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Humanistic school science: Research, policy, politics and classrooms

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Abstract

This article establishes a rational, feasible, and necessary conclusion to reform high school science content into an equitable experience for its wide diversity of students' self-identities. Research indicates that 85% of graduates would not normally have enrolled in any science course unless required. Their values are more aligned with their everyday world and/or the world of the humanities, to varying degrees. The 15% had already fulfilled their science prerequisite for postsecondary science-related programs, to varying degrees. The article's conclusion rests mainly on historical and economic evidence, respectively: (1) The Sputnik crisis that instilled public fear and anxiety about the perceived technological gap between the United States and Soviet Union. This led to reforming high school science and implementing National Aeronautics and Space Administration. (2) The on-growing climate-change crisis for which the smart international money is increasingly investing in sustainable businesses and industries, which catalyze a shift in public values from the current "profit society" to a "sustainable society." The article's rationale connects the two historical events. Over the past 30 years, the nature of normal science has evolved into post-normal science. Today the public square also includes: (a) an international assessment project that receives a negative validity audit in this article; (b) a vocal small minority within the 85%, proud of their antiscience self-identities and their leaders' hostile behavior (a problem to ameliorate by a reformed sustainable science education); and (c) instances of small-scale, suitable reform examples developed over the last 70 years, often referred to as humanistic school science.

KEYWORDS
curriculum renewal, high school science, humanistic

1 | INTRODUCTION

Post-Sputnik political tensions arose in 1957 between the United States' lower science and engineering prowess compared to the Soviet Union's. President John F. Kennedy declared on September 12, 1962, that by the end of the decade, the United States would land astronauts on the Moon. His political challenge further mobilized two major sectors of society: (a) the US Congress implemented the National Aeronautics and Space Administration (NASA), and (b) the science education establishment, which includes: the National Academy of Sciences, National Science Education Standards, National Science Foundation, National Science Board, American Association for the Advancement of Science, and National Science Teachers Association; all of whom influence, but not determine, then and today, science curricula and teacher certification; the responsibility of each state's education authorities.

These two sectors' intense response to Kennedy's challenge led to national funding for collaboration among some science, technology, engineering, and mathematics (STEM) professors and science educators. They developed the "alphabet soup" courses, such as Biological Sciences Curriculum Study (BSCS), CHEM Study, Physical Science Study Committee and Harvard Project Physics in high schools, plus new elementary programs such as Science: A Process Approach. They all provided a more sophisticated scientific content, audio-visual teaching aids and improved labs (e.g., BSCS Learning, n.d). These courses reflected the structure and nature of the sciences (Aikenhead, 1973; Klopfer & Cooley, 1961) in keeping with their more rigorous in-depth treatment of the sciences.

Pedagogy was also a major part of the conversation back then (e.g., DeBoer, 1991; Duschl, 1990, 2020; Rudolph, 2019). For a review and analysis of learning progressions and teaching sequences, Duschl et al. (2011) offer an update on this line of pedagogy. However, the present article focuses on the politics of content reform. The topic of pedagogy is beyond the scope of this focus.

In retrospect in 1992, Fensham assessed the politics of content reform as an attempt to induct all students into the world of the research scientists. Gallagher (2000) and Jenkins (2006) concurred. The resulting curriculum projects explicitly rejected the interests of the larger target group, the group for whom those courses were initially intended: scientifically literate citizens.

As a novice science teacher at the time, I participated in professional development offerings, both locally and at NSTA conferences. They augmented an interest in viewing science as a human endeavor, such as investigating the interaction among science, technology, and society (STS) (Gallagher, 1971) and the nature of science (Aikenhead, 1974). Two overlapping meanings for the phrase "nature of science" exist in public and professional discourses:

1. In a general sense, it takes on its denotation: "the basic quality or character of science" (Complex nature of science, n.d, website quote), and in this article it will be logically labeled "*the nature of science*." It addresses, for example, "students" views concerning worldview presuppositions underpinning science" (Hansson, 2014; p. 743), and answers the question, "Is the world really ordered, uniform, and comprehensible?" (p. 743).
2. In a specific sense, it will refer to the science education research community's catalog of examples, labeled by its acronym "*NOS*" (e.g., Bayir et al., 2014; Duschl, 2022; Klopfer, 1969; Lederman, 2007; Nouri & McComas, 2021).

1.1 | Interactions among science education research, policy, and classroom practice

In July of 1969, US astronauts Neil Armstrong and Buzz Aldrin did walk on the Moon. This success, in part, arose from the interaction among: (a) politicians setting goals, (b) STEM educators preparing future employees for Research & Development (R&D), (c) the heavy financial investment by the the federal government, and (d) an intense effort by the education establishment.

University science education professors seldom enter the profession because it harbors political action. On the contrary. I suggest that most can be represented metaphorically by Figure 1, which expresses a belief that our research alone should influence both classroom practice and policy that in turn also influences classroom practice. The National Association for Research in Science Teaching (NARST)'s mission statement comes to mind: improving science teaching and learning through research.

But what really happened on September 12 in 1962, I submit, is not represented in Figure 1. The specific politics of Pres. Kennedy's Moon landing goal motivated the science education establishment to supply financial and human resources to achieve that specific goal; depicted in Figure 2 as "Politics A". When the political cog in Figure 2 moves, the other three cogs tend to move accordingly. Expressed in general terms, Figure 2 represents four politically motivated goals and their concomitant agendas described in this article.

For instance, the preprofessional training (PPT) agenda for high schools was mobilized by the education establishment's agenda A_1 (shown in Table 1) during the 1960s. This agenda brought political and economic resources into play. The influence of politics was certainly positive and pervasive in fulfilling Pres. Kennedy's "Goal A" (Figure 2 and Table 1). Beginning in the 1970s, its PPT emphasis was, in part, challenged by "Politics B," that brings its own political resources to conduct agenda B_1 (Table 1).

Fensham (2016) identified the most important local authoritative political entity since the beginning of school science in public education in the 19th century:

> Since it is an authoritative decision to develop a new curriculum or a major new direction, unless the authority also takes the implementation phase seriously, with funding over significant time, the gap

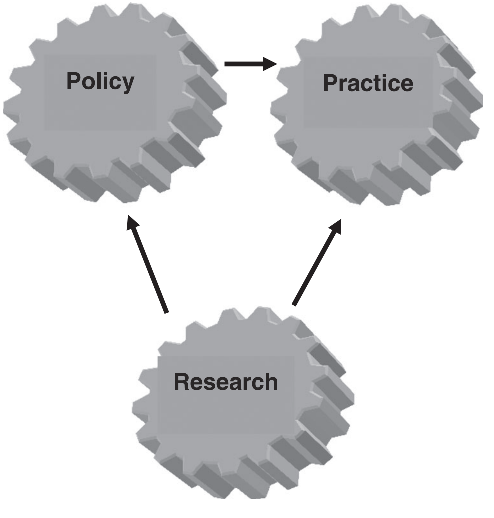

FIGURE 1 Representing a popular academic assumption about the influence (depicted by arrows) of science education research on policy and classroom practice. Source: Aikenhead (2020, p. 685).

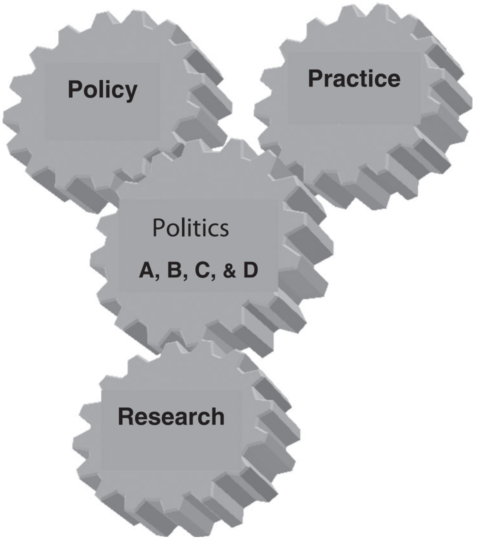

FIGURE 2 The reality for getting things accomplished: politics becomes involved. The figure represents four instances of political goals (A, B, C, and D; summarized in Table 1) discussed in the article. Source: Based on Aikenhead (2020, p. 68).

TABLE 1 Clarification of political goals and agendas for Politics A, B, C, and D (see Figure 2)

A	In the political context of rivalry with the Soviet Union, President Kennedy's goal to have astronauts on the Moon by the end of the 1960s decade.
	A_1 agenda: Science education establishment in full support by emphasizing PPT[a].
B	Balance the PPT curriculum/assessment focus with HSS[b] content.
	B_1 agenda: R&D[c] with HSS content, pedagogy and teaching materials.
	B_2 agenda: Science education establishment offers HSS token support, yet marginalizes HSS.
C	General public's antiscience movement against COVID-19 restrictions imposed.
	C_1 agenda: Science deniers mobilize on social media and with demonstrations and intimidation.
	C_2 agenda: Implement HSS targeting non-STEM oriented students.
	C_3 agenda: Science education establishment emphasizes more rigorous PPT.
D	Climate change targeted to be neutralized.
	D_1 agenda: Curricular reforms around including HSS, as proposed in this article.

[a]Preprofessional training.
[b]Humanistic school science (Klopfer & Aikenhead, 2022; Southerland & Settlage, 2022).
[c]Research and development.

> between the intended curriculum and the curriculum in practice will often remain alarmingly large. (p. 182)

Society has evolved over the past 60 years in part due to two political crises: the 1950s Sputnik crisis that led to Pres. Kennedy's goal; and more recently, the climate change crisis (Carney, 2021; Gore, 2006). Both crises have affected the meaning of the nature of science and NOS. These two *consequences* have evolved simultaneously.

2 | THE CHANGING MEANINGS OF THE NATURE OF SCIENCE AND NOS

NOS has evolved from Kuhn's (1970) narrow bifurcation of the scientific enterprise into "normal" and "extraordinary" science that addressed both its professional knowledge and its internal sociology of the scientific community. The change from "normal" to "extraordinary" science occurs during periods of scientific *paradigm shifts*, described by Kuhn as "changing the constellations of group commitments" (pp. 181–187).

2.1 | Frontier science

NOS expanded its meaning significantly with Cole's (1992) "frontier science" (i.e., scientific research that explores completely new territory). It involves both the scientific and lay communities during periods of collaborative socio-scientific decision making (e.g., Duschl, 2020; Jenkins, 2006; Kolstø, 2001a; Kolstø et al., 2006). Participating scientists in these decisions embraced differing values, ideologies and judgments over the frontier science's validity (Fensham, 2014) characterized by less certainty. These features augment the controversial nature of the decision making (Kolstø, 2000; Samuelson & Zeckhauser, 1988) within an attentive public. Two such examples are: (a) the link between the electromagnetic radiation given off by high voltage wires and child leukemia; and (b) as a result, the decisions over regulating power grids.

Collaborative discussions usually boil down to an issue of who, and whose data, do you trust (e.g., Cobern et al., 2022; Hendricks et al., 2020; Kolstø, 2001b; Suldovsky et al., 2019)? Fensham (2014) points out that the counterpoint of trust is skepticism, which is also a scientific value. However, Fensham also cautions, "It is only in relation to emerging and uncertain scientific contexts [frontier science] that students should be taught about skepticism" (p. 649); that is, there is both rational and irrational skepticism—an appropriate context for addressing trust and social media. In a 20-country survey, the relationship between trust and social media related to the medical sciences was found to be influenced by a country's culture, with respect to "individualism/collectivism and power distance" (Huber et al., 2019; p. 759).

Researchers have consistently found that students give much higher priority to their own values, common sense, and personal experience than to scientific knowledge and evidence (e.g., Fensham, 2014; Kolstø, 2001b; Zeidler et al., 2002). It is notable that the topic "When to trust a scientist and their data" is not in many curricula. It is certainly absent in a national science education framework from K-12 (National Academies of Science, Engineering and Medicine, 2012); and it is certainly absent in high-stakes testing, such as the Program for International Student Assessment (PISA) science test administered by the Organization for Economic Co-operation and Development (OECD). Yet the question of trust is a fundamental issue for non-STEM adults trying to be a savvy citizen in their democracy. Therefore, when students complain that school science is irrelevant to their everyday world, they have a valid point in terms of what is missing from their science curriculum.

2.2 | Postnormal science and implications for high school science

On the one hand, PPT prepares high school students for enrolling in pure and applied STEM postsecondary programs that "address fairly narrowly defined problems investigated in reasonably well-controlled conditions" (Barwell, 2013; p. 4). In other words, "a process where true scientific facts simply determine the correct policy conclusions" (Funtowicz & Ravetz, 1993; p. 744).

But on the other hand, this position is naïve for some critical situations, as the complexities of pandemics and climate change have demonstrated. A new type of science, *postnormal* science, has been added to the pure and applied sciences (Ziman, 1998). "[I]t is urgent, complex and involves a high degree of uncertainty (Barwell, 2013; p. 1).

Postnormal science evolved over the past three decades in which: (a) facts are often contradictory, (b) uncertainty runs rampant, and (c) facts and values are interwoven with politics (Barwell, 2013). "Deciding which information to use, which voices to hear and which methods to try, depends as much on values as it does on scientific facts" (p. 5). Its socio-scientific reasoning requires "communicative competencies" (Solli, 2021; p. S983) and holistic thinking (Zeyer & Kyburz-Graber, 2021). The public who are smitten with social media's irrational conspiracy theories, constitute a negative political sway (agenda B_3 in Table 1) within postnormal science.

As described below in the "Appendix," it turns out that 15% of Grade 12 graduates qualify to enter STEM college or university programs. *Normal science* (PPT) appeals to this minority of students. On the other hand, *postnormal school science* (a.k.a. humanistic school science) is designed to prepare 100% of Grade 12 students to participate rationally in their democratic society (Gallagher, 1971; Hurd, 1990; Klopfer & Aikenhead, 2022; Ziman, 1980). Specific examples are described below in the subsection "Post-Normal School Science." Two academic pathways (Normal and PostNormal) have promise for the future if science education is able to ameliorate the influence of an antiscience movement (agenda C_1).

2.3 | Believers of social media versus a postnormal scientist

A recent postnormal science scenario from the COVID-19 pandemic illustrates: (a) just how badly the rift has become between scientists and some of the general public; and therefore, by implication: (b) just how badly high school science has failed teaching the nature of science (Duschl, 2022) and failed accommodating the equity of many students because NOS topics are essentially off the science education establishment's agenda that determines, by and large, the science standards governing: graduation criteria, curricula, the assessment of students, and teacher credentials. These shortcomings are certainly not the fault of our dedicated science teachers.

The consequences of some science-related societal issues have grown extraordinarily serious internationally. The COVID-19 pandemic was, and continues to be, fatal for millions of citizens. Moreover, horrendous debts are accruing from the devastation of climate change. Carney (2021) explains that the values that guide such decisions are invariably political to some degree.

Many scientists agree, and some have incorporated "positive politics into their new postnormal science" (Funtowicz & Ravetz, 1993; p. 739), but some have faced very negative political tactics from certain segments of society.

For example, Dr. Anthony Fauci, director of the US National Institute of Allergy and Infectious Diseases, was interviewed by Ayed (2021, website quotes) during a public radio broadcasting program.

> Ayed: In the 19th century in the West, science displaced religion as an ultimate authority in society. But now the authority of science in the public sphere is in danger of being displaced by social media and political rhetoric. I'm wondering what you think happened?
>
> Fauci: This is something that is so disturbing to me as a physician, as a scientist and as a public health person. If ever you could imagine the worst possible environment into which a global pandemic emerges, it would be in an environment of antiscience [and] complete normalization of lies.
>
> It is just mind-boggling. It's when you have this kind of combination of divisiveness with the complete accessibility and spread of complete falsehood. ...As a member of society, reaping all the benefits of being a member of society, you have a responsibility to society.
>
> Ayed: I'm wondering if there's anything we can learn from eradicating viruses that could help us in eradicating misinformation?

Fauci: I lose as much sleep …worrying about the overall implications of the rampant spread of misinformation and disinformation on society. … It's as easy to say something crazy as it is to say something that's based on years of scientific evidence. …[And then comes a] false equivalency. “You know, a Nobel laureate who discovered this says this.” “But Joe Johns on their Facebook said that.” That has to be frightening, because it's happening.

Ayed: How do we restore scientific authority in the public sphere?

Fauci: One of the things that has been the source of considerable confusion is the lack of appreciation that science is evidence and data. …Science evolves and science corrects itself. There are many people who interpret that as flip-flopping. (Website quote)

This sorry state of affairs suggests that a significant and growing public with irrational perspectives are missing the fundamentals of science needed to participate rationally in their democratic country. For instance, they need to understand the NOS item “science produces tentative but trustworthy evidence and knowledge.” This crucial nature of science and NOS concept tends to get ignored in the PPT that prepares students for entrance into college and university STEM programs (Aikenhead, 2006).

Writing in 1998, the eminent physicist John Ziman anticipated this public incursion of the misinformed: “I interpret it as symptomatic of the transformation of science into a new type of social institution. As their products become more tightly woven into the *social fabric* of science, scientists are having to perform new roles” (p. 1813, emphasis added). *These new social roles for scientists require parallel reforms in science education*, to update students who intend to pursue a university STEM program; but ever more so, the vast majority who will become tomorrow's lay public. Will school science help restore scientific authority in the public sphere? Not by students becoming experts at balancing chemical equations. Not by memorizing a catalog of concepts concerning the nature of science (NOS), especially the “tentative nature of scientific knowledge” (Bromme et al., 2015, p. 68; Cobern et al., 2022; online).

2.4 | Postnormal school science

According to the content in standards-based testing, it would seem that the science education establishment emphasizes canonical science content at the expense of learning the depths of NOS and societal interactions content.

The current status quo tends to create in high school graduates: (a) a susceptibility to misinformation concerning the nature and social aspects of science (Duschl, 2022), (b) a lack of knowing how to figure out who and whose data to trust (Hendriks et al., 2020; Suldovsky et al., 2019), and (c) an incompetence to challenge science-irrational and misinformed people who they may encounter daily.

Alternatively, postnormal science requires two different types of expertize: (a) STEM professionals conversant with the dynamics with the general public; and (b) a general public conversant in the broad nature and social aspects of science, because their high school science emphasized these humanistic aspects of science (Brickhouse, 2022; Klopfer & Aikenhead, 2022; Southerland & Settlage, 2022). For instance, class discussions or student projects can be organized around five points (Barwell, 2013):

- What are the facts? How are these facts produced? Where is the uncertainty?
- What is valued and what is devalued?
- What is at stake? Who benefits from particular versions of the facts? Who benefits from emphasizing some values and not others?
- What decisions are possible? What decisions are not possible? What action can we take? (p. 12)

The type of experience in postnormal school science helps to prepare students for a highly positive contribution to society as science savvy adults (Brickhouse, 2022; Gallagher, 1971; Levy et al., 2021; Zeyer & Kyburz-Graber, 2021).

The Next Generation Science Standards (NGSS, 2013) pay homage to humanistic school science by providing a comprehensive listing of both “the nature of science” and NOS items, suitable for postnormal school science (NGSSa, Appendix H); as well as a modest introduction to science-technology-society-environment (STSE) (NGSSb, Appendix J). These entries, however, seem to be overshadowed by the overall PPT emphasis of the NGSS website. Its appendices H and J tend to get lost in the encyclopedism assortment of appendices. But NGSS can claim they include this humanistic science content. While the appearance of Appendices H and J does offer credibility to humanistic content for those few policy makers and teachers who are already favorably predisposed to humanistic school science innovations (Zucker, 2021), the *politics* to advance their agenda (C_2) is missing from the NGSS document. When the political agenda is missing, humanistic school science is overshadowed.

As represented by Figure 2, political plans and strategies are a prerequisite to their successful enactment. As discussed earlier, Goal A was the astronauts landing on the moon. It initiated Goal A_1, the science education establishment's full support and participation.

This, in turn, precipitated Goal B: replace the narrow PPT focus with a balanced approach contextualized by the everyday realities familiar to humanistic approaches, which are more amenable to the 85% majority of high school graduates. For example, research and development (R&D) projects were completed and some became commercialized (Aikenhead, 2006) (politics agenda B_1). A transformation is needed for a status quo school science to become a slightly modified version with its PPT emphasis contextualized in a few societal issue themes for the minority 15% of students. This was accompanied by agenda B_2, the science education establishment's opposition to the humanistic movement, by marginalizing it, though borrowing some of its rhetoric, and by funding a few token projects. Political agenda B_2 has persistently been associated with the oil, coal, and automobile industries (Bencze et al., 2006; Cannato, 2011). Figure 2's meaning will continue to evolve to keep up with this article's storyline.

Then COVID-19 happened, accompanied by the masking, isolation, and vaccination mandates. An important proportion of the electorate reacted to their perception of a loss of personal freedom. This was their crisis and their political goal C (Figure 2). Dr. Fauci was the recipient of their strategy of going public with fake news, conspiracy theories, and hate; agenda C_1. Some science educators reinforced their agenda B_1 by updating to a C_2 agenda. Some in the science education establishment sought greater rigor in PPT curricula (C_3) to counter C_2, but some also included NOS content to a small degree. No unanimity has yet been reached.

Those who challenge the presence of politics in the planning and execution of postnormal school science should be reminded that politics are the essence of the science education establishment's status quo. They defend their agendas with their own political plans and strategies (i.e., Political agendas B_2 and C_3 in Figure 2). A closer examination of those status quo politics is well overdue.

3 | THE POLITICS OF STEM

In this article, the story of STEM begins with the birth of its acronym by a scientific administrator at the National Science Foundation (NSF) in 2001 (Hallinen, n.d.):

> [A] report of the U.S. National Academies of Science, Engineering, and Medicine, emphasized the links between prosperity, knowledge-intensive jobs dependent on science and technology, and continued innovation to address societal problems. U.S. students were not achieving in the STEM disciplines at the same rate as students in other countries [student scores on the PISA—Program for International Student Assessment—international test]. The report predicted dire consequences if the country could not compete in the global economy as the result of a poorly prepared workforce. Thus,

attention was focused on science, mathematics, and technology research; on economic policies; and on education. Those areas were seen as being crucial to maintaining U.S. prosperity. (website quote)

This crisis sentiment was echoed in the US Congress' bipartisan STEM Education Caucus. The above details, well known to science educators, were repeated here as an agenda for reporting highly credible refutations to this NSF position.

First of all, it would seem that the NSF changed its definition of STEM from being the highly qualified high school STEM scholars headed to university STEM programs (Chin et al., 2004), to anyone employed in a job dealing with technology; for example, "installation, maintenance and repair, construction trades, and production occupations" (Okrent & Burke, 2021; website quote). In short, NSF's "STEM workforce" comprises both *academic STEM* and *workplace STEM* (also known as the National Science Board STEM). The reaction by the NSF in 2019 was to claim having 23% (website quote), about twice the proportion of the total US workforce than it had previously. Political positioning is strengthened through increased numbers of members. This exemplifies a strategy in agenda B_2 (Table 1).

A second Politics B_2 strategy is to maintain the status quo by promoting a STEM crisis. They claim a shortage of high school graduates entering the STEM workforce—the *nonacademic* STEM graduates who learn the procedural science on the job, without having to master the abstract knowledge and then apply it like the academic STEM graduates do. Most school science curricula emphasize *academic* STEM, as the NSF-EHR Directorate National Science Foundation— Education and Human Resources (2020) does in its *Education for the Future: A Visioning Report*; in addition to its welcome emphasis on student equity in gaining access to those academic STEM courses.

Highly credible sources, supported by solid evidence, contradict the NSF assertion that there is a STEM employee deficit crisis (e.g., Charette, 2013; Council of Canadian Academics, 2015; Palmer et al., 2018). Non-economic variables have a much greater influence on a country's economic prowess than the availability of STEM graduates. Boldeanu and Constantinescu (2015) itemized such influences: (a) "efficiency and demand" (p. 330); and (b) "values of goods and services supplied" (p. 330).

Over time, the influences on economic development have remained stable and depended on factors beyond the supply of STEM graduates. These other factors included: emerging technologies, industrial restructuring, poor management decisions, and government policies that affect military development, monetary exchange rates, wages, and licensing agreements (Bishop, 1995; David, 1995; Drori, 1998; Halsey et al., 1997). "There are also socio-political factors and events that have a major influence" (Boldeanu & Constantinescu, 2015; p. 330). "There is still not a consensus on the key determinants of growth" (p. 329).

A position more reasonable than the above dichotomy comes from Xue and Larson's (2015) article entitled, "STEM crisis or STEM surplus? Yes and yes." They recognize the political strategy of crafting a definition amenable to one side or the other: "Depending on the definition, the size of the STEM workforce can range from 5 percent to 20 percent of all U.S. workers. …[T]here is less consensus on areas such as medicine, architecture, science education, social sciences, and blue-collar manufacturing work" (website quote). These US Bureau of Labor Statistics researchers liken the STEM employee supply-demand issue to taxicab stands and the number of taxis in the city.

On the one hand, the side promoting a crisis is championed by National Academy of Sciences: National Academy of Engineering, and Institute of Medicine (2012) and by "the National Academies" (2007) report *Rising Above the Gathering Storm*, which called for improvements in kindergarten through 12th-grade science and mathematics education and increasing the attractiveness of higher education, among other recommendations" (National Science Board & National Science Foundation, 2022; website quote).

On the other hand, for example, "there are significantly more science and engineering graduates in the United States than *attractive positions* available in the workforce" (National Science Board & National Science Foundation, 2022; website quote, emphasis added). In some instances, industry does not make their positions attractive enough in terms of pay and security. Carter (2017) suggests an ulterior political ploy is at work: the larger the employee pool, the less they get paid, and the greater the shareholders' dividends. Another agenda B_2 strategy, perhaps?

In summary, a more in-depth analysis came from Xue and Larson (2015):

> considerable concern regarding a shortage of STEM workers to meet the demands of the labor market. At the same time, many experts have presented evidence of a STEM worker surplus. A comprehensive literature review, in conjunction with employment statistics, newspaper articles, and our own interviews with company recruiters, reveals a significant heterogeneity in the STEM labor market: the academic sector is generally oversupplied, while the government sector and private industry have shortages in specific areas. (website quote)

Ultimately, therefore, an insistence on a generalized STEM employee shortage as a defining rationale for *all* students enrolled in school science is rationally highly problematic and even suspiciously political. It is simply propaganda that propagates misinformation, which also exemplifies political agenda B_2 (Table 1).

Roemer et al. (2020) blame the competitive ethos in many STEM subjects for exacerbating the continuing enrollment decreases in the high school STEM pipeline. The NSF and general public place a heavy emphasis on comparing their country's ranking by the OECD's PISA science proficiency test results. This contributes to the ethos identified by Roemer et al. (2020). Zeyer (2022) points out the influence of school science scientism on this ethos.

4 | THE POLITICS OF OECD'S PISA PROJECT

What is PISA? "PISA is the OECD's *Program* for International Student *Assessment*. PISA measures 15-year-olds' ability to use their reading, mathematics and science knowledge and skills to meet real-life challenges" (OECD, 2019; p. 1, emphasis added). PISA is both a proficiency test and an array of questionnaires for students, teachers, and principals to fill out. Its results, collected once every 3 years, enjoy a high status among the general public and scientific community for supplying country rankings. The science education establishment relies on the student proficiency scores, but does so without critiquing the validity of the whole PISA program. A grasp of the program's politics is described here by way of a critique in terms of its validity.

As a comprehensive "assessment," it assesses more than students' proficiencies in science. In total, it collects data on three major attributes of an educational jurisdiction and reports the results in its reports: (a) student *proficiency* in science, assessed by multiple-choice and short answer exams composed by an international committee with its headquarters in Paris; (b) an educational jurisdiction's *equity* of student proficiency (taking into consideration the differential proficiencies by immigrants and by the neighborhood's social-economic status); and (c) an education jurisdiction's *efficiency*—the financial expenditure on science education as a function of their students' proficiency scores.

As a comprehensive "program," its validity audit will encompass the whole cycle: from the development of the latest assessment project to the consequence and public reaction to its results.

In the present context, "validity" is defined as the trustworthiness that one has in the whole PISA project in terms of what it claims to measure (Messick, 1989). Is PISA sufficiently trustworthy to match its high international status? The studies reported here point to the conclusion that it is not deserved, because PISA is a "political project masquerading as an educational tool" (Sjøberg, 2015; p. 4).

Beware of the masquerade tactic that claims an item addresses a societal issue, but really does not. For example, PISA's "Catching the Killer" question (189 words long) is about police asking everyone in a community where a murder has taken place to give a DNA sample for analysis. Statistical information is provided in a newspaper item format "DNA TO FIND KILLER" along with two people's DNA profiles. That is an excellent context for a humanistic science question. But the actual narrow simple question asked, "What is DNA?" (OECD, 2009; website quote), belies its description as a question related to a societal issue.

4.1 | The variable of culture

Andrews (2016) investigated PISA from a cultural perspective, beginning with an evidence-based viewpoint that culture underpins all school subjects. His concept of "culture" is defined as a noun: "culture can be construed as a *way of life*" (p. 10, original emphasis). He illustrated how "curricular mathematics [and science] and its classroom presentation varies according to culturally established norms" (p. 13).

Andrews (2016) singled out Finland for a case study analysis, in which its early success at always reaching the highest PISA rankings was explored by Andrews in depth. Several European and non-European countries went to great lengths and expense to duplicate Finland's pedagogy, but all ended with no significant improvement to their PISA rankings. Andrews concluded, "culture may play a more significant role than pedagogy in determining the [student proficiencies] of a country. …[T]o assume that school mathematics [and science] is the same wherever it is experienced … is simply not true" (p. 19). To some degree, "the PISA project" itself has a natural culture bias and is not as objectively neutral as it would like the public to believe. Some of its subjectivity can arise from the variation of the syntax of the questions formulated by the writing committee. While there is natural variation within a country (e.g., formal vs. informal), culture is bound to make a difference internationally.

This conclusion is strongly evidenced in European countries as well as for the 10 Canadian provinces. Ever since the inception of PISA, the Province of Québec's rankings have stood out head and shoulders above any other province; even those provinces that openly teach to the PISA test. Québec prides itself in having a European French culture significantly different from the culture of the other provinces. PISA tests, as reported above, are composed predominantly by European academics and educators from around the world. Culture would seem to matter to some degree, a situation that questions PISA's objectivity, and in turn, its trustworthiness.

4.2 | Invalidities by associations

Sjøberg and Jenkins (2020) argued that the claims by the PISA project were questionable. "The conflicts between the recommendations and priorities of scientists as well as science educators on the one hand, and PISA results on the other are highly problematic and require investigation" (p. 5). Examples included:

1. "[M]any countries with the highest mean PISA science score were at the very bottom of the ranking of students' 'interest in science,' 'future-oriented motivation to learn science,' (r = -0.83) as well as 'future science job' (r = -0.53)" (p. 3)
2. High scoring countries have students who "have very low self-confidence and self-efficacy related to science and mathematics" (p. 4).

Moreover, "As a project of the OECD, PISA reflects the desire to promote the economic development that gives the organization its raison d'être …a view embodying the economic function of schooling" (p. 9). This creates a type of conflict of interest between enhancing public education by providing highly valid results, and promoting differences on average scores to produce winners and losers in the international competition for economic investments.

4.3 | A pretence of validity

To express the problem, Sjøberg and Jenkins quoted Breakspear (2012): "PISA has now become an almost global standard, and is now used in over 65 countries and economies. PISA has become accepted as a reliable instrument for benchmarking student performance worldwide" (p. 1). This implies that student diversity, curriculum diversity such as humanistic school science, and culture diversities are "overridden by using PISA as a normative instrument of educational policy and governance. …As a result, PISA *does not measure* [achievement] *according to national school curricula* but according to an assessment framework made by OECD-appointed PISA experts" (Sjøberg & Jenkins, 2020; p. 9, original emphasis).

Sjøberg and Jenkins (2020) conclude that there are too many unknowns about the quality of PISA to treat its "results as *valid measures* of the quality of national school systems" (p. 10, emphasis added). "PISA scores and rankings are not facts, nor are they objective or neutral outcomes of the project. There is therefore an important task facing the science education community, namely to give the PISA project the rigorous scholarly examination it deserves" (p. 11). Simply put, trustworthiness has not been earned.

The present article's validity audit addresses all aspects of the PISA project that would affect a country's ranking: (a) its content and developers, (b) the soundness of the statistics used, (c) the students who write the test, (d) the misinterpretations of those results by influential citizens, and (e) how the rankings are used by the international economic community.

The OECD (2010) calculated "that an increase in 25 PISA points (a quarter of a standard deviation) over time would increase the GDP of Germany 8,088 million U.S. dollars" (p. 23). PISA seems preoccupied with foreign investment. It is interesting that OECD's economic case ignores the tremendous education expenditure to accomplish a 25-point raise; for example, hiring more teachers for smaller class sizes, extensive teacher in-service programs, new sophisticated teaching materials, etc. By ignoring these educational costs in its calculations, the OECD portrays a self-serving marketing agenda rather than an educational one.

Under the rubric "science literacy," OECD (2016) asserts, "An understanding of mathematics [and science] is central to a young person's preparedness for life in modern society…. Mathematics [and science] is a critical tool for young people as they *confront issues and challenges* in personal, occupational, societal, and scientific aspects of their lives" (p. 25, emphasis added). But PISA does not include any item on the test that comes close to assessing its science literacy. Its trustworthiness loses points here.

4.4 | Content and syntax invalidities

What is the match between that content composed of OECD's experts, on the one hand, and a student's local curriculum content, on the other? This factor can seriously reduce the content validity of PISA scores. Given the culture bias that Andrews (2016) identified, the syntax of a test item will likely differ between the OECD experts' and the local protocol faraway from Europe. Decontextualized textbook-like questions are somewhat challenging to the 85% of high school graduating students who tend to respond with greater understanding to items contextualized in a way familiar to them (Doolittle, 2006). But usually a scientific context is used pretending it is an everyday context, to which the science-challenged students have been known to respond with "why bother so incredibly much" (Serder & Jakobsson, 2015; p. 1). The chances are slim that the item constructors' and the student's local everyday experiences will match. The normal language translations are often problematic. This potential for miscommunication detracts severely from a test's trustworthiness (Aikenhead, 1988).

4.5 | Statistical invalidity

A standard item analysis statistical calculation, "item discrimination" (Office of Educational Assessment, n.d., p. 3) can determine, to various degrees, an individual test item's ability to distinguish between students who will score well on the whole test and those who will not. PISA test items were found to only predict well for students who score high marks (Sjøberg & Jenkins, 2020)—the 15% of students (a statistic reported in "the Appendix"). Those items are not all that valid for the 85% group of students. This means that for the sake of PISA's validity, it should only be administrated to the top third of Grade 9 students. The test's validity fails otherwise.

4.6 | Sampling invalidity

Random sampling is an absolute condition for test validly when comparing PISA scores from state to state, or country to country. The OECD carefully chooses schools at random within each education jurisdiction. Those plans get undermined by the schools in some countries that need to attract foreign investment (the subtext of OECD's projects such as PISA). In spite of the automatic exclusion rate of 5% to compensate for students with language difficulties or other disabilities, on the day of the test in some school jurisdictions, students who typically score poorly are given a day away from the school. Such an event for some schools, desperate to attract foreign investment, is part of the PISA project according to in-sider eye witnesses, and it destroys several statistical assumptions that PISA relies on; thereby shredding the test validity for these unidentified countries.

4.7 | Cherry picking the results

During the process of interpreting the released results, a major blow to PISA's project validity occurs regularly. Recall there are three major outcomes for PISA: student proficiency, equity of student achievement, and the government's efficiency. Most of the public and some science critics look at average proficiency scores and treat them erroneously as absolutes rather than measurements with confidence limits. As a result, these politicians and journalists seldom understand the concept of ties among education jurisdictions, so they misinterpret the results. But even much worse, "The response of legislators to PISA results and the attendant publicity has been to propose ways in which school curricula can be modified in order to maximize PISA performance" (Sjøberg & Jenkins, 2020; p. 10). Excellent curriculum policy is best reached through deliberation, focused on the best interests of a diversity of students and informed by research and innovative developments.

Politicians, the press, and the public cherry pick PISA's major results by ignoring the equity and efficiency assessments. By doing so, decreased students scores from the last test are blamed on teachers. If efficiency were in pubic view and the students' scores decreased, politicians would be blamed by the public for not spending sufficient money of science education. And equity in student achievement relates to racism, immigration, and social-economic-status in which public schools play a role in maintaining (Berger & Archer, 2016); uncomfortable topics to discuss in public by politicians.

4.8 | What happens when no cherry picking occurs?

There is a much more rational way to assess the overall success of any educational jurisdiction (e.g., a country, state, of province). Combine all three variables (proficiency, equity, and efficiency) using a standard statistical method. In addition to each jurisdiction's student proficiency scores, an overall ranking per jurisdiction could be assigned, which is an equivalent to a student's grade point average (GPA). PISA does not do this. Their customers—educational jurisdictions—prefer to mention student proficiencies only; a selective process known as cherry picking the main results.

However, when all three variables are statistically combined for each country, the results are surprising (Craw, 2015; Parkin, 2015). Individually, Finland, Estonia, and Canada were ranked at 11, 12, and 13, respectively, on their math proficiency scores. The more sophisticated three-factor analysis resulted in a tie, with a ranking of 1. Simply put, they were the best countries participating in the PISA project when all three PISA assessment variables were considered together. Ranking is not as objective as the public believes it is. PISA's silence on this finding is notable.

4.9 | Conclusion to the politics of PISA

As the above subliminal features of PISA emerge, its validity wanes. Headlines such as, "U.S. Students' Academic Achievement Still Lags That of Their Peers in Many Other Countries" (DeSilver, 2017; website quote), or claims such as, "The average U.S. science score was higher than the OECD average and has improved by 13 points since 2006" (National Science Board—NSB, 2022, p. 5); require a trust analysis when one discovers the article is based on PISA student proficiency results only. The above headline and claim: (a) play into PISA's political posturing; (b) undermine PISA's expressed notion of science literacy; and (c) support PPT (preprofessional training) school science that dominates curricula worldwide (Breakspear, 2014) for the ultimate economic advantage to the OECD; thereby adding to "agenda A_1" in Table 1, by and large.

Given that the PISA project has failed this validity audit, two questions remain: Is it ethical to use PISA now? If so, under what conditions?

4.10 | PISA's positive move

Recently communicated future plans for PISA's 2025 science framework happen to harmonize with some of the reform content for postnormal school science proposed in this article (Oxford University Press, n.d.): relevant humanistic contexts that emphasize students' self-identities; where identity mediates learning and understanding. Students' science identities express their science capital, critical science agency, inclusive science practices, inclusive science experiences, ethics and values can be discussed. Xiaomin and Auld (2020) have written "a historical perspective on the OECD'S 'humanitarian turn'" (p. 503) for OECD's 2030 learning framework.

Although this is a positive direction to initiate, evidence through action is required before the turn is seen as authentic, rather than smooth marketing or a façade similar to the societal contextualized "Catching the Killer" test question described above.

5 | THE ULTIMATE THREAT OF CLIMATE CHANGE

Death threats on social media and at demonstrations aimed at specific scientists during the COVID-19 pandemic and during international meetings on climate change are on a relatively small scale compared to the death threat to much of humanity on a global scale by climate change.

If the science education establishment can respond to the 1960s political crisis over technological superiority between rival nations (Politics A, Figure 2), one would think it can certainly respond dramatically to a mega death threat to human populations by climate change (Politics D, Figure 2).

However, political agenda B_2 was persistently all about the financial economy (Bencze et al., 2006), stimulated in the 1960s by the political goal of landing astronauts on the Moon (Politics A). Now that many economies are increasingly being challenged by climate change's costly wild fires, flooding etc., what can one learn from the history of economics that will shed light on implications for science education's unavoidable role in Politics D?

6 | LESSONS FROM THE HISTORY OF ECONOMICS

The science education establishment needs to become savvy to current international economic imperatives. The establishment's highly successful 60 years of R&D for the military, business and industry communities have had the unexpected result of augmenting climate change. Therefore, one would think that this ultimate challenge would become the highest priority for the science education establishment. How did we get to today's tipping point in a climate-change crisis? Economics offers a helpful historical map to explore.

What follows here draws heavily on Carney's (2020a, 2000b, 2021) work and experience. The following abridged bio of him will offer helpful evidence related to the reader's trust analysis of his ideas and evidence. Born in 1965, Northwest Territories, Canada, Mark Carney has become an internationally renowned economist (Keller, n.d.); rising to: (a) the managing director of investment banking at Goldman Sachs; (b) Governor of the Bank of Canada and then the Bank of England; and today (c) “Special Envoy of the UN Secretary General for Climate Action, and UK Prime Minister's Adviser for Climate Change” (Carney, 2021; p. 316); (d) chairman of the Committee on the Global Financial System at the Bank for International Settlements; and (e) chairman of the Financial Stability Board, based in Switzerland. Simply put, he excels at being an economist, academic, and humanitarian.

6.1 | Becoming a sustainable society

Carney (2020a) provided the following broad perspective on human values. He first described the historical transformation that Western societies underwent in the 18th century: from being ruled by *values* that royalty and noblemen held, to being ruled by the value *financial profit* for the purpose of national progress—popularized by Adam Smith's open-market theory of capitalism introduced in his 1776 book *Wealth of Nations*, from which the adage arose: trust the market, it is invariably right (Stout, 2002).

Global market enterprises exercise power subliminally over: the investment world, the socio-military-business-industrial-scientific sectors of a nation, national governments, and even science and mathematics education (Carney, 2020a). The OECD, for instance, with its headquarters in Paris, applies this power simultaneously in two fields: (1) advising on worldwide investments in natural and human resources, and (2) promoting its version of science and mathematics education through their PISA project, described above in section “The Politics of the OECD's PISA Project.” Bencze et al.'s (2006) research sheds light on science teachers' tendencies to make science appear to be relevant by associating it with commercial profit-driven contexts. After all, that is the science education establishments' rationale for increasing the number of STEM graduates from schools and postsecondary education.

Carney (2020b, 2021) noted that a worldwide societal transformation is already underway; visible to international economists, but invisible to many of the general public. To update the future public school, science can teach current interactions between science and society when students learn scientific content contextualized in (Klopfer & Aikenhead, 2022): (a) socio-scientific issues, (b) civic science education, (c) science | environment | health, (d) history of science cases, or (e) the nature of science. Each approach, or various combinations thereof, would engage the future general public in their everyday world of science-society interactions. Out-of-school science could also be learned informally or as usual, on the job.

World economists are moving from a profit society to a sustainable society (Carney, 2020b; Stout, 2002); this time for the purpose of raw *human survival* (Reis, 2022), to manage the disastrous and costly effects of mud slides and the disappearance of ocean-front territory. The financial costs of climate change have already severely impacted families, communities, and some industries. *There is no profit to be made living on an inhabitable planet*.

Thus, Carney's challenge and his international colleagues' commitment to a sustainable society requires Politics D (Figure 2, Table 1), a permanent neutralization of climate change. Finland, for example, is poised to meet this neutralization of zero-carbon emission over preindustrial levels by 2035 (Dorst, 2021); a “prerequisite to solving climate change” (Carney, 2021; p. 312). *Finland's culture tends to give priority to the common good over individual agency*.

Carney (2021) wrote: “In my experience, the upheaval the world has been experiencing demonstrates that it is vital to rebalance the essential dynamism of capitalism with our broader social goals” (p. 148). “[E]vidence suggests that our planet is headed to between 3°C and 4°C warming” (p. 310) (compared to preindustrial levels), well above the current target of 1.5°C to 2°C. "[Behind the ultimate goal—a sustainable economy—requires endorsing the values that underpin it. The values of solidarity, of fairness and, yes critically, of dynamism" (p. 312). "Against a backdrop of climate protests and children striking to draw attention to their climate fate, an increasing number of voters are ranking climate as a key influence on their vote" (pp. 312–313). "[We] won't solve climate change in the future without the private sector" (p. 317). Carney strongly advocates using "financial technology to ensure that every financial decision takes climate change into account" (p. 316).

7 | IMPLICATIONS FOR 21ST CENTURY HIGH SCHOOL SCIENCE

Parallel to our society's economic transformation into a sustainable society, a fundamental high school science content transformation is needed for two clusters of future citizens: the majority and the minority. This article's delimitation to school content excludes school pedagogy, such as learning progressions and trajectories based on developmental pathways (e.g., Duschl et al., 2011; Fensham, 1992); a topic for another article.

First, there is the 85% majority of future citizens (the Appendix explains the figure "85%"). This majority of savvy public participants in postnormal science could urge and support political action to expedite the transition to a sustainable society. These participants could challenge people who deny anthropogenic climate warming (Aikenhead, 2003). For example, postnormal science curricula could "arm" these participants by their learning about the science-in-action at sustainable companies in their country, where the smart money in finance is found today (Carney, 2021). This will help challenge the science-denying students with appropriate humanistic school curricula content (Klopfer & Aikenhead, 2022).

A key question is: What is some of the canonical science content that employees need to know? Develop a curriculum around some of that content. Most students will appreciate this out-of-school science knowledge as being relevant to the everyday world of sustainability. It also focuses on the nature of science and science-society interactions relevant to a sustainable society.

Secondly, the minority 15% is a figure also explained in the Appendix A. Their interests, predilections, or expertize in STEM subjects have already begun their education journey to create the scientific, mathematical and engineering innovations to navigate and sustain the historic societal transformation into a sustainable society. These students will continue with a first class PPT program. Extraordinary efforts are required to encourage those who have been traditionally discouraged by systemic discrimination, such as "the racism of low expectations" (Bellringer, 2019; p. 13). Equity audits and established corrective actions must accompany these porous high school science pathways.

Sixty years after Pres. Kennedy's 1962 Moon-landing challenge (Politics A, Figure 2), the sense-making strategies of a notable portion of the general public have changed. The COVID-19 pandemic, for example, led to the death threats against Dr. Fauci and scorn on certain research scientists.

Remedies proposed or enacted for climate change intensify such threats from the public. Carney's (2021) message is that we do not need more STEM graduates; we need both smarter STEM graduates and more savvy non-STEM graduates, measured in terms of their understanding of nature, technology and humanity, plus the value of commitment to the common good (a.k.a., membership expectations in a democratic society). The STEM clusters of students would be roughly framed by international baccalaureate school science with humanistic science enrichment and the non-STEM groups by humanistic school science. Both groups would have different but equally rigorous content to master (e.g., Roth, 2022; Sills, 2010).

The crisis of climate change has unleashed a host of political agendas related to science education (Table 1): Politics D (Figure 2, Table 1) represents Carney's, (2020b, 2021) international economics activities to bring about sustainable societies. The deniers of anthropogenic climate change will launch their own style of politics (a repeat of political agenda C_1). This creates a politically negative science-society interaction that must be challenged within postnormal science education (political agenda C_2) (Sills, 2010); not by the pure and applied normal sciences that were so successful in the culture of the 1960s (political agenda A_1).

A third distinct style of politics, agenda C_3, occupied by the sectors within the education establishment, which for 70 years of their agenda B_2 have constantly resisted significantly expanding evidence-based domains of humanistic school science into components of mainstream curriculum for the majority of students; a topic reviewed in Klopfer and Aikenhead (2022); of which Science|Environment|Health (Zeyer & Kyburz-Graber, 2012) is a prime example.

As a reminder, humanistic school science also had its political agendas (B_1, C_2, and D_1 Table 1). Its realms include (Klopfer & Aikenhead, 2022): NOS (see section "Introduction"), (science-technology-society; Gallagher, 1971; Solomon and Aikenhead, 1994), (science-technology-society-environment; Pedretti et al., 2008), SSI (socio-scientific issues; Zeidler and Sadler, 2011), CSE (civic science education; Levey et al., 2021), S | E | H (science, environment, health; Zeyer & Kyburz-Graber, 2012, 2021), and CE (civics education; Brickhouse, 2022). These humanistic approaches are superb motivators for engaging the majority cluster of students (Sadler, 2011). Humanistic school science fits well with helping: (a) to promote a sustainable society, and (b) to diminish the political impact of the antiscience deniers of climate change. Some researchers call this "socially responsible science education" (Fuchs & Tan, 2022; p. 9).

Under the rubric "science literacy," the OECD (2016) recognized the fundamental importance of engaging "with science-related issues, and with the ideas of science, as a reflective citizen" (p. 28), and "finding solutions to complex social and environmental problems" (p. 6). As mentioned previously, this was promotional propaganda. Perhaps it was written under the naïve impression that students would apply the abstract science, all on their own. But it can still serve OECD in its transition into joining Carney's (2020b) vision of a sustainable society. This depends, of course, on the credibility of OECD's PISA 2025 Science Framework (Oxford University Press, n.d.).

Science education's contribution to society's transition into being sustainability-oriented while achieving reasonable profits, must be fought on two levels: (1) producing innovatively competent scientists, engineers and mathematicians needed for a sustainable society; and now equally important (2) educating a public who will understand the humanistic dimensions of the science and engineering enterprises (i.e., their nature, social aspects, and interactions with society) and who can rationally act on that learning. Therefore, a science education for human survival requires two different pathways to ensure success for both clusters for students. Mathematics education faces a steeper challenge: the 21st century's Digital Revolution that has considerably narrowed how mathematics is now being used in the general labor market and by PhD graduates (Borovik, 2017).

8 | CONCLUSION

There were successes in science education, such as the collaborative effort to update its curriculum content in the 1960s, and there were concomitant failures; for example, a failure to consider seriously the needs of the large majority of high school students. The science and engineering successes in the military, business and industrial sectors of today's profit society inadvertently intensified today's climate change crisis. This consequence is beginning to lower government budgets for education and NASA.

This article explored the invisible power and politics in the interactions of science education with the scientific community and society. The purpose was to clarify, in broad brush terms, a rational and feasible future for high school science. Given their social maturity and interest, high school students are generally more amenable to learning the content expected in humanistic school science.

8.1 | The elephant in the room

A rendering of science education history has laid out some of its successes and apparent failures. There is evidence for both. Successes seem to occur when there is resonance between what the scientific enterprise has to offer and the agendas of a political or social authority. Dissonance tends to occur when the values of the science education community diverge from an authority's values expressed as a political agenda. This article's storyline intentionally interrogated the instances of resonance and dissonance.

One way to map out this historical development was to identify changes to the social or political authority in the context of a changing society. Very few science educators choose their profession because of the politics involved; on the contrary. Consequently, to understand the political nature of science education is to explore the proverbial "elephants in the room;" such as economic agendas and the values that underlie the political agendas. They are so subliminal that they become taken for granted features of a county's culture that rarely get questioned seriously. This article intensely interrogated some "elephants" in science education's room.

The humanistic innovations in science education (Klopfer & Aikenhead, 2022; Southerland & Settlage, 2022) have mostly been killed on the alter of academic STEM for *all* students. This excessive emphasis on preprofessional training (PPT) has created the following subliminal cycle:

1. Myths about the privileged practicalities of possessing scientific knowledge (i.e., its "value in use," Carney [2021, p. 22]) associated with the goal "academic STEM for *all* students" (see section The Politics of STEM);
2. the public's widespread beliefs held about those myths;
3. social power bestowed by society upon those who hold such beliefs;
4. privileges gained by that social power ("value in exchange" for higher marks; [Carney, 2021; p. 22]).

Schooling tends to reinforce the social-class status-quo of society (Andrews, 2016; Anyon, 1980; Jorgensen, 2016), expressed by the myth cycle—a popular elephant in the room.

8.2 | Trends

As the nature of science changed from normal science to extraordinary science, to frontier science, and finally to postnormal science; social ramifications to the societal decisions made by scientists increased the interactions between scientists and the public; increasing a significant portion of public negativity towards science.

At the same time, the science education establishment applied steady pressure for PPT to produce more academic STEM graduates from high schools and universities. When making policy statements, PPT authorities generally ignored the diversity of students by beginning those statements with the phrase or assumption "all students." On the one hand, they did express eloquent definitions of "scientific literacy," but that content seldom appeared in their curricula or in high-stakes assessment. Thus, its promised relevance to students failed to materialize among the 85% group of students.

Some science educators assumed that student diversity mattered significantly. They advanced their political agenda B_1 (Table 1) that included *both*: (a) humanistic school science amenable to postnormal science and to students who valued making connections holistically and intuitively (Gilligan, 1982); and (b) normal PPT school science amenable to academic futures and to students who valued rules, abstractions and reductionism (Gilligan, 1982). This diversity was acknowledged by the descriptors 85% and 15% proportions of students, respectively, knowing that reality indicates a continuum of student attributes, not a dichotomy. Dichotomies are useful shorthand when used for that limited purpose.

Another trend was how the social context changed remarkably from the challenge to reaching the Moon to saving humanity as we know it. Already the current costs to governments due to climate change are decreasing education budgets, thereby negatively impacting the quality of science education. There is little evidence other than tokenism that suggests the science education establishment is significantly embracing postnormal school science in the crisis of climate change.

Politics matters. Student diversity matters. Humanistic school science currently exists with great successes in small pockets (Aikenhead, 2006; Klopfer & Aikenhead, 2022); for instance: (a) the NSF funded Science Education for Public Understanding Program (SEPUP Science for Public Understanding Program, 2021; Thier & Nagle, 1994); and (b) Nouri and McComas (2021) report on "the role of [the history of science] in communicating NOS" (p. S291), offered by the nationwide UTeach program developed at the University of Texas, Austin. Thus, the high school reform proposed here is rational, feasible, and necessary.

Political agendas C_2 and D_1 (Table 1) need the most attention today by: the science education establishment, university science education faculty, and classroom teachers. Both politics and action are priorities (Figure 2).

Will science education recover from its oversights? Will that be the next trend?

CONFLICT OF INTEREST

The author declare no conflict of interest.

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APPENDIX A

Student Diversity: An explanation for 15% and 85%

Two large scale studies measured different but related characteristics of Grade 12 students:

1. US Office of Technology Assessment's (OTA) 16-year longitudinal study (Frederick, 1991), Table 2, began in 1977 with 4 million Grade 10 students, of whom 18% of this original sample expressed an "interest in natural science or engineering" postsecondary programs (p. 389) (i.e., *Interest*). This decreased to 15% near the end of Grade 12; and then to 9% of the original sample for those who actually enrolled in a college or university natural science or engineering program.

TABLE 2 US Office of Technology Assessment (OTA) pipeline data for students expressing an interest in future “natural science or engineering” programs (Frederick, 1991; p. 389)

Year:	1977	1977	1979	1980
Grade:	10	10	12	College Entry
Number of Students:	4,000,000	730,000	590,000	340,000
% of initial sample:	100%	18%	15%	9%

2. The National Bureau of Economic Research (NBER) collected data on the percentage of Grade 12 graduates with sufficient STEM credentials (i.e., *STEM-readiness*) to attend a college or university, whether or not they actually enrolled in a postsecondary STEM program (Card & Payne, 2017). Their postsecondary enrollment was not recorded for this NBER “STEM-ready” (p. 2) group. Their results comprised” 14.5% females and 15.3% males” (p. 3) of Grade 12 graduates. Merging the two percentages, makes 14.9% of all graduates (15% rounded off). Because this is almost identical to the OTA's result, the 40 years difference between the two studies is not an issue. And not much seems to have changed in science education during the intervening 40 years that would increase or decrease STEM readiness.

Both projects' dependent variable was cast as a dichotomy for the convenience of researching and discussing student diversity in a simplistic way.

A More Authentic Dependent Variable Proposed

Students' *science identities* speak to their intrinsic motivation to do well in science (Avraamidou & Schwartz, 2021) and are closely associated with a student's sense-making processes used in their everyday world—the lens through which they view their world—and the way others identify the student with science; plus how strongly a student feels that connection. The stronger their science identity, the more they: believe in science, value scientific ways, and want to become a scientist (Brickhouse, 2007). The degree to which a student identifies with science, the stronger the student's science identity becomes (Aschbacher et al., 2010; Nasir, 2002). The following six-category ordinal continuum is suggested to avoid an overly simplistic dichotomy (e.g., a science person, a nonscience person) for researchers' consideration, or for a teacher's self-professional development project. It is shown here in a student self-reporting format:

Science-resistant: I generally distrust science; or I can get terribly anxious or sometimes even sick over learning science, especially when preparing for, and writing tests.

Science-avoidance:I avoid thinking about science in or out of school, as much as I can get away with ignoring it.

Science-disinterested: Science is not interesting to me, but I can usually memorize my way to a pass mark or higher.

Science-interested: Science is interesting to me most of the time, although other subjects can be more interesting.

Science-curious: Science is cool; it makes me curious most of the time.

Science-oriented: Science is the best; I look forward to doing challenging science problems and learning new ideas as preparation for a science-related career.