another domain within the humanistic school science: *cultural studies*. This includes instances of Indigenous "sciencing"—the analog to Western sciences (e.g., Aikenhead, 1997, 2002; Kawagley, 1990; McKinley, 2001, 2005).

Indigenous languages are verb-based, whereas Western languages are noun-based (Kawasaki, 2002). This fundamental difference between these two cultural worldviews is acknowledged by the term "sciencing" (a verb) (Lunney Borden, 2013), which means that by their actions in everyday life Indigenous people learn from, and use daily, their land-based wisdom gained from Mother Earth. This cross-cultural instruction (Aikenhead, 2020; Meyer & Aikenhead, 2021) is a strategy for making personal connections between Western science and Indigenous sciencing. It is a humanistic experience for all students, and particularly helpful for increasing Indigenous (American Indian) students' "mastery of science and math concepts, deeper levels of student engagement in science and math and increased student achievement in math and science" (U.S. Congress House of Representatives Subcommittee on Early Childhood Elementary and Secondary Education, 2008, p. 13).

3 | TEACHING SCIENCE THROUGH ITS HISTORY

An understanding of science as a human endeavor was not a conventional objective of school science during the Sputnik era of the late 1950s. This was when the Russian space program appeared superior to America's. According to "several nationwide surveys and studies" (Klopfer & Cooley, 1963, p. 33), high school graduates had "*not* attained a realistic understanding of science and scientists, as a result of their science instruction" (p. 33, original emphasis). Not only were students' understandings inadequate, but they were also "frequently a gross distortion of what actually exists" (p. 33):

> [V]ery few instructional procedures specifically designed for this purpose have been proposed. To help fill this gap in the instructional resources of science teachers,…Klopfer developed a series of History of Science Cases for High Schools (HOSC), which use material drawn from the history of science to convey certain important ideas about science and scientists. (p. 33)

The following case studies were "intended to be used as units of instruction within existing courses in high school biology, chemistry, or physics" (p. 33): *The Sexuality of Plants*, *Frogs and Batteries*, *The Cells of Life*, *The Discovery of the Halogen Elements* (revised/corrected from *The Discovery of Bromine*), *The Chemistry of Fixed Air*, *Fraunhofer Lines*, *The Speed of Light*, and *Air Pressure*.

What was the context that spurred this innovation? By tradition, Harvard University has had a History of Science Department that not only teaches about science and scientists but also about science's two-way interactions with society. This department influenced others on campus. For instance, Harvard University President and scientist Conant (1947b) published "a historical view of a number of the great scientists, of what their generation knew of their subjects, of the problem they set out to examine, and of how they solved it" (p. 33). For example, his On Understanding Science booklet series included *The Overflow of the Phlogiston Theory*, which continues to be a popular book today (Phlogiston was a 17th century concept, later used to explain the process of burning until it was replaced with today's oxygenation theory of burning). It makes an excellent history of science case study because it explicitly reveals one way science typically progresses today. Conant's (1947a) book, *On Understanding Science*, continues to be read today.

President Conant appointed astronomer Fletcher Watson to the Graduate School of Education in 1946. Watson later became an advisor to doctoral candidate Leo Klopfer and encouraged him to develop the HOSCs. "The history of science can serve as an important source of insights and materials for the teaching of science" (Klopfer, 1969, p. 87). Past and current history of science is a dynamic context that involves real human beings (Klopfer & Watson, 1957; Klopfer, 1996).

To be engaging for students, scientists' names and dates in the history of science should only serve as scaffolding, not content for assessment. An effective case history of science is (Klopfer, 1969):

- a story,
- accompanied by activities, investigations, conversations, and arguments,
- to learn: the scientific content, who the people are, how they know what they know, their assumptions, their passion, and rational ways they decide what to believe as a tentative truth, and
- the ways science affects society's political–industrial–military–environmental–economic complex, and vice versa; as well as affecting students' personal lives.

Simply put, to be effective history of science teaching materials, students must see them as participatory drama. That was observed when two of Klopfer's (1969) HOSC's were used in a locally produced Grade 10 STS/SSI course, Science a Way of Knowing (Aikenhead, 1979).

Another 11 history-of-science case studies were produced for first-year education students enrolled in a general science course (Hall, 1972). An experimental group read them during the semester, while a control group read a science textbook. The experimental group significantly outperformed the control group responding to the Test of Aspects of Scientific Thinking. In Greece, Koliopoulos et al. (2007) wrote: “short extracts from historical texts” (p. 44); one on electromagnetism for elementary grades and the simple pendulum for lower secondary grades.

An activity-enhanced history-of-science story is a major pathway to engage even the science-reticent school students who feel more comfortable seeing their world through the lens of the humanities than through the lenses of the sciences, to varying degrees.

Some science educators believed that preservice or in-service teachers, or high school or university students on their own, could figure out the messages about science, scientists, and the roles they play in societal issues, just from reading or participating in a case study. However, *it is far more effective* when these understandings become *explicit* to students (Abd-El-Khalick & Lederman, 2000), either through group collaboration, or by teachers sharing their understandings, or both. In any case, the result must be assessed appropriately.

4 | ASSESSING THE HUMANISTIC CONTENT LEARNED

To initiate using history of science teaching materials, teachers invariably ask how to assess students. In Lederman's (2007) extensively researched review of NOS, he discussed its development and student assessment. For example, he wrote:

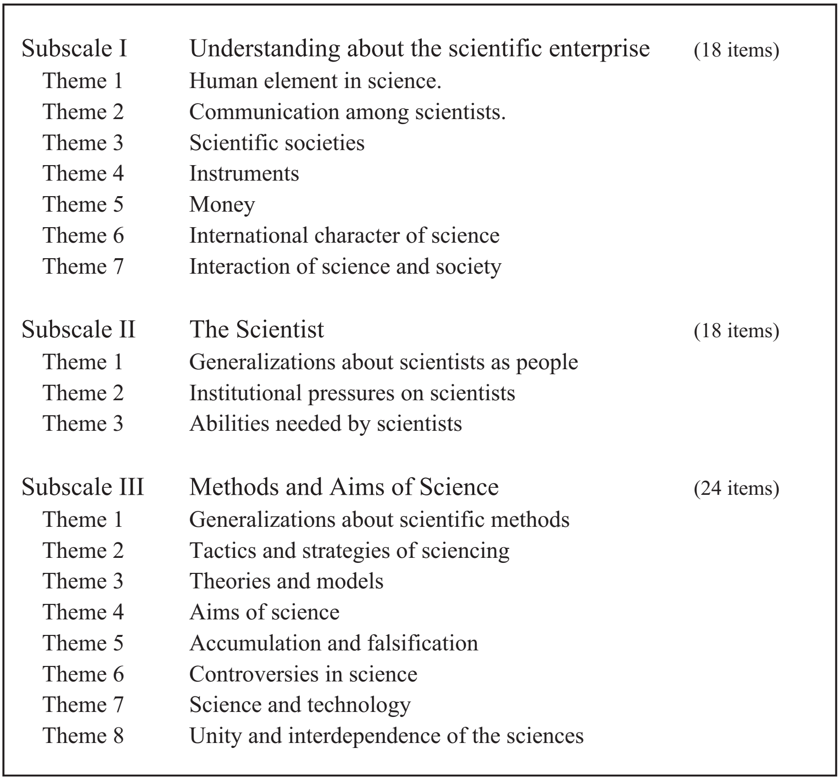
> Klopfer and Cooley (1963) developed the first curriculum designed to improve students’ conceptions of NOS. The curriculum was called, “History of Science Cases for High Schools” (HOSC). The rationale for the curriculum was that the use of materials derived from the history of science would help to convey important ideas about science and scientists. (p. 842)

Since then, a plethora of diverse humanistic courses consistently showed significant increases in pre-post test results; for instance, a Grade 10 course, “Science: A Way of Knowing” (Aikenhead, 1979), in which students completed Klopfer's HOSCs: the “Discovery of the Halogen Elements” and “Cells of Live.”

Developing instruments to assess student learning has spawned a half century in the evolution of questionnaires, tests, and inventories. Lederman's (2007) “Table 28.1” (p. 862) lists 28 of them made public between 1954 and 2004. Abd-El-Khalick's (2014) “Table 31.1” (p. 624) of instruments covers the period 1954–2014. The Klopfer “Test On Understanding Science” (TOUS) was published by the Educational Testing Service at Princeton, NJ (Klopfer & Cooley, 1961). Figure 1 provides a description of the TOUS. It addresses many overlapping themes. For example, some NOS themes are found in all three subscales; such as in Subscale I: themes 1, 2, 3, 4, and 6. Not only was TOUS used by 300 or more educational researchers, it inspired other instruments to be developed; such as the “Science Process Inventory” (SPI) (Welch, 1966).

The TOUS and SPI were used to assess a national physics course, legally entitled “The Project Physics Course” authored by Harvard Project Physics, but also known as *Harvard Project Physics* (HPP) (Holton et al., 1970). Holton (2003) called it “a humanistic and historical approach [to] physical science” (p. 6). It caused an increase in Physics enrollment. However, over time, teachers who had become comfortable teaching elite students eventually became tired of dealing with average students interested in a humanistic physics course and subsequently switched back to a traditional physics course; as related by Fletcher Watson in 1978, at his festschrift celebration in Boston.

In addition to the HPP's assessment research that required conventional statistical techniques to analyze the pre- and posttest scores, Aikenhead (1974) posed the question: What humanistic content did students actually learn in the project's national random sample of physics teachers? In other words: Which *items* made statistically significant improvement between the pre- to posttests? Those items were combined to produce a different type of



Subscale I	Understanding about the scientific enterprise	(18 items)
Theme 1	Human element in science.	
Theme 2	Communication among scientists.	
Theme 3	Scientific societies	
Theme 4	Instruments	
Theme 5	Money	
Theme 6	International character of science	
Theme 7	Interaction of science and society	
Subscale II	The Scientist	(18 items)
Theme 1	Generalizations about scientists as people	
Theme 2	Institutional pressures on scientists	
Theme 3	Abilities needed by scientists	
Subscale III	Methods and Aims of Science	(24 items)
Theme 1	Generalizations about scientific methods	
Theme 2	Tactics and strategies of sciencing	
Theme 3	Theories and models	
Theme 4	Aims of science	
Theme 5	Accumulation and falsification	
Theme 6	Controversies in science	
Theme 7	Science and technology	
Theme 8	Unity and interdependence of the sciences	

FIGURE 1 Contents of the Test On Understanding Science, form W (TOUS) (Klopfer & Cooley, 1961, pp. 3–4). It is a four-alternative 60-item multiple-choice test. The items are categorized into three subscales

assessment instrument—one not based on course objectives or theoretical frameworks from the philosophy of science; but instead, one empirically based on what the students appeared to have learned. This paradigmatic shift from (a) the conventional, theoretical, framework-based instrument, to (b) an instrument derived from the diverse perspectives of students, was a meristem (i.e., a region on a tree trunk or branch tissue from which shoots develop) to a new branch of student assessment in science education.

This paradigmatic shift in assessment instruments was articulated in a study by Aikenhead (1988) entitled "An analysis of four ways of assessing student beliefs about STS topics." The four ways and their results were the following (all quotes come are from p. 607):

1. The conventional *Likert-type response* turned out to be the most ambiguous, and thus, "the most inaccurate, offering only a guess at student beliefs"
2. *A paragraph* written by a student turned out to contain "significant ambiguities in about 50% of the cases"
3. *A semistructured interview* was "the least ambiguous" of the four response modes, but was highly time-consuming
4. Choosing among *empirically developed multiple-choice items* that were composed based on a plethora of student paragraphs about an STS topic. This response mode "reduced the ambiguity to the 20% level"

Researchers had assumed that the same meaning of the instruments' wording was shared by: the students, the test developers, and the analyzers of students' scores. The assumption turned out to be significantly problematic.

Lederman (2007) wrote that the next innovation in student-based assessment occurred when a student-monitoring instrument, Views on Science–Technology–Society (VOSTS), was developed by Aikenhead et al. (1987). It gives great flexibility to researchers in terms of its content and nuanced positions held by students (see point #4 just above). A researcher selects 15 to 20 items of interest from a catalog of VOSTS's 114 items. The items address the following topics: science and technology; influence of society on science/technology and vice versa; influence of school science on society; characteristics of scientists; collaborative construction of scientific knowledge; and the nature of scientific knowledge. Every item has a variable number of "student viewpoints." One is selected by a respondent. Aikenhead and Ryan (1992) provide a full description of VOSTS and some instructions on how to tailor it into one's own short instrument. Vázquez and Manassero (1999) translated it into Spanish for their extensive research program in Spain and developed a sophisticated quantitative scoring scheme.

Since then, other instruments have been developed: several versions of Views of Nature of Science (VNOS), a 10-item questionnaire/interview instrument (Abd-El-Khalick, 2014; Lederman et al., 2002). The content addresses the following topics. Science is: (a) "a human endeavour, directed by theory and culture," (b) "reliant on empirical observation," and (c) "subject to change" (Imperial College London, n.d., website quotations).

The development of more instruments and analytical techniques will continue into the future. For instance, Clough (2017) developed the History and Nature of Science (HNOS) test. Peters-Burton et al., 2019 used an epistemic network analysis on its students' responses. This allowed them to pinpoint "particular ideas that are meaningful to the group, indicating clusters of ideas that are related and illustrating the way informed, transitional and naïve ideas intermingle" (p. 1027).

5 | SSI

The general public grapples with social issues and dilemmas for which science plays various important roles (e.g., COVID-19, nuclear energy, climate change, medical advances, etc.). For a vast majority of students who will not enter a STEM-related profession, the most probable *context* in which they will use what they picked up at school is the social context of their everyday lives, where issues or dilemmas require reasoned opinion (Sadler, 2011a; Zeidler et al., 2005) or thoughtful decisionmaking (Aikenhead, 1985, 1989) (the phrase "vast majority" is defined in the section Enrollment Trends, Education Reforms, and Humanistic Science).

Well-chosen history of science cases can empower "lay people to deal fruitfully with social issues with a science dimension" (Kolstø, 2008, p. 977); for instance, the controversy over who discovered insulin (Bliss, 1982). Kolstø articulates a connection between "historical case studies to prepare for citizenship" (p. 977) on the one hand and "education for democratic citizenship" (p. 977) on the other.

In Holton's (1978) *The Scientific Imagination: Case Studies*, Part I includes the case concerning the Millikan-Ehrenhaft dispute; see Kolstø (2008) and Niaz (2000) as well. Part II deals with the sociology of science and the psychology of scientists; for example, developing a group reputation within the international physics community; and answering the question, "can science be measured?" Part III includes essays on science, technology, and life; as well as historical commentaries on Newton and Einstein.

The term "socioscientific issues" entered the science education research literature around the turn of the new millennium (Sadler, 2004, 2011a). Hughes (2000) explained that SSI was being marginalized by STS science educators. Zeidler et al. (2002) concurred. Similarly, Avraamidou and Schwartz (2021) pointed out a serious omission in the standard content of NOS: it ignores "the politicized NOS or the political, ethical and cultural dimensions of science" (p. 337). Interestingly, these dimensions are found in the TOUS test—themes I.7, II.2, III.4, III.6, and III.7 (Figure 1). Sadler (2011b) offers a comprehensive summary of SSI by answering in detail the question: What do we know about science education in the context of SSI?

Along with the history of science, we submit that SSI is a highly humanistic domain among the other domains that have undergone the crucible of classroom research. SSI can engage most students deeply in an authentic context of collective decision-making on social issues (Aikenhead, 1985, 1989; Solli, 2021).

A new humanistic research program, civic science education (CSE), was recently introduced by Levy et al. (2021). It focuses locally on civic life, science, and education, with an emphasis on public, rather than on private, decisionmaking. In doing so, it extends the current humanistic school science agenda by advocating the civil duty of activism (Bencze et al., 2012). Levy et al. (2021) detail "the great potential of such practices" (p. 1053) and CSE's potential "to have a tremendously positive impact on science education, civic engagement, and civil society" (p. 1067).

6 | AN EXAMPLE OF STS/SSI TEACHING MATERIALS

Substantial research in The Netherlands established the most effective five-step sequence for the organization of STS, equally applicable to STSE, SSI, or CSE lessons, units, or textbooks. This sequence is exemplified by a published, STS/SSI, Grade 10, academic, science textbook and teacher's guide, *Logical Reasoning in Science and Technology* (LoRST) (Aikenhead, 1991, 1992). It integrated curriculum topics in the physical and biological sciences found in most Canadian curricula at that time. Eijkelhof and Kortland's (1987) five steps are (illustrated by LoRST):

STEP 1: *Introduce students to the socio-scientific issue*, which in LoRST is the avoidance of drinking and driving. It is important to pick an issue which is either enduring (e.g., drinking and driving) or an issue timely in the students' real world. LoRST began with the recent death of a famous sports hero due to his driving when drunk. In groups, students read a media report and discussed questions related to the tragedy (e.g., organ donations). They responded to conflicting opinions on the tragedy. The benefit is that students forge personal connections to the science class.

In the textbook, a lesson followed about court cases concerning criminal charges for drinking and driving. From these, students learned to distinguish between legal and scientific decisions; both based on different values. Of the many NOS concepts presented in LoRST, two are values (i.e., reliable data and accurate data) discovered by students during an activity. The book's 32 activities and labs ensure that students become physically engaged, as well as answering questions that demand a deep analysis; for instance: (a) to distinguish between subjectivity and objectivity to understand that science can only minimize subjectivity (i.e., all measurements have a margin of error, but that does not make them unreliable) and (b) to participate in inductive and deductive reasoning activities, and then identify their characteristics and differences before labeling them "inductive" and "deductive." Understanding concepts preceded what they are called, whenever feasible.

STEP 2: *Identify a technology, if possible, associated with that issue*. In LoRST, the technology was the Borkenstein breathalyzer. It was introduced by the *history* of its development as told by Robert Borkenstein during an interview; an example of research and development (R&D)—taught as the combination of science and technology. Because students learned of the breathalyzer's importance during their analysis of court cases, their curiosity about the technology was strong.

As seen just above, NOS topics can naturally arise when a technology becomes the context for introducing students to science topics. In LoRST, students learned to distinguish between the NOS concepts: science and technology; plus, how they are historically related. Sometimes science precedes technology (e.g., atomic fission) and sometimes technology precedes science (e.g., the steam engine and laws of thermodynamics).

Both steps 1 and 2 in an SSI lesson or module create a need-to-know in students' minds the content in Step 3. For pedagogical purposes, some of the technology's details are introduced in STEP 3, which can make their association with science content much clearer, depending on the topic.

STEP 3: *Draw on science concepts and processes to explain how the technology works or how it is used*. LoRST addresses a wide range of science content: What happens in a person's body after taking a sip of wine? The alcohol is absorbed by the digestive system, then flows throughout the circulatory system. Most alcohol ends up being eliminated by the liver. The remainder eventually exists through the respiratory system via the alveoli in the lungs. This *exhaling breath* mixture is what the breathalyzer actually measures.

But it is designed to estimate the *blood* alcohol concentration (BAC). The critical *legal* measurement in North America for a driver to be legally charged is usually 80 mg per 100 ml in a person's blood. The breathalyzer uses the mg/ml units for which the critical measurement is 0.08, while others simplify it further to 8.0 per cent. The science of mixtures becomes important to learn; for example, hetero/homogeneous mixtures, the technology of salad dressings (emulsifiers), diffusion, concentration (volume to volume, weight to volume, parts per million, etc.) beyond the topic of the breathalyzer, but important to contexts in students' everyday worlds.

To understand the court cases that challenge the accuracy of the breathalyzer's "translation" of the gaseous alcohol concentration to the liquid BAC, students gladly learn details of how it works. For instance, a specific quantity of a breath sample is bubbled through a dark yellow solution of potassium dichromate, which causes a chemical reaction to occur between it and the alcohol. Thus, chemistry needs to be learned to understand the breathalyzer manual: chemical symbols, atoms, molecules, chemical equations, and balancing simple equations. This 2-week diversion into didactic instruction includes a drama activity and manipulations of molecular models to make sense of the conservation of matter.

The chemical reaction between potassium dichromate and alcohol causes the dark yellow solution to lighten; an indication of the alcohol concentration. The degree of color change is measured by a photoelectric cell that produces an electric current—a function of the intensity of light that passes through the dichromate solution. This current is calibrated by an electrical device that produces the BAC readings displayed on the breathalyzer. Accordingly, some fundamentals of optics are studied to understand this function in the breathalyzer and to better understand lighting costs around the home.

Obviously, the breathalyzer has an electric circuit. This triggers the need to learn something about their fundamentals by exploring simple circuits. In doing so, students discover that Ohm's law is not universal but temperature dependent. Other NOS content is included by distinguishing between scientific laws and theories.

STEP 4: *Return to other technologies*. A police officer introduces students to more modern hand-held detectors and answers their always-interesting questions. The relevance of school science peaks here. In LoRST, Step 4 overlapped with Step 3 due to the abundance of scientific content to be learned throughout several book chapters.

STEP 5: *Return to the social issue*. Address the initial question or social issue by engaging students in how to make "thoughtful decisions"—those based explicitly on their knowledge and personal values. This topic explicitly connects students to their future as citizens in a democratic country.

Research into the process of decisionmaking (Aikenhead, 1985, 1989) preceded the development of LoRST. The observations in classrooms during LoRST's early development led to a 10-point guide for making a thoughtful decision (Figure 2). Students learn to draw on: relevant concepts, processes, and values to make judgments about, for instance, whose research and conclusions to trust (Kolstø, 2001). This process can be guided by Figure 2.

7 | ENROLLMENT TRENDS, EDUCATION REFORMS, AND HUMANISTIC SCIENCE

There is a "rising tide of students who were staying longer in secondary education" (Fensham, 2016, p. 162) but not enrolling in science courses proportionately. As a result, university-bound high school science graduates have become a shrinking minority.

The U.S. Office of Technical Assessment's nationwide longitudinal survey tracked 4,000,000 Grade 10 students, from 1977 through until 1992, by following those who remained "interested in natural science and engineering" (Frederick, 1991, p. 389). In Grade 10, 18% met this criterion. By the end of Grade 12, 15% of the sample had maintained their interest. Those *who enrolled in a STEM-related program* during their first year of college or university dropped to 9%. In other words, between 85% and 91% of high school graduates are not involved in

1. Issue:

2. Articulate the decision question:

3. Type of decision to be made:

4. Possible Choices	**5.** Risk Benefit Analysis Assessed	**6.** Validity and Probability	**7.** Values Assumed

Alternative 1

Negative Consequences:

Positive Consequences:

Alternative 2

Negative Consequences:

Positive Consequences:

Alternative 3

Negative Consequences:

Positive Consequences:

8. Priority of Values:
(most to least important)

9. Choice of alternative and Reason:

10. Action Recommended:
(what? by whom? and when?)

FIGURE 2 A guide for thoughtful decisionmaking (after G. Aikenhead, 1991, p. 239)

postsecondary natural science or engineering programs. The percentage figure used depends on the context being considered. In any context, however, the range "between 85% and 91%" represents a significant majority of students.

Using a different type of measurement, Card and Payne (2017) found that the proportion of Ontario high school graduates *who took the prerequisites* for a postsecondary STEM program was 29.8% (rounded off to 30%).

Because data were not collected on how many actually enrolled in a postsecondary institution, it seems reasonable to assume this figure is inflated (i.e., the true figure is *less than 30%)*. Furthermore, it is understandable that to keep their post-high-school options open some of these students enrolled in STEM courses even though they were unsure of their interest in STEM. In other words, Card and Payne's sample comprised *greater than 70%* who did not intend to pursue a STEM program after graduating.

Considering just the *majority* of students, one can combine the results from the U.S. Office of Technical Assessment and from Card and Payne. One can characterize the size of the *majority* group of high school graduates as being between "greater-than-70% and 91%"; still a significant majority. Logically, the small *minority* can be quantified as well: "9% to less-than-30%. The corresponding data for the *minority* of graduates will be between "9% and less-than-30%."

Snow (1956) famously identified two academic solitudes, the sciences and the humanities. This "greater-than-70% to 91%" majority high school group tends to experience their world more from a humanities perspective than a sciences perspective. Therefore, it seems only reasonable to develop an educational policy that offers this majority a rigorous, preadult-citizenship, and humanistic science program that deals with their authentic everyday world. This certainly occurs in some university science departments that offer, for instance, qualitative physics for humanities students.

The post-Sputnik "Science for All" movement has been alleged to contribute to drops in school science enrollments (Fensham, 2016):

> the new curricula for science [in the 1960s and 1970s] …reordered the content of the existing secondary disciplinary courses. … [In the 1980s] The language of STS started to be used in curriculum debates, science teacher meetings, and even official statements. Its ideas about …societal issues as starting points for engaging students more actively were, however, still restricted to trial schools and willing teachers. (p. 168)

This was a disappointing failure. Therefore, folk wisdom would suggest that attempting a Science-for-All strategy again and expecting different results is not a sane option. All the established domains within humanistic science have demonstrated their contributions to contemporary science education; producing significant successes for the majority group of students oriented to the humanities, to varying degrees; and welcomed enrichment for the small minority of students seeking pre-professional STEM training. These all lie within educational reform (Donnelly, 2004).

Some educational jurisdictions have successfully melded a humanistic science policy framework with science curriculum *revisions*. The Council of Ministers of Education, Canada (CMEC, 1997) established a Pan-Canadian Framework organized around: "STSE, skills, knowledge, attitudes" (p. iv).

Political debates over renewing science curricula are invariably policed by state standards, teachers' concerns, and public opinion aimed at the *minority* of science-interested students (i.e., the 9% to less-than-30%). These debates often revolve around the political context of international test scores from the Program for International Student Assessment (PISA); scores are often misinterpreted by the general public or misrepresented by politicians who cherry-pick the data and who are unable to critique the validity of PISA itself (Sjøberg & Jenkins, 2020).

8 | CONCLUSION

Over the past 70 years, beginning with Harvard President Conant (1947b), there has been a steady evolution in the development of interesting contexts for teaching some pre-professional training content, and for producing new species of research agendas that accentuate insights into the scientific enterprise itself as a human endeavor. This humanistic knowledge has a direct bearing on peoples' adult lives in a democracy, as Gallagher (1971) pointed out;

quoted in Section 1, but well worth repeating: “An awareness of the interrelations between science, technology, and society may be a prerequisite to intelligent action on the part of a future electorate and their chosen leaders” (p. 337). “Since the 1960s, major changes have taken place in our society resulting in widespread calls for the reform of science education” (Hurd, 1990, p. 413, 1998b).

Over the past 70 years, political, societal, and economic events have caused science education to follow policies contrary to what the general public finds relevant (Fensham, 2016). When in high school, these adults were the majority group of the more-than-70% to 91%. In response, humanistic science educators have created research programs, policy papers, teaching materials, and pedagogies that were the force of their research and development (R&D). As evident in this article, these educators have developed, and continue to invent, a well-founded and enduring curriculum framework for the majority of secondary science students.

Carney (2020), former Governor of the Banks of Canada and then of the United Kingdom, recently described the current, global, economic transition from profit societies to sustainable societies. The transition is responding to the truth that business and industry cannot make a profit on a planet ravaged by climate change. This transition to sustainable economics adds responsibilities for secondary school science curricula to educate a future public, savvy in their critical understanding of science and society's roles, and therefore do their part to achieve global sustainability goals in their everyday worlds.

Humanistic science education is more a verb than a noun. This guarantees greater engagement by students to forge their self-identities (Brickhouse, 2001, 2007). “From a social cognition perspective …learning happens as individuals become *particular kinds of people*. Learning is the acquisition of discourses of thinking, acting, valuing, interacting, feeling that makes you a particular kind of person” (Brickhouse, 2007, p. 90). Therefore, a student's self-identity is open to change over time. This is the kind of person who works locally in harmony with a sustainable future, by drawing upon their humanistic school science engagement (Ekborg et al., 2013). These pathways for future adults have been pioneered by science educators working within the six domains of the humanistic school science community (i.e., the history of science, STSE, the NOS, cultural studies, SSI, and CSE; plus combinations thereof).

Now is the time for science educators to energize their Humanistic Science Education Agendas! Our advice for gaining support for curriculum reform, targeting the “more-than-70% to 91%” student group, is to become politically potent by forming a recognizable group: to make tangible connections with public media outlets; to organize symposia at conferences; and to deliberate with ministries or departments of education, teacher educators, professional organizations, science departments, and other key stakeholders.

Deliberation ensures that: significant problems are identified and solutions reached; appropriate evidence is collected; and the problems and evidence are shared with all stakeholders (Orpwood, 1985). Within about a decade of completing this 4-year deliberation strategy by the Science and Education Committee, formed by the Science Council of Canada (1984), the Council of Ministers of Education, Canada (CMEC, 1997) published its Common Framework of Science Learning Outcomes.

A U.S. national deliberation project would merit a major NSF grant. Attaining NSF funding would be highly desirable.

DATA AVAILABILITY STATEMENT

Data sharing is not applicable to this article as no new data were created or analyzed in this study.

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How to cite this article: Klopfer, L. E., & Aikenhead, G. S. (2022). Humanistic science education: The history of science and other relevant contexts. *Science Education*, 106, 490–504. https://doi.org/10.1002/sce.21700