A Framework to Guide Science Educators' Efforts in Confronting Misinformation

by Lara Smetana, Loyola University Chicago; Jack Gorman, Critica; Sara Gorman, Critica; & David Scales, Critica

Abstract

This article synthesizes background research, presents a framework, and shares a frequently updated resource guide (see Science Educator Response to Misinformation: Framework and Resource Collection) for science educators' multifaceted response to science and health misinformation. We developed this framework and guide as a tool to help science teachers and teacher educators think about the complexity of the issue of science and health misinformation, visualize the connected and interrelated avenues to confront the issue, and identify opportunities to take action in their courses.

Introduction

Numerous discussions have and will continue to take place about the goals of science education and how best to reach those goals. The authors—a university science teacher educator, a psychiatrist, a public-health specialist, and a physician and sociologist—have had many such conversations with teachers and community stakeholders over the past year. The overarching goal that we seek is a public who can make informed decisions about socioscientific issues that face them and their local and global communities; has a functional understanding of science concepts, practices, applications, and the nature of scientific knowledge; seeks out and utilizes scientific expertise; appropriately judges and critiques scientific knowledge claims; is able to distinguish reliable from suspect sources of information; and is robust against and able to cope with science and health misinformation. We define misinformation as "information that is false, inaccurate, or misleading according to the best available evidence at the time" (U.S. Department of Health and Human Services, Office of the U.S. Surgeon General, 2021, p. 4). In this article, we primarily focus on false or inaccurate information (i.e., misinformation) while acknowledging the related thread of false information that is intended to deliberately mislead (i.e., disinformation).

This overarching goal is not new, but the stakes have been raised as the world becomes increasingly complex, interconnected, and polarized (Carothers & O'Donohue, 2019; Organisation for Economic Co-operation and Development, 2018; McGrath, 2011). Additionally, the barrage of misinformation becomes more constant in what has been referred to as a posttruth era (McIntyre, 2018) and an infodemic (Eysenbach et al., 2002; Zarocostas, 2020). Although incorrect information about scientific topics has been offered to the public in many formats for centuries (Scheufele et al., 2021), the internet, social-media platforms, and now artificial intelligence (AI) text generators make it possible for it to spread more widely and rapidly than ever before. Research suggests that false information spreads faster than correct information on the internet (Vosoughi et al., 2018). The ever-increasing use of AI is influencing, both positively and negatively, how information is disseminated and evaluated. Although AI has the potential to provide information that is easier to understand, it can also make the spread of mis- and dis-information more pronounced (Spitale et al., 2023).

Studies have also shown that misinformation has real consequences that can jeopardize public health. Misinformation about a wide range of health and science topics, including climate change (Cook, 2019), vaccines such as the HPV vaccine (Calo et al., 2021; Kornides et al., 2023) or COVID-19 vaccines (Lee et al., 2022; Neely et al., 2022; Romer et al., 2022), cancer treatment (Johnson et al., 2022), and reproductive health (Rowlands, 2011; Pleasants et al., 2021), have the potential to interfere with the ability of people to make scientifically informed decisions. Further, misinformation can lead to weakened trust in science or overall rejection of scientific consensus (Druckman, 2022). Indeed, the Commission for the Human Future (2020) deemed the proliferation of misinformation and related science denial, or the "systematic rejection of empirical evidence to avoid undesirable facts or conclusions" (Liu, 2017, p.129), to be among the top threats to global society in the 21st century.

We consider science educators and their students important first responders in the current infodemic and misinformation crisis. The surge of attention around the issue of science misinformation is both encouraging and overwhelming. We developed the Science Educator Response to Misinformation (SERMI) framework and resource collection to inform our own and other educators' thinking about the complexity of the issue of science and health misinformation. The framework helps visualize the connected and interrelated avenues that are necessary to come together to confront the issue and identify opportunities to take action on a regular basis in our classrooms and courses.

Education as a Key Intervention

Education has a critical role to play in addressing science misinformation, but what does that look like? Current challenges and weaknesses within educational systems in the United States need to be acknowledged and addressed so that they do not continue to aggravate the problem, and multifaceted and interdisciplinary efforts need to be expanded (Barzilai & Chinn, 2020). Although a comprehensive discussion of these issues is beyond this scope of this article, some examples are shared below.

Within the science education literature, attention is drawn to both the strengths and weaknesses of *A Framework for K-12 Science Education* (National Research Council [NRC], 2012) and the resulting *Next Generation Science Standards* (NGSS; NGSS Lead States, 2013). The strengths include an emphasis on the classroom as a knowledge-generation environment, as opposed to a knowledge-transmission environment, with students actively engaging in core scientific practices as they generate and defend explanatory model-based accounts of natural phenomena (Berland et al., 2016; Ko & Krist, 2019). Critiques of the NGSS include the omission of socioscientific topics that concern students' lives (Osborne et al., 2022) and issues of social justice (Kayumova et al., 2018; Morales-Doyle, 2017) and an overall portrayal of the neutrality and objectivity of science despite the inherent influence of culture, values, and social contexts (Erduran & Dagher, 2014). Educators may certainly choose to bring socioscientific issues and the kinds of questions and dilemmas that scientific developments raise at personal, social, and global levels, but they are not explicitly included in the standards and, thus, can easily be excluded, intentionally or unintentionally. Together, these limitations mean students may not see school science as something that is accessible to or representative of them (Avraamidou & Schwartz, 2021; Calabrese Barton & Tan, 2019) or useful in their lives and communities (Morales-Doyle, 2017; Stroupe et al., 2020). Therefore, some students lack consistent opportunities to develop a robust view of what science is, how the processes of science and the social practices of the scientific community work to produce trustworthy knowledge, and why this understanding matters (Klaver et al., 2023; Osborne & Pimentel, 2023; Osborne et al., 2022).

Addressing the challenge of science misinformation extends what science educators may have typically considered within their domain. Information and media literacy have more often been considered part of the humanities curriculum than the science curriculum (Lyiscott et al., 2021), but this is changing. There has been an encouraging movement of legislative action adding information and media literacy standards across grade levels and content areas (e.g., Illinois and New Jersey). Zucker et al. (2020) developed and disseminated a unit aimed at helping secondary students learn how to evaluate the quality of scientific information, and in fall 2023, Media Literacy Now launched a science-focused media literacy project.

Similarly, statistical and data literacy are traditionally more likely to fall under the domain of mathematics (Aziz & Rosli, 2021). In this case, skill development for using data is often emphasized over critical thinking and understanding and interpreting data (Sharma, 2017; Van Audenhove et al., 2020). Although awareness of algorithm bias is growing, the teaching of algorithmic media literacy—what algorithms are, how media platforms use them, and how peoples' media environments are controlled by them—is rare (Ciccone, 2021; Cohen, 2018). It is also unclear where and how often students have opportunities to understand the psychology of misinformation (cognitive, social, and affective factors) and evidence-based strategies for addressing the threat of misinformation (Ecker et al., 2022; Gorman & Gorman, 2021).

We also see the complexity of classroom teachers' work as both a challenge and an opportunity. Effective science teachers attend not only to the science content they teach but also to their learners and to the social space of the classroom learning environment (Lemke, 2001; Rogoff, 2003). We have found that educators encounter science misinformation during formal lessons and, perhaps even more commonly, during informal interactions with students that include conversations with students, student references to social media, and student peer interactions outside of class. Thus, the response must also recognize the socially and relationally situated nature of learning and of decision-making around socioscientific issues (Cian, 2020; Feinstein & Waddington, 2020; Klaver et al., 2023).

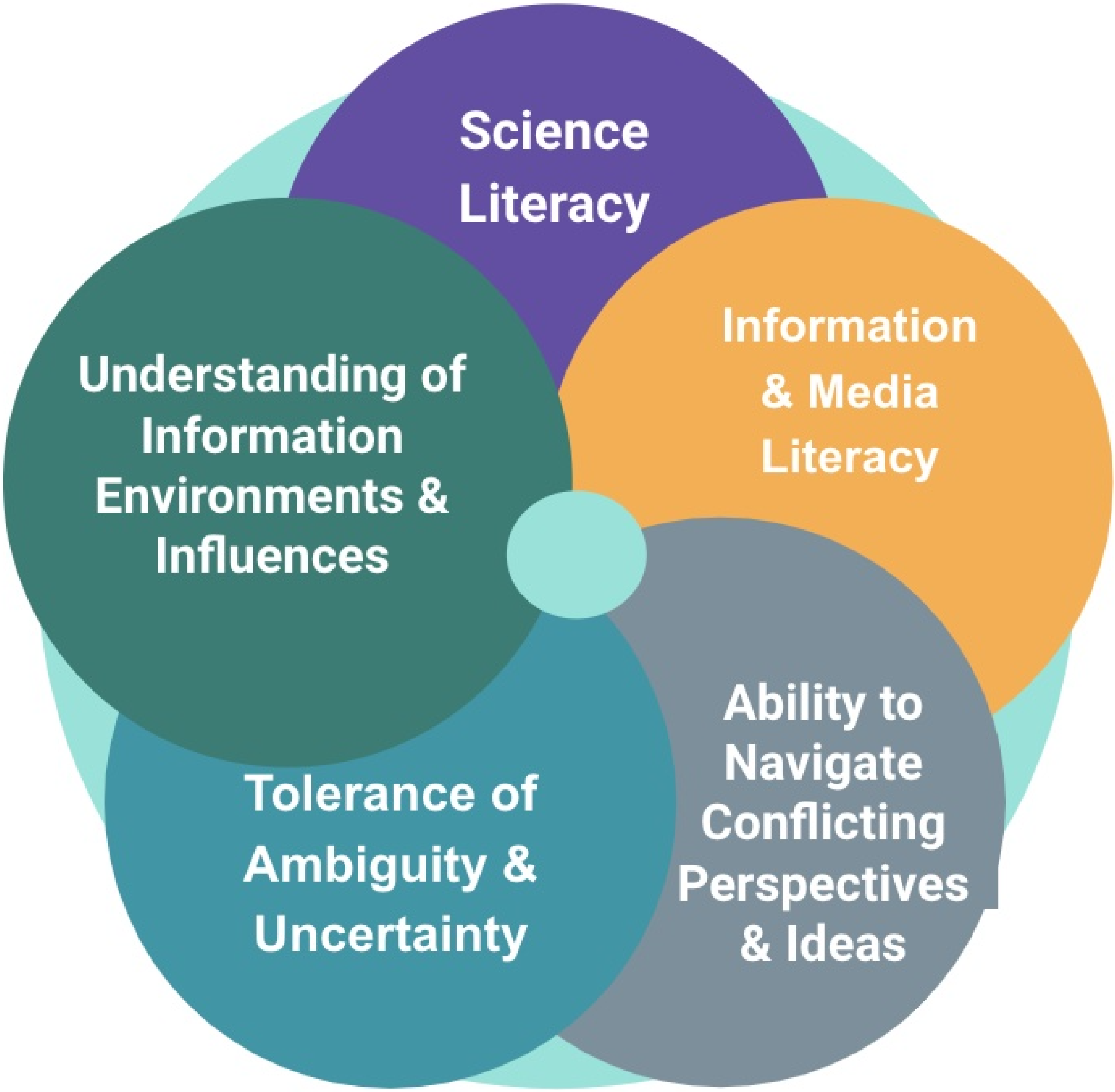
We posit that these are all necessary components of a response to resisting science and health misinformation and that none of these are sufficient alone. As the examples in this section illustrate, science misinformation is a collective problem and, thus, requires a collective response embedded as a regular part of instructional practice. The following sections outline a framework for science educators' multifaceted approach to addressing misinformation.

Overview of the Science Educator Response to Misinformation (SERMI) Framework

The framework consists of five components that are presented in no particular order: (a) science literacy, (b) the tolerance of uncertainty and ambiguity, (c) the ability to navigate conflicting perspectives and ideas, (d) information and media literacy, and (e) understanding information environment and influences (see Figure 1). Discussion of each component is accompanied here by practice-based questions for educators to ask themselves as they consider their curriculum and instruction, identify what they already do well, and find areas to provide more or deeper opportunities for students to develop their resistance to science and health misinformation, and some sample applications. A summary of each SERMI component, the practice-based questions, and links to some of our favorite existing resources are included in the accompanying digital teacher's resource guide (Science Educator Response to Misinformation: Framework and Resource Collection), which is updated frequently. To illustrate how the five components of SERMI are thematically linked, we will use the example of incorrect beliefs and misinformation about the COVID-19 pandemic throughout each section.

Figure 1

The Science Educator Response to Misinformation (SERMI) Framework



Science Literacy

Broadly, science or scientific literacy is concerned with the knowledge, understanding, and dispositions needed to engage with science in various personal and societal contexts (National Academies of Sciences, Engineering, and Medicine [NASEM], 2016; NRC, 2012). However, science literacy has been defined and conceptualized in many different ways (see John Rudolph's 2023 historical survey). NASEM's (2016) *Science Literacy* report identified seven components of science literacy, and Sharon and Baram-Tsabari (2020) argued that four of those components are most likely to assist in "identifying [and responding to] misinformation in everyday life: (a) Understanding of scientific practices, (b) Identifying and judging appropriate scientific expertise, (c) epistemic knowledge, and (d) [scientific] dispositions and habits of mind” (p. 876). In our work, we focus on those four components of science literacy.

An *understanding of core scientific practices*—such as asking questions, planning and carrying out investigations, collecting and analyzing data, and interpreting scientific findings—is essential to understanding what science is and how science works. An understanding of the practices of science also includes an understanding of scientific procedures such as randomized control trials versus observational studies, isolating and controlling variables, peer review, and standards of evidence quality. Although K–12 students should have opportunities to engage in core scientific practices themselves (NRC, 2012), their understanding of those practices also enables them to ask informed questions about topics and issues within highly complex and specialized domains of scientific knowledge (Sharon & Baram-Tsabari, 2020). Thus, scientifically literate individuals are also able to *identify and judge appropriate scientific expertise*. Doing so relates to the core scientific practice of obtaining, evaluating, and communicating information (NGSS Lead States, 2013) and involves critically examining what was said (the quality and strength of scientific claims) as well as the credentials and track records of who said it.

Science literacy also involves *epistemic knowledge*. This refers to knowledge about the defining features of science and how, why, when, and where scientists can produce useful and reliable knowledge as well as where and why science is limited (Zetterqvist & Bach, 2023). Epistemic knowledge encompasses how scientific claims are supported by scientific evidence, what constitutes strong evidence, and how to evaluate the strength of the evidence supporting a scientific claim. This facet of science literacy entails both developing a scientific worldview and the understanding that multiple worldviews can coexist, such as Western science and religious and indigenous worldviews (Feinstein & Waddington, 2020).

Finally, Sharon and Baram-Tsabari’s (2020) research highlights the importance of scientific *dispositions and habits of mind* in relation to confronting and defending against misinformation. These include open-mindedness, inquisitiveness, and a curiosity about science, how science works, science news, scientists from diverse backgrounds, and science endeavors and careers. Indeed, curiosity has been shown to be a key predictor of the ability to accept scientific consensus (Kahan et al., 2017). Scientific dispositions and habits of mind also emerge in relation to other components of the SERMI framework, as will be discussed later.

Practice-Based Questions to Consider

When thinking about science literacy, educators might ask themselves questions such as the following. What science practices will students have opportunities to engage in, and how will they reflect on this engagement? What scientific communication practices are or could be involved in the learning activities, and how will students reflect on this engagement? What scientific habits of mind are or could be activated, and how will students reflect on these? How can we motivate students to be ambassadors for good science? Is the instruction around science literacy and the nature of science explicit, such that students realize when they are thinking or acting scientifically? Where do students have access to critiquing science and scientific knowledge? Where do students have opportunities to consider the relationship between science and other worldviews, such as indigenous ways of knowing? Can students identify experts and prepare questions to ask of them?

Turning to an example from the pandemic, one early and persistent objection to the COVID-19 mRNA vaccines was that they were supposedly developed too fast, in less than a year, whereas it usually takes decades for a new vaccine or medication to go through the process of preclinical development and clinical trial testing. Here, a scientifically literate individual would pause and ask if it could really be the case that the COVID-19 mRNA vaccines were developed in such a short timeframe. This would lead to inquiring about the very nature of how scientific ideas are developed, from initial hypotheses and recognition of need through trial and (much) error experimenting in the laboratory and finally to human clinical trials. It would involve the individual in trying to understand the complex process of new drug development. In this case, of course, it would be revealed that there was actually a multidecade process that began with the thought that mRNA might be a way to deliver vaccines and other medications that long preceded the actual phase-three clinical trials that led to the approval of the mRNA vaccines. This process is exemplified by the recent awarding of the Nobel Prize in Medicine or Physiology to two of the mRNA pioneers (Katalin Karikó and Drew Weissman), who began their work many years before the idea became a clinical reality.

Tolerance of Uncertainty and Ambiguity

Tolerance of uncertainty and ambiguity is an important mindset that is related to the above discussion of science literacy. We present it as a separate component in the framework due to the significance it plays in confronting misinformation. During the COVID-19 pandemic, several instances illustrated the phenomenon whereby uncertainty about a scientific question led to unease and acceptance of misinformation. For example, recommendations about the utility of face masks in protecting against the acquisition and transmission of viral infection changed over time. There were a few reasons for this, an important one being the simple fact that there was initially a paucity of high-quality studies about face masks, and guidance changed as more evidence accumulated. That, of course, is consistent with the nature of science: Conclusions and consensus change over time as new studies challenge results from older research. But uncertainty is difficult to cope with. It is human nature to want to anchor our beliefs and behaviors on clear principles that seem immutable. Therefore, when science changes, there is a tendency to dismiss new recommendations and adhere instead to simpler explanations, often offered by unreliable sources. Returning to the example of face masks, they do not eliminate the chances of acquiring or transmitting an airborne viral infection entirely; randomized controlled trials (RCTs) attempting to adjudicate their efficacy are often compromised, forcing the field to use evidence from less satisfying observational studies; and wearing them is uncomfortable and inconvenient. Despite good evidence that facemasks are indeed effective in limiting the spread of infectious illnesses such as COVID-19, it is easier to listen to sources that highlight uncertainty about their effectiveness and promulgate misinformation about them. In this case, it may seem much simpler and more convenient to believe that the changing science means the scientists do not know what they are talking about and that face masks do not work or are even dangerous.

Humans are not good at accurately grasping probability or relative frequency and are prone to make the systematic errors of overestimating small probability and underestimating large probability (Ren et al., 2021). We crave certainty, to be told that something is 100% the case and then be able to see the truth of this fact in our own experience. For instance, if we are told that reliable research indicates a particular vaccine reduces the risk of serious illness by 80%, we may be persuaded that the vaccine doesn't work if we know one acquaintance who was vaccinated but still gets very ill. The concept of reduction of risk creates a feeling of uncertainty, and this is easy for misinformants to exploit. How can we equip students to understand that many things about science are uncertain and will change over time, but this does not mean recommendations based on the best available current research findings should be ignored? We do not understand everything about evolutionary biology, and yet we are secure in stating that natural selection is a fundamental biological reality. We do not know exactly what happened during the Big Bang, but no reliable scientist would deny that the universe is billions of years old. We do not know for sure how the virus that causes COVID-19 emerged, but it represents a real threat to health and that vaccines are effective in reducing that threat. In each of these instances, it is easy to exploit the elements of uncertainty to dissuade people from accepting scientific consensus.

Evidence suggests that if people expect uncertainty about science, they will be less likely to ignore scientific advice (Walker et al., 2022). Furthermore, transparent communication of uncertainty does not appear to interfere with a person's acceptance of evidence (Kerr et al., 2022). Thus, it is crucial to reinforce efforts to make uncertainty in science tangible to students, help students understand what uncertainty in science means, and help them learn how to manage it. Educators are encouraged to lean into rather than retreat from uncertainty, allowing students' uncertainty to drive lessons and learning.

Uncertainty can be leveraged as a pedagogical resource to promote and scaffold students' deep learning of science (Beghetto, 2013, 2017; Chen, 2022; Chen & Techawitthayachinda, 2021). To do so, teachers skillfully raise, maintain, reduce, and (possibly) resolve uncertainty through collective knowledge building. Strategies that educators have taken to integrate epistemic uncertainty in the classroom include allowing questions to emerge from the class learning community, incorporating activities that involve or approximate the core practices of science, and carefully scaffolding classroom discussion (Kervinen & Aivelo, 2023). Rather than quickly moving away from uncertainty and providing solutions, teachers and students together reason about problematized phenomena, what they do and do not know, and dig into their own reasoning.

It is important that students work through scenarios and have open discussions about what to do when scientific information is unsettled. How can you decide what to believe and what not to believe when so much is unknown? How do you know when someone has legitimate new findings versus someone offering explanations with a thin evidence base? When students collect and analyze their own or others' data, they can be encouraged to play devil's advocate with their findings and consider multiple alternative explanations for their results. They can discuss how to determine which explanations are most robust and most likely to be correct, which explanations should be discarded, and what additional information would help them to be convinced by a given explanation.

Citizen science projects can serve as one such opportunity by engaging students in authentic research and real-world results (see Kervinen & Aivelo, 2023). Another resource we particularly like is Data Nuggets (http://datanuggets.org/), which exposes elementary through college-age students to contemporary research and offers opportunities to engage with authentic and often "messy" data (Kjelvik & Schultheis, 2019) while learning about data analysis, graphing, and interpretation. This experience can, among other things, build confidence around iterative research components within a scientific process (Schultheis & Kjelvik, 2020). Accompanying stories share how scientists conducted their research, including how they handled any unexpected or unclear results. Activities also contain "meta moments" that prompt students to stop and think about their thinking as they work through data analysis and interpretation.

Practice-Based Questions to Consider

In thinking about helping students develop their tolerance of uncertainty and ambiguity, educators can ask the following questions. What authentic data sets could students work with? Is there room for some messiness in the results or explanations students grapple with that exposes them to the complexity that can accompany science data? What room is there for students to confront scientific issues that are both settled and unsettled? How can we handle competing explanations and evidence? How do students currently understand what scientific consensus is and how it is reached?

Ability to Navigate Conflicting Perspectives and Ideas

Navigating conflicting perspectives and ideas is essential to making informed decisions around the sorts of complex socioscientific issues that face the world today, which often require distinguishing scientific knowledge from mis- and dis-information (Herman et al., 2022). A contextual approach to science education (Feinstein & Waddington, 2020) aims to empower learners who have the skill sets and desire to engage in collective efforts to make meaning and build consensus via critical discourse. If this is a goal, the science classroom must be a space that establishes a culture of academically productive communication and helps students develop their ability to navigate conflicting perspectives and ideas, including ones that fall outside of one's own worldview and immediate area of expertise.

This SERMI framework component is related to the previous framework component, tolerance of uncertainty and ambiguity. When uncertainty is leveraged as a pedagogical resource, the classroom facilitates science-related civic discourse by establishing a culture of academically productive communication that allows students to socially express, articulate, and negotiate their individual uncertainty. Students identify what they know, what they do not know, and what they want to investigate. They explore and test out a variety of competing hypotheses and decide if the information or evidence supports or contradicts competing explanations. Then, students deepen their own understanding and develop evidence-based explanations based on the class's collective thinking and ways of reasoning with scientific phenomena.

In these discursive environments, learners are exposed to norms of science communication: presenting and discussing claims, evidence, and interpretations of evidence; seeking and providing peer feedback; and working to reach consensus about an outcome. By making intellectual virtues such as open-mindedness and intellectual humility, courage, and diligence explicit, learning activities encourage students' appreciation for and development of these norms, behaviors, and dispositions (Lapsley & Chaloner, 2020; Sharon & Baram-Tsabari, 2020). Not only are students better prepared to understand the nature of scientific knowledge and resist science misinformation, but they may also develop their empathy, caring, and responsibility (Zeidler, 2014). These dispositions and intellectual virtues come into play again in a subsequent framework component: understanding information environments and influences.

A difference of opinion that became contentious and the source of considerable misinformation involves the origin of SARS-CoV-2, the virus that is the cause of COVID-19. Most scientists posit a zoonotic source with bats as the original vector; however, some have raised the possibility that the virus emerged as a result of an accidental lab leak (Gostin & Gronvall, 2023). Although this difference in legitimate scientific opinion has unfortunately been politicized, it remains a disagreement that may never be resolved because of incomplete data. Students may ask, how can it be that scientists are unable to determine exactly where this virus came from? The proper response is to help them understand that differences of opinion are far from uncommon in science because data can sometimes be interpreted in multiple ways, especially when we are forced to rely on incomplete data sets. The important thing is to try to understand the arguments made by proponents of the different theories; recognize that, without all the facts, neither side can be absolutely certain they are correct; and avoid drawing fanciful conclusions from the disagreement, such as believing that the virus was deliberately engineered and released as a bioweapon.

Practice-Based Questions to Consider

When thinking about navigating perspectives, educators might ask themselves questions such as the following. What opportunity is there, or could there be, for sharing ideas, confronting ideas different from one's own, science argumentation, critical discourse, building consensus, and peer feedback? These might take place formally, through a science seminar, or more informally, through the regular use of accountable talk moves that encourage students to work with and on ideas (e.g., comparing ideas, adding onto or elaborating upon a prior idea, or clarifying the understanding of an idea). Educators might also ask themselves the following question: Are students encouraged to practice and celebrate the enactment of virtuous behaviors and dispositions (e.g., open-mindedness and intellectual humility, courage, and diligence) in their classroom interactions?

Information and Media Literacy

Expanding traditional conceptions of both literacy and texts, information and media literacy entails a range of understanding and competencies related to accessing, analyzing, evaluating, creating, and utilizing all forms of communication (National Association for Media Literacy Education [NAMLE], 2007, 2023). As Kathleen Tyner (1998), who served as a founding board member of the Alliance for a Media Literate America, explained 25 years ago, information and media literacy is, in essence, a process of inquiry about media culture. Information and media formats have evolved since then, but this focus on engagement holds true. How does one access, analyze, and evaluate mediated messages and experiences? How does one assess and reflect on the influence media messages have on one's and others' thoughts, feelings, and behaviors? How does one express and communicate ideas and information? How does one productively, thoughtfully, and conscientiously participate in a global culture that is not merely shaped by media but is defined by it? Information and media literacy includes understanding how information is created, produced, and shared; the difference between facts, points of view, and opinions; and ethical standards around the production of information. It requires critical thinking about what constitutes a healthy media landscape and the economic, legal, social, and political issues and implications that surround the varied uses of information. Today, competencies for both working with data and understanding data and data systems are highly pertinent (Gould, 2021), and so are questions, concerns, and possibilities of algorithms and artificial intelligence (Van Audenhove et al., 2020).

The Center for Media Literacy (CML; https://www.medialit.org) articulates five foundational concepts and provides guidance on how people of all ages can apply them to deconstruct, construct, and participate with media (Thoman & Jolls, 2008). These five core concepts are: (1) "All media messages are constructed," (2) "media messages are constructed using a creative language with its own rules," (3) "different people experience the same media message differently," (4) "media have embedded values and points of view," and (5) "most media messages are organized to gain profit and/or power" (Thoman & Jolls, 2008, p. 23).

The CML also outlines a way to organize media literacy education, describing what they refer to as an "Empowerment Spiral" of *awareness*, *analysis*, *reflection*, and *action* (Thoman & Jolls, 2008).

All educators have a responsibility to help students develop as critical, creative, and reflective thinkers and communicators who can make meaning of media experiences and make informed and socially responsible decisions about issues that affect individuals, communities, and society (Breakstone et al., 2018; Hobbs & Jenson, 2009; Jones, 2023; MacKenzie, 2020; NAMLE, 2023). In the past 5 years, more states have taken legislative action to add media and information literacy education in K–12 schools, but there is much work to be done. According to Media Literacy Now's February 2023 report on the status of media literacy laws in the United States, of the 18 states that have done so, only three states (Delaware, New Jersey, and Texas) require it in all K–12 classrooms. In most states, standards are formally integrated into humanities curricula at the high school level, as opposed to across all subjects and grade levels. It is encouraging that resources are being developed to help schools recognize opportunities to incorporate aspects of media literacy into all subject areas and disciplinary curricular plans. For instance, the Illinois Media Literacy Coalition developed a crosswalk (https://ilmlc.org/resources) highlighting connections across and within disciplinary content areas, for instance, between the NGSS science and engineering practices and core media literacy practices.

The field of science education is increasingly attentive to not just how scientific information is generated but how scientific information interacts with and is potentially transformed through various communication channels, including social media, for better or worse (Allchin, 2012). As researchers Höttecke and Allchin (2020) explain, "We are especially concerned about the displacement of traditional media gatekeepers who help ensure the reliability of scientific claims in public discourse" (p. 642). Research around what has been called science media literacy (Austin et al., 2021; Höttecke & Allchin, 2020; MacKenzie, 2020) and science media education (Reid & Norris, 2016) highlights the potential and the value of combining science learning objectives with media literacy experiences (Hobbs & Jenson, 2009). Students can engage in activities that introduce the complementary and shared vocabulary and learning activities of media literacy and science (Hobbs & Jensen, 2009), develop source-evaluation and argumentation skills (Brickman et al., 2012), and confront and deal with epistemic problems posed by various types of contemporary media (Allchin, 2018). Students can practice critically examining scientific information referenced in social-media ads as well as gathering and presenting evidence behind various claims for peers or other audiences they care about (Sharon & Baram-Tsabari, 2020). In such learning tasks, it is important that educators be explicit about epistemic beliefs, including using the language and concepts of intellectual virtues such as open-mindedness and intellectual humility, courage, and diligence (Chinn et al., 2021; Sharon & Baram-Tsabari, 2020). Students can look for and discuss positive and negative examples of these virtues in the communications that they review and construct themselves. They can compare reports on current socioscientific topics, investigating and reflecting on what makes them more or less reliable. Media literacy in general and science media literacy specifically are highly connected with the ability to resist scientific and health misinformation and disinformation (Austin et al., 2021) and, thus, should be among the goals and objectives of all science courses.

The contexts in which media presents new findings can make an enormous difference in how we understand their significance. For instance, a finding emerged from surveillance of many reports of adverse outcomes from COVID-19 vaccines that they can cause myocarditis (inflammation of heart tissue) in a very small number of recipients, mostly young men (Husby & Køber, 2022). A media presentation that sensationally announces this finding could mislead readers or viewers into believing this is a common adverse side effect that usually has long-term effects, even though studies suggest that it is rare and usually mild and self-limited. Indeed, myocarditis as a possible side effect of the COVID-19 vaccine has been distorted and exaggerated by misinformants attempting to dissuade people from being vaccinated. A media presentation that puts the risk of myocarditis in context is more likely to lead to the conclusion that COVID-19 vaccines are overall a safe intervention and that the possible risks associated with the vaccine substantially outweigh the severe risks associated with the virus. Hence, how media present a scientific finding is critical to how we receive it; therefore, it is consequential that students learn the vagaries of these presentations.

Practice-Based Questions to Consider

As educators think about information and media literacy, they might ask themselves questions such as the following. Which media literacy practices align with science and engineering practices in lessons? Do students have opportunities to reflect on connections between science practices and media literacy practices? Are there opportunities to help students develop an understanding of what safe, responsible, and critical consumption of social media and other media forms entails? Are students exposed to, and given opportunities to reflect upon, positive and negative exemplars of intellectual virtues (and vices) in the media? What are reliable and unreliable information sources for science news, and what criteria determine reliability? What other colleagues (e.g., educators in other subject areas, resource specialists, or librarians) would be useful to connect with regarding these goals?

Understanding Information Environments and Influences

It might seem that access to information is a good thing, but the sheer amount of information that is at one’s fingertips today can be overwhelming. An *infodemic* refers to an information vortex—be it misinformation, disinformation, or just an overload of information, accurate or not—that leads to susceptibility to misinformation by sowing confusion and mistrust and drowning out accurate information (“The COVID-19 Infodemic,” 2020). Similar to epidemiology, misinformation and infodemic researchers (known as infodemiologists) are concerned with people’s information environments. Just as we can be mindful of air and water quality, we must also attend to the quality of science and health information we are exposed to in person and online (U.S. Department of Health and Human Services, Office of the U.S. Surgeon General, 2021). We have defined a “healthy information environment” as an environment “in which people and communities are immersed in high-quality information of public health importance and enveloped by a communication context that underscores the trustworthiness and importance of that quality” (Scales & Gorman, 2022, p. 2). Concerningly, many are exposed to unhealthy information environments online via television, radio, and social media as well as through interactions with peers, friends and families, and community members. This exposure can even come from within schools or classrooms when rules inhibit discussion of accurate scientific information.

Although information environments are constantly changing as new technologies emerge and as social and political circumstances shift, educators can take steps to understand and assess their own and their students’ information environments. We can also help our students learn to be mindful of the same. First, what do we know about the composition of the information environments our students inhabit? Where are students going to get information? What sources do they regard as accurate, and how do they make that assessment?

Next, how are students engaging with their information environment? Do they trust and believe the information that they are encountering? Do they understand what constitutes a reliable source of information? Are they aware of how search engines, AI, and social-media platforms shape access to information? Sometimes, it is not merely a lack of exposure to high-quality information that leads to false belief formation. There are multiple “cognitive, social[,] and affective factors [that can] influence the formation of false beliefs” (Ecker et al., 2022, p. 14). For instance, people often rely on “intuitive (or ‘lazy’) thinking” (p. 14) rather than deliberation, are biased to believe information that aligns with their worldviews and values, and “overlook, ignore, forget[,] or confuse cues about the source of information” (p. 15). One’s mood and feelings about information can also influence evaluation and credulity.

Not only can educators be on the lookout for “drivers of false beliefs” (Ecker et al., 2022, p. 14) and “barriers to belief revision” (p. 15), but we can also help students understand these as well as how to productively foster positive change. It is worth taking the time in science classes or in collaboration with other content area instructors, librarians, and media center specialists for students to learn about misinformation (and disinformation) tactics and how to spot them, such as impersonating science and health experts, appealing to fear or anger to manipulate people’s emotions, “astroturfing” and “flooding” to shape narratives and create false impressions about messages and opposing viewpoints, and amplifying conspiracy theories (Gorman & Gorman, 2021; Cybersecurity and Infrastructure Security Agency, 2022). During the pandemic, we have certainly seen abundant examples of these tactics launched by antivaccination advocates who cherry-pick every instance of alleged adverse vaccine outcome and spin it to represent broad threats engineered by international conspiracies. Students need to be able to press pause when they see a headline like “turbo cancer caused by COVID-19 vaccines" and learn to consider its source while reaching for reliable sources of information. It is critical in a case like this to point out how the very use of the word *cancer* evokes fear in people, making them more susceptible to believing misinformation. In fact, "turbo cancer" is not a recognized medical term. The evidence used to support this claim comes from a single case report from a study that involved mice, and there has been no evidence of an increased rate of any form of cancer associated with COVID-19 vaccines. These facts are easily obtained by searching reliable sources.

With this information and insight, educators are better able to anticipate the sorts of misinformation themes that they are most likely to encounter in their classes and prepare fact-based alternative narratives and resources. Research is still investigating the most effective combination of strategies for responding to misinformation and related cognitive and socioaffective factors. Whatever the case, when it comes to responding to science and health information, researchers have found that empathetic approaches are most effective (Abroms et al., 2023; Ecker et al., 2022; Gorman & Gorman, 2021). Opening legitimate and considerate conversations does more to advance scientific understanding than asserting scientific authority. At the 2023 Nobel Prize Summit on Truth, Trust, and Hope, Nat Kendall-Taylor of The FrameWorks Institute emphasized leading conversations with broad and highly resonant principles and working toward "how" explanations for scientific phenomena (Nobel Prize, 2023).

Finally, educators and students alike need to be aware of how we influence, positively or negatively, intentionally or unintentionally, the potential spread of misinformation by what we share and how we respond to messages and information shared by others. Several clever game-like tools (see the resource guide for more information) have been developed to bring awareness to misinformation and how it spreads and build skill sets for identifying and responding to misinformation. These types of tools can help build students' resilience against harmful misinformation. They also promote a healthier information environment that is more conducive to what Darner (2019) terms science acceptance, or "the willingness to engage in critical evidence evaluation, despite its potential to contradict one's preferred conclusion" (p. 229).

Practice-Based Questions to Consider

In thinking about information environments and influences, educators can ask the following questions. What misinformation will you be looking out for? What barriers to belief and understanding will you be looking out for? What misinformation mitigation strategies could you be ready to employ? How might your approach to a given lesson change when considering all the different influences on students' processing of the information within the lesson? How might an understanding of information environments and different influences on students' beliefs change the way you approach addressing misinformation and trust in science?

Reflections on Implementation

We have had the opportunity to share the SERMI framework with secondary STEM educators as part of a miniconference held at Loyola University Chicago in winter 2023. Feedback from exit surveys ($N = 34$) was positive overall. Eighty-three percent of respondents indicated that they were *very satisfied* or *extremely satisfied* with the learning materials, and the remainder were *somewhat satisfied*. Likewise, 83% of respondents were *extremely likely* or *very likely* to use the materials in their professional lives, and the rest indicated that they were *likely* to use the materials. The framework has also been shared with secondary science teacher candidates as part of Smetana's science methods courses.

Overall, educators shared that they appreciated the resource list, especially its organization and practitioner questions, which helped them to be able to find resources aligned with specific goals. They also shared that although some aspects of the framework were familiar, others were new to them. The concept of information environments and how to conduct an information environment assessment has been new to most educators we've worked with. Similarly, the idea of uncertainty and ambiguity in the context of science has been novel to many of the educators we've worked with and not something that they emphasize in their classes. Overall, feedback from educators we've worked with suggests that the SERMI framework can help teachers and, in turn, their students, develop a more sophisticated epistemic understanding of scientific practice and increase their resistance to science and health misinformation.

Conclusion

In this article, we have offered an organizing framework and sample resource collection designed to help science teachers and science teacher educators think about the complexity of the issue of science and health misinformation, visualize connected and interrelated avenues to confront this issue, and take action in the classroom. The aim is for science educators to use the framework and resource collection as tools for reflecting on where one's practices are already working toward the goal of confronting science misinformation, where one could be more explicit about the connection between classroom practices and the issue of misinformation, and where there are opportunities to go deeper with or extend one's current instructional practices to address this complex problem. We also see the accompanying guide as the start to a conversation. We hope to open a space for educators to easily share their efforts and other resources, knowing that teachers are facing and responding to these challenges every day and thus knowing that classroom-based strategies and responses are likely much broader than those currently perceived by the research community.

References

Abroms, L. C., Koban, D., Krishnan, N., Napolitano, M., Simmens, S., Caskey, B., Wu, T.-C., & Broniatowski, D. A. (2023). Empathic engagement with the COVID-19 vaccine hesitant in private Facebook groups: A randomized trial. *Health Education & Behavior*. Advance online publication. https://doi.org/10.1177/10901981231188313

Allchin, D. (2012). What counts as science. *The American Biology Teacher*, *74*(4), 291–294. https://doi.org/10.1525/abt.2012.74.4.17

Allchin, D. (2018). Alternative facts & fake news. *The American Biology Teacher*, *80*(8), 631–633. https://doi.org/10.1525/abt.2018.80.8.631

Allchin, D. (2023). Ten competencies for the science misinformation crisis. *Science Education*, *107*(2), 261–274. https://doi.org/10.1002/sce.21746

Austin, E. W., Austin, B. W., Willoughby, J. F., Amram, O., & Domgaard, S. (2021). How media literacy and science media literacy predicted the adoption of protective behaviors amidst the COVID-19 pandemic. *Journal of Health Communication*, *26*(4), 239–252. https://doi.org/10.1080/10810730.2021.1899345

Avraamidou, L., & Schwartz, R. (2021). Who aspires to be a scientist/who is allowed in science? Science identity as a lens to exploring the political dimension of the nature of science. *Cultural Studies of Science Education*, *16*(2), 337–344. https://doi.org/10.1007/s11422-021-10059-3

Aziz, A. M., & Rosli, R. (2021). A systematic literature review on developing students' statistical literacy skills. *Journal of Physics: Conference Series*, *1806*, Article 012102. https://doi.org/10.1088/1742-6596/1806/1/012102

Barzilai, S., & Chinn, C. A. (2020). A review of educational responses to the "post-truth" condition: Four lenses on "post-truth" problems. *Educational Psychologist*, *55*(3), 107–119. https://doi.org/10.1080/00461520.2020.1786388

Beghetto, R. A. (2013). *Killing ideas softly? The promise and perils of creativity in the classroom*. Information Age.

Beghetto, R. A. (2017). Inviting uncertainty into the classroom. *Educational Leadership*, *75*(2), 20–25.

Berland, L. K., Schwarz, C. V., Krist, C., Kenyon, L., Lo, A. S., & Reiser, B. J. (2016). Epistemologies in practice: Making scientific practices meaningful for students. *Journal of Research in Science Teaching*, *53*(7), 1082–1112. https://doi.org/10.1002/tea.21257

Breakstone, J., McGrew, S., Smith, M., Ortega, T., & Wineburg, S. (2018). Why we need a new approach to teaching digital literacy. *Phi Delta Kappan*, *99*(6), 27–32. https://doi.org/10.1177/0031721718762419

Brickman, P., Gormally, C., Francom, G., Jardeleza, S. E., Schutte, V. G. W., Jordan, C., & Kanizay, L. (2012). Media-savvy scientific literacy: Developing critical evaluation skills by investigating scientific claims. *The American Biology Teacher*, *74*(6), 374–379. https://doi.org/10.1525/abt.2012.74.6.4

Calabrese Barton, A., & Tan, E. (2019). Designing for rightful presence in STEM: The role of making present practices. *Journal of the Learning Sciences*, *28*(4–5), 616–658. https://doi.org/10.1080/10508406.2019.1591411

Calo, W. A., Gilkey, M. B., Shah, P. D., Dyer, A.-M., Margolis, M. A., Dailey, S. A., & Brewer, N. T. (2021). Misinformation and other elements in HPV vaccine tweets: An experimental comparison. *Journal of Behavioral Medicine*, *44*(3), 310–319. https://doi.org/10.1007/s10865-021-00203-3

Carothers, T., & O'Donohue, A. (Eds.). (2019). *Democracies divided: The global challenge of political polarization*. Brookings Institution Press.

Chen, Y.-C. (2022). Epistemic uncertainty and the support of productive struggle during scientific modeling for knowledge co-development. *Journal of Research in Science Teaching*, *59*(3), 383–422. https://doi.org/10.1002/tea.21732

Chen, Y.-C., & Techawitthayachinda, R. (2021). Developing deep learning in science classrooms: Tactics to manage epistemic uncertainty during whole‐class discussion. *Journal of Research in Science Teaching*, *58*(8), 1083–1116. https://doi.org/10.1002/tea.21693

Chinn, C. A., Barzilai, S., & Duncan, R. G. (2021). Education for a "post-truth" world: New directions for research and practice. *Educational Researcher*, *50*(1), 51–60. https://doi.org/10.3102/0013189X20940683

Cian, H. (2020). The influence of context: comparing high school students' socioscientific reasoning by socioscientific topic. *International Journal of Science Education*, *42*(9), 1503–1521. https://doi.org/10.1080/09500693.2020.1767316

Ciccone, M. (2021, June 29). Algorithmic literacies: K-12 realities and possibilities. In M. Ito, R. Cross, K. Dinakar, & C. Odgers (Eds.), *Algorithmic rights and protections for children*. MIT Press Works in Progress. https://doi.org/10.1162/ba67f642.646d0673

Cohen, J. N. (2018). Exploring echo-systems: How algorithms shape immersive media environments. *Journal of Media Literacy Education*, *10*(2), 139–151. https://doi.org/10.23860/JMLE-2018-10-2-8

Commission for the Human Future. (2020). *Surviving and thriving in the 21st century: A discussion and call to action on global catastrophic risks*. https://humanfuture.net/sites/default/files/CHF_Roundtable_Report_March_2020.pdf

Cook, J. (2019). Understanding and countering misinformation about climate change. In I. E. Chiluwa & S. A. Samoilenko, (Eds.), *Handbook of research on deception, fake news, and misinformation online* (pp. 281–306). IGI-Global. https://doi.org/10.4018/978-1-5225-8535-0.ch016

The COVID-19 infodemic. (2020). *The Lancet: Infectious Diseases*, *20*(8), 875. https://doi.org/10.1016/S1473-3099(20)30565-X

Cybersecurity & Infrastructure Security Agency. (2022, October 18). *Tactics of disinformation* [Infographic]. https://www.cisa.gov/resources-tools/resources/tactics-disinformation

Darner, R. (2019). How can educators confront science denial? *Educational Researcher*, *48*(4), 229–238. https://doi.org/10.3102/0013189X19849415

Druckman, J. N. (2022). Threats to science: Politicization, misinformation, and inequalities. *The ANNALS of the American Academy of Political and Social Science*, *700*(1), 8–24. https://doi.org/10.1177/00027162221095431

Ecker, U. K. H., Lewandowsky, S., Cook, J., Schmid, P., Fazio, L. K., Brashier, N., Kendeou, P., Vraga, E. K., & Amazeen, M. A. (2022). The psychological drivers of misinformation belief and its resistance to correction. *Nature Reviews: Psychology*, *1*(1), 13–29. https://doi.org/10.1038/s44159-021-00006-y

Erduran, S., & Dagher, Z. R. (2014). *Reconceptualizing the nature of science for science education: Scientific knowledge, practices and other family categories*. Springer. https://doi.org/10.1007/978-94-017-9057-4

Eysenbach, G., Powell, J., Kuss, O., & Sa, E.-R. (2002). Empirical studies assessing the quality of health information for consumers on the World Wide Web: A systematic review. *JAMA*, *287*(20), 2691–2700. https://doi.org/10.1001/jama.287.20.2691

Feinstein, N. W., & Waddington, D. I. (2020). Individual truth judgments or purposeful, collective sensemaking? Rethinking science education’s response to the post-truth era. *Educational Psychologist*, *55*(3), 155–166. https://doi.org/10.1080/00461520.2020.1780130

Gould, R. (2021). Toward data-scientific thinking. *Teaching Statistics*, *43*(S1), S11–S22. https://doi.org/10.1111/test.12267

Gorman, S. E., & Gorman, J. M. (2021). *Denying to the grave: Why we ignore the science that will save us* (Rev. ed.). Oxford University Press. https://doi.org/10.1093/oso/9780197547458.001.0001

Gostin, L. O., & Gronvall, G. K. (2023). The origins of Covid-19—Why it matters (and why it doesn’t). *New England Journal of Medicine*, *388*(25), 2305–2308. https://doi.org/10.1056/NEJMp2305081

Herman, B. C., Clough, M. P., & Rao, A. (2022). Socioscientific issues thinking and action in the midst of science-in-the-making. *Science & Education*, *31*(5), 1105–1139. https://doi.org/10.1007/s11191-021-00306-y

Hobbs, R., & Jensen, A. (2009). The past, present, and future of media literacy education. *Journal of Media Literacy Education*, *1*(1), 1–11. https://doi.org/10.23860/jmle-1-1-1

Höttecke, D., & Allchin, D. (2020). Reconceptualizing nature-of-science education in the age of social media. *Science Education*, *104*(4), 641–666. https://doi.org/10.1002/sce.21575

Husby, A., & Køber, L. (2022). COVID-19 mRNA vaccination and myocarditis or pericarditis. *The Lancet*, *399*(10342), 2168–2169. https://doi.org/10.1016/S0140-6736(22)00842-X

Johnson, S. B., Parsons, M., Dorff, T., Moran, M. S., Ward, J. H., Cohen, S. A., Akerley, W., Bauman, J., Hubbard, J., Spratt, D. E., Bylund, C. L., Swire-Thompson, B., Onega, T., Scherer, L. D., Tward, J., & Fagerlin, A. (2022). Cancer misinformation and harmful information on Facebook and other social media: A brief report. *JNCI: Journal of the National Cancer Institute*, *114*(7), 1036–1039. https://doi.org/10.1093/jnci/djab141

Jones, C. (2023, March 7). We're not doing enough to teach media literacy. *EdSource*. https://edsource.org/2023/were-not-doing-enough-to-teach-media-literacy/686493

Kahan, D. M., Landrum, A., Carpenter, K., Helft, L., & Hall Jamieson, K. (2017). Science curiosity and political information processing. *Political Psychology*, *38*(1), 179–199. https://doi.org/10.1111/pops.12396

Kayumova, S., Avraamidou, L., & Adams, J. D. (2018). Science education: Diversity, equity and the big picture. In L. A. Bryan & K. Tobin (Eds.), *Critical issues and bold visions for science education: The road ahead* (pp. 285–297). Brill/Sense. https://doi.org/10.1163/9789004389663_016

Kerr, J. R., Schneider, C. R., Freeman, A. L. J., Marteau, T., & van der Linden, S. (2022). Transparent communication of evidence does not undermine public trust in evidence. *PNAS Nexus*, *1*(5), Article 280. https://doi.org/10.1093/pnasnexus/pgac280

Kervinen, A., & Aivelo, T. (2023). Secondary school students' responses to epistemic uncertainty during an ecological citizen science inquiry. *Science Education*, *107*(5), 1352–1379. https://doi.org/10.1002/sce.21809

Kjelvik, M. K., & Schultheis, E. H. (2019). Getting messy with authentic data: Exploring the potential of using data from scientific research to support student data literacy. *CBE—Life Sciences Education*, *18*(2), Essay 2. https://doi.org/10.1187/cbe.18-02-0023

Klaver, L. T., Walma van der Molen, J. H., Sins, P. H. M., & Guérin, L. J. F. (2023). Students' engagement with socioscientific issues: Use of sources of knowledge and attitudes. *Journal of Research in Science Teaching*, *60*(5), 1125–1161. https://doi.org/10.1002/tea.21828

Ko, M.-L. M., & Krist, C. (2019). Opening up curricula to redistribute epistemic agency: A framework for supporting science teaching. *Science Education*, *103*(4), 979–1010. https://doi.org/10.1002/sce.21511

Kornides, M. L., Badlis, S., Head, K. J., Putt, M., Cappella, J., & Gonzalez-Hernandez, G. (2023). Exploring content of misinformation about HPV vaccine on twitter. *Journal of Behavioral Medicine*, *46*(1–2), 239–252. https://doi.org/10.1007/s10865-022-00342-1

Lapsley, D., & Chaloner, D. (2020). Post-truth and science identity: A virtue-based approach to science education. *Educational Psychologist*, *55*(3), 132–143. https://doi.org/10.1080/00461520.2020.1778480

Lee, S. K., Sun, J., Jang, S., & Connelly, S. (2022). Misinformation of COVID-19 vaccines and vaccine hesitancy. *Scientific Reports*, *12*, Article 13681. https://doi.org/10.1038/s41598-022-17430-6

Lemke, J. L. (2001). Articulating communities: Sociocultural perspectives on science education. *Journal of Research in Science Teaching*, *38*(3), 296–316. https://doi.org/10.1002/1098-2736(200103)38:3<296::AID-TEA1007>3.0.CO;2-R

Liu, D. W. C. (2012). Science denial and the science classroom. *CBE—Life Sciences Education*, *11*(2), 129–134. https://doi.org/10.1187/cbe.12-03-0029

Lyiscott, J., Mirra, N., & Garcia, A. (2021, April). *Critical media literacy and popular culture in ELA classrooms* [Policy research brief]. National Council of Teachers of English. https://ncte.org/wp-content/uploads/2021/04/SquireOfficePolicyBrief_CriticalMediaLiteracy_April2021.pdf

MacKenzie, A. H. (2020). Scientific media literacy. *The Science Teacher*, *87*(5), 6. https://doi.org/10.2505/4/tst20_087_05_6

McGrath, R. (2011, August 31). The world is more complex than it used to be. *Harvard Business Review*. https://hbr.org/2011/08/the-world-really-is-more-compl

McIntyre, L. (2018). *Post-truth*. MIT Press. https://doi.org/10.7551/mitpress/11483.001.0001

Media Literacy Now. (2023, February). *U.S. media literacy policy report 2022: A state-by-state status of media literacy education laws for K-12 schools*. https://medialiteracynow.org/wp-content/uploads/2023/05/MediaLiteracyPolicyReport2022.pdf

Morales-Doyle, D. (2017). Justice-centered science pedagogy: A catalyst for academic achievement and social transformation. *Science Education*, *101*(6), 1034–1060. https://doi.org/10.1002/sce.21305

National Association for Media Literacy Education. (2007). *The core principles of media literacy education in the United States*. https://namle.net/wp-content/uploads/2021/06/Core-Principles.pdf

National Association for Media Literacy Education. (2023). *The core principles of media literacy education*. https://namle.net/wp-content/uploads/2023/05/NAMLE-Principles-Final-2.1.pdf

National Academies of Sciences, Engineering, and Medicine. (2016). *Science literacy: Concepts, contexts, and consequences*. National Academies Press. https://doi.org/10.17226/23595

National Council of Teachers of English. (2021, March 8). *Where civics meets literacy: The Digital Democratic Dialogue (3D) Project*. https://ncte.org/blog/2021/03/digital-democratic-dialogue-project/

National Research Council. (2012). *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas*. National Academies Press. https://doi.org/10.17226/13165

Neely, S. R., Eldredge, C., Ersing, R., & Remington, C. (2022). Vaccine hesitancy and exposure to misinformation: A survey analysis. *Journal of General Internal Medicine*, *37*(1), 179–187. https://doi.org/10.1007/s11606-021-07171-z

NGSS Lead States. (2013). *Next generation science standards: For states, by states*. National Academies Press. https://doi.org/10.17226/18290

Nobel Prize. (2023, May 31). *How to make mindsets matter | Nat Kendall-Taylor | Nobel Prize Summit 2023* [Video]. YouTube. https://youtu.be/mfYwemeEHpY?si=iwD92MUc1FR08eyP

Organisation for Economic Co-operation and Development. (2018). *Preparing our youth for an inclusive and sustainable world: The OECD PISA global competence framework*. https://www.oecd.org/education/Global-competency-for-an-inclusive-world.pdf

Osborne, J., & Pimentel, D. (2023). Science education in an age of misinformation. *Science Education*, *107*(3), 553–571. https://doi.org/10.1002/sce.21790

Osborne, J., Pimentel, D., Alberts, B., Allchin, D., Barzilai, S., Bergstrom, C., Coffey, J., Donovan, B., Kivinen, K., Kozyreva. A., & Wineburg, S. (2022). *Science education in an age of misinformation*. Stanford University.

https://sciedandmisinfo.sites.stanford.edu/sites/g/files/sbiybj25316/files/media/file/science_education_in_an_age_of_misinformation.pdf

Pleasants, E., Guendelman, S., Weidert, K., & Prata, N. (2021). Quality of top webpages providing abortion pill information for Google searches in the USA: An evidence-based webpage quality assessment. *PloS ONE*, *16*(1), Article e0240664. https://doi.org/10.1371/journal.pone.0240664

Reid, G., & Norris, S. P. (2016). Scientific media education in the classroom and beyond: A research agenda for the next decade. *Cultural Studies of Science Education*, *11*(1), 147–166. https://doi.org/10.1007/s11422-015-9709-1

Ren, X., Luo, H., & Zhang, H. (2021). Automatic and fast encoding of representational uncertainty underlies the distortion of relative frequency. *Journal of Neuroscience*, *41*(16), 3692–3706. https://doi.org/10.1523/JNEUROSCI.2006-20.2021

Rogoff, B. (2003). *The cultural nature of human development*. Oxford University Press.

Romer, D., Winneg, K. M., Jamieson, P. E., Brensinger, C., & Jamieson, K. H. (2022). Misinformation about vaccine safety and uptake of COVID-19 vaccines among adults and 5–11-year-olds in the United States. *Vaccine*, *40*(45), 6463–6470. https://doi.org/10.1016/j.vaccine.2022.09.046

Rowlands, S. (2011). Misinformation on abortion. *European Journal of Contraception & Reproductive Health Care*, *16*(4), 233–240. https://doi.org/10.3109/13625187.2011.570883

Rudolph, J. L. (2023). Scientific literacy: Its real origin story and functional role in American education. *Journal of Research in Science Teaching*. Advance online publication. https://doi.org/10.1002/tea.21890

Scales, D., & Gorman, J. (2022). Screening for information environments: A role for health systems to address the misinformation crisis. *Journal of Primary Care & Community Health*, *13*. https://doi.org/10.1177/21501319221087870

Scheufele, D. A., Krause, N. M., & Freiling, I. (2021). Misinformed about the “infodemic?” Science’s ongoing struggle with misinformation. *Journal of Applied Research in Memory and Cognition*, *10*(4), 522–526. https://doi.org/10.1016/j.jarmac.2021.10.009

Schultheis, E. H., & Kjelvik, M. K. (2020). Using messy, authentic data to promote data literacy & reveal the nature of science. *The American Biology Teacher*, *82*(7), 439–446. https://doi.org/10.1525/abt.2020.82.7.439

Sharma, S. (2017). Definitions and models of statistical literacy: A literature review. *Open Review of Educational Research*, *4*(1), 118–133. https://doi.org/10.1080/23265507.2017.1354313

Sharon, A. J., & Baram-Tsabari, A. (2020). Can science literacy help individuals identify misinformation in everyday life? *Science Education*, *104*(5), 873–894. https://doi.org/10.1002/sce.21581

Spitale, G., Biller-Andorno, N., & Germani, F. (2023). AI model GPT-3 (dis)informs us better than humans. *Science Advances*, *9*(26), Article eadh1850. https://doi.org/10.1126/sciadv.adh1850

Stroupe, D., Hammerness, K., & McDonald, S. (2020). *Preparing science teachers through practice-based teacher education*. Harvard Education Press.

Thoman, E., & Jolls, T. (2008). Literacy for the 21st century: An overview & orientation guide to media literacy education (2nd ed.). Center for Media Literacy.

Tyner, K. (1998). Literacy in a digital world: Teaching and learning in the age of information. Erlbaum.

U.S. Department of Health and Human Services, Office of the U.S. Surgeon General. (2021). *Confronting health misinformation: The U.S. Surgeon General's advisory on building a healthy information environment*. https://www.hhs.gov/sites/default/files/surgeon-general-misinformation-advisory.pdf

Van Audenhove, L., VandenBroeck, W., & Mariën, I. (2020). Data literacy and education: Introduction and the challenges for our field. *Journal of Media Literacy Education*, *12*(3), 1–5. https://doi.org/10.23860/JMLE-2020-12-3-1

Vosoughi, S., Roy, D., & Aral, S. (2018). The spread of true and false news online. *Science*, *359*(6380), 1146–1151. https://doi.org/10.1126/science.aap9559

Walker, A. R., Navarro, D. J., Newell, B. R., & Beesley, T. (2022). Protection from uncertainty in the exploration/exploitation trade-off. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *48*(4), 547–568. https://doi.org/10.1037/xlm0000883

Zarocostas, J. (2020). How to fight an infodemic. *The Lancet*, *395*(10225), 676. https://doi.org/10.1016/S0140-6736(20)30461-X

Zeidler, D. L. (2014). Socioscientific issues as a curriculum emphasis: Theory, research, and practice. In N. G. Lederman & S. K. Abell (Eds.), *Handbook of research on science education* (Vol. II, pp. 697–726). Routledge.

Zetterqvist, A., & Bach, F. (2023). Epistemic knowledge—a vital part of scientific literacy? *International Journal of Science Education*, *45*(6), 484–501. https://doi.org/10.1080/09500693.2023.2166372

Zucker, A., Noyce, P., & McCullough, A. (2020). Just say no! Teaching students to resist scientific misinformation. *The Science Teacher*, *87*(5), 24–29. https://doi.org/10.2505/4/tst20_087_05_24