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Science education in the age of misinformation

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Introduction

Unprecedented challenges are facing the field of science. While news is more accessible than ever, misinformation, disinformation, and pseudoscience are mainstream, undermining public trust in science. At one stage, publishers and editors were the gatekeepers of information. Today, the internet provides users with an unrestricted space to share content widely. Fact checks and corrections struggle to keep up with the speed at which false claims go viral. However, the current science education model overlooks an essential goal: to prepare students as "competent outsiders," non-experts in science education who are not equipped with deep content knowledge but with evaluative and social competencies that enable them to engage with scientific information (Osborne and Allchin, 2024). **Competent outsiders are capable of evaluating scientific claims with a critical lens and judging the credibility of scientific information presented in secondary sources, even when the science itself is beyond their comprehension (Osborne and Pimentel, 2023).** To address this goal, science should be taught as a social practice, a discipline that contributes to establishing reliable and valid consensus (Allchin et al., 2024). There is an urgent need for a crucial reorientation of science education and a revision of the goals of science curricula to untangle the concepts of misinformation, disinformation, and pseudoscience (Allchin et al., 2024; Osborne and Pimentel, 2023). Experts identify key competencies, including an understanding of our epistemic dependence on experts, recognizing deceptive tactics, and developing scientific media literacy (Allchin, 2022; Osborne et al., 2022, 2023). The paper proposes a framework combining science education reform, inoculation theory, and scientific media literacy to build misinformation resilience (Figure 1).

Following formal education **(i.e., after completing high school),** students increasingly depend on mass media to stay informed about critical topics such as health, the environment, biotechnology, and others, to name a few. Such knowledge is often a mix of credible science and misinformation. Scientists frequently appear in the media to provide the public with an accessible, although sometimes simplified, overview of scientific progress in different fields. This democratization of information facilitated the widespread and rapid sharing of intentional and unintentional misinformation, thus posing a significant threat to science, society, and democracy (Lewandowsky et al., 2017; Petersen et al., 2019; Vosoughi et al., 2018).

Inoculation theory is a leading theory for building resistance against pseudoscience and misinformation, successfully applied in various contexts, including public awareness initiatives, social media campaigns, and classroom activities where different inoculation methods can be combined (Compton et al., 2021; Trecek-King and Cook, 2024). The theory is guided by the concept of vaccination that preemptively exposes individuals to weakened doses of misinformation. Consequently, reasonable scientific viewpoints are protected, and unsubstantiated positions are positively influenced to change. It is a

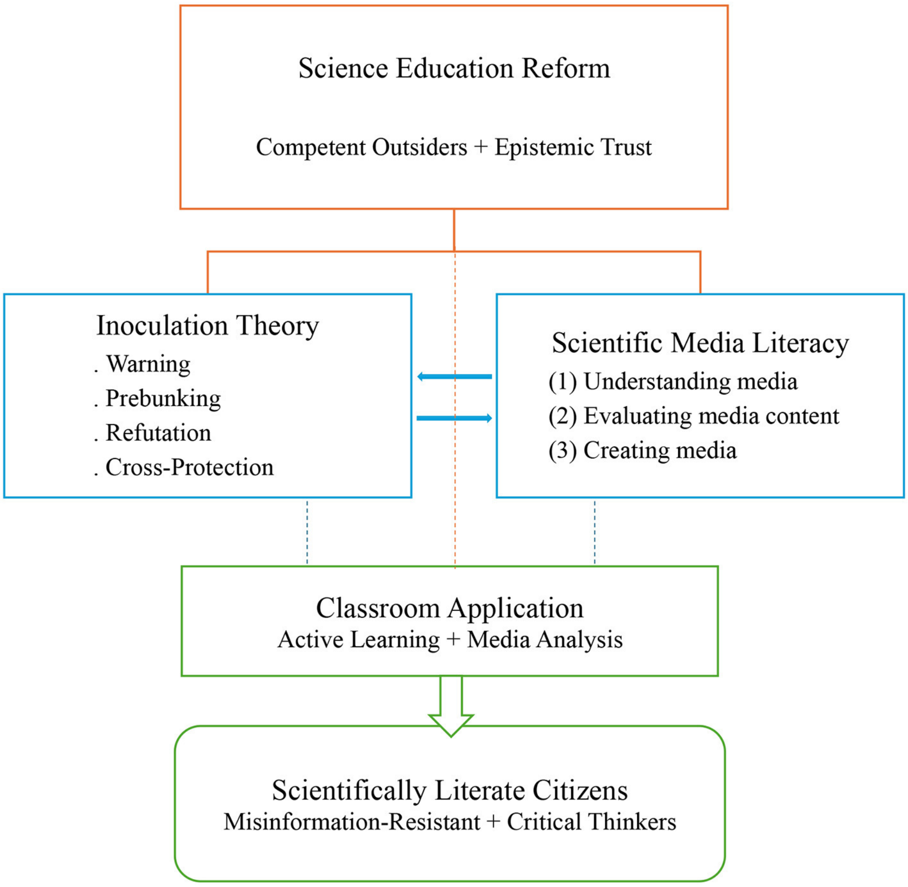

FIGURE 1
An integrated framework for combating misinformation through science education—the framework demonstrates the parallel implementation of Inoculation Theory and scientific media literacy as complementary, mutually-reinforcing approaches. Classroom application is the crucial converging point bridging the gap between theory and practice and between formal science and the realities of public discourse through active learning and media analysis activities, ultimately producing scientifically literate citizens.

practical immunization framework against misinformation, ensuring that individuals can grapple with the complexities of science in the media.

The rise of digital misinformation

Misinformation is not a recent event. The rapid circulation of misinformation was first put on record by Harper's Magazine in 1925 (Wang et al., 2019). Fast forward to 2013, the World Economic Forum warned against "digital wildfires" spreading at an unprecedented pace, fundamentally changing communication dynamics and global connections World Economic Forum (2013). The health sector is particularly at risk as people get bombarded with conflicting claims about medical treatments, dietary choices, and various other critical health issues. Moreover, misinformation often elicits negative emotions like fear, disgust, and surprise, giving it "an edge in the competition for human attention" (Lewandowsky and Van Der Linden, 2021, p. 358; Vosoughi et al., 2018). As ideas compete for public attention, sensationalized and oversimplified news dominates credible, complex scientific information. Journalists often report scientific research inaccurately, overstating progress, magnifying risks, or portraying science as a series of "success stories" (Einsiedel, 1992; McClune et al., 2012). As a result, science is often framed as a string of dramatic breakthroughs rather than a continuous process of discovery, misleading the public's perception of the scientific process.

Repeated exposure to misinformation can enhance its perceived credibility, even when debunking efforts are successful (Pennycook et al., 2018; Swire et al., 2017). Once accepted, correcting misinformation becomes a significant challenge, often leading to major societal costs as individuals often continue to rely on the misinformation they encounter to make critical decisions (Chan et al., 2017; Swire et al., 2017). The continued influence effect allows misinformation to persist, which can weaken the effectiveness of debunking strategies and sabotage prebunking efforts (Lewandowsky et al., 2012; Vosoughi et al., 2018). 'Inoculation' is a proactive alternative to these threats. Likened to a "jiu-jitsu" defense against persuasion, where an opponent's force is redirected against them, inoculation exposes students to persuasion tactics in advance, enabling them to recognize and resist misinformation (Hornsey and Fielding, 2017).

The inoculation theory

Although William McGuire (1964) developed the inoculation theory before the internet era, today's digital misinformation spreads like a virus, rapidly transmitting from person to person without physical interaction (Budak et al., 2011; Kucharski, 2016). In medicine, exposure to a weakened pathogen stimulates the production of antibodies, offering protection against possible future infections. Similarly, inoculation theory suggests that exposing individuals to a weak argument, followed by a refutation, can build resistance by developing 'mental antibodies' against future persuasion techniques (McGuire and Papageorgis, 1961).

Originating in psychology, this adaptable framework includes technique-based inoculation **(e.g., exposing students to a fake news article that uses ad hominem attacks or false dichotomies),** which focuses on deceptive methods and logical fallacies, and fact-based inoculation, which corrects falsehoods with factual information **(e.g., presenting scientific data to refute the myth that vaccines cause autism;** Banas and Miller, 2013; Schmid and Betsch, 2019). Experiential inoculation is a more recent method that deliberately deceives students to reinforce their understanding of misinformation techniques **(e.g., having students fall for a fabricated climate change infographic before debriefing them on its misleading tactics;** Trecek-King and Cook, 2024). Although research has generally shown slight differences between various inoculation techniques (Banas and Rains, 2010), inoculation could still offer broad protection against misinformation without using issue-specific interventions or tailored content (Trecek-King and Cook, 2024).

There are different forms of inoculation messages. A passive approach does not require engagement with the inoculation message. In contrast, an active approach encourages students to create misinformation as an active learning activity. An inoculation message consists of two essential components: (i) a warning that alerts individuals to the risk of being misled and (ii) refutations that explain why the information is false. Inoculation messages typically begin with an argument that contradicts students' beliefs (e.g., that genetically modified organisms, or GMOs, are safe) in order to trigger potential weaknesses in their position and motivate them to defend their stance. The message then presents a series of weakened opposing arguments (e.g., claims that GMOs are unsafe) and counterarguments explaining why these claims are flawed. Students are encouraged to counterargue in a process known as refutational preemption (Geegan et al., 2023). Inoculation strategies can be broadened by focusing on general persuasion techniques rather than specific topics. Exposing students to a persuasion technique in one context (such as medicine) can help them recognize and resist the same technique in another context (such as climate change; Cook et al., 2017). This "cross-protection" suggests that inoculation messages can create a protective effect that extends beyond the specific issue addressed, offering resistance to related misinformation (Parker et al., 2016).

Training **school students** to recognize flawed reasoning can serve as a broad-spectrum defense against misinformation (Lewandowsky and Van Der Linden, 2021). A key challenge is determining how long the protective effects of inoculation interventions persist. Research suggests that the benefits of cognitive inoculation tend to fade over time (Niederdeppe et al., 2014; Lewandowsky et al., 2016; Zerback et al., 2021). However, repeated exposure to misinformation tactics can help sustain resistance to deception. Another significant challenge is expanding cognitive inoculation to achieve widespread "herd immunity" against misinformation (Lewandowsky et al., 2016). Crucially, just as in medical herd immunity, not everyone must be inoculated for the population as a whole to benefit; those who are resistant help shield those who remain vulnerable (Lewandowsky et al., 2016). If a sufficient number of people develop resistance, the spread of misinformation is significantly reduced.

Scientific media literacy

Scientific media literacy refers to the ability to apply knowledge of science and media to select, understand, evaluate, and respond to various representations of science across news outlets, websites, novels, documentaries, television, advertisements, films, music, and other domains (Reid and Norris, 2016). Scientific media literacy supports traditional science education by requiring an understanding of media and knowledge of scientific epistemology and content. Scientific media literacy encompasses three key areas of media education: (1) understanding the broad context of media, (2) developing the skills to evaluate media content, and (3) creating media (Reid and Norris, 2016). Formal and informal science education often focus on the first two areas. However, due to curriculum constraints, the third area is rarely considered.

Scientific media literacy:

- connects school science to everyday life.
- depends on current and relevant science news.
- increases student interest in science.
- encourages debate and discussion.
- fosters skills for lifelong learning.

However, teachers may worry that:

- There is limited instructional time to focus on scientific media literacy skills.
- The language is complex and scientific articles are too detailed.
- Curriculum requirements impose constraints.
- Selecting and preparing scientific articles for instruction or assessment is time-consuming and requires significant effort.

Scientific media literacy helps students recognize that while the internet provides access to a diverse range of scientific resources, it also increases exposure to scientific misinformation. Students may overestimate the credibility of scientific claims, confuse causation with correlation, or struggle to identify reliable evidence and reasonable conclusions. Media representations of science frequently lack detailed methodological explanations, present findings with definitive rather than cautious language, and may omit essential data. Teachers should be directly involved in driving change in science education, as they are central to the success of any educational reform. Effective reform can only occur when teachers' existing knowledge, attitudes, and beliefs are considered.

Discussion

Science education often results in what some call "marginal insiders," graduates who have learned different scientific concepts and theories but possess only a surface-level understanding of the scientific process (Osborne and Pimentel, 2023, p. 4). Content knowledge is inarguably a necessary foundation, but it is often inadequate when it comes to making sense of the complex scientific issues encountered in everyday life. For those who do not pursue careers in science, this reality makes them outsiders to the discipline, much like they would be in any profession outside their expertise. As a result, science education should shift focus to equipping students to become "competent outsiders" who can critically assess scientific claims and determine their credibility despite not being scientists themselves. Despite it being a daunting challenge for some, it must be taught and reinforced from an early age, starting as early as second grade until it becomes second nature (Osborne and Pimentel, 2023).

Public trust in science is closely tied to understanding how scientific knowledge is tested, validated, and established within the scientific community (Sharon and Baram-Tsabari, 2020). Science research undergoes rigorous peer review before being accepted as reliable knowledge (Höttecke and Allchin, 2020). This process filters out unreliable information, leaving behind a body of knowledge continuously refined despite the minor flaws in the system. Students struggle to acquire this understanding outside of formal education. Moreover, it is unreasonable to expect science education to include all the domain-specific knowledge students will need throughout their lives. Many urgent and emerging global scientific issues, such as those that arose during the COVID-19 pandemic, require expertise beyond what is typically taught in school science curricula, such as understanding the mode of transmission of viruses, their reproduction, and their impact on the body. Additionally, the field of science is constantly evolving. Many of today's discoveries did not exist a decade ago. In 20 years, entirely new fields of knowledge will likely emerge that formal education has not yet included in its curricula. Given this reality, what kind of knowledge remains universally important? Determining whether a scientific claim is trustworthy and understanding how science operates as a social system should be core components of science education at all levels, "from the cradle to the grave," ensuring that students can critically engage with scientific information in an ever-changing world (Osborne and Pimentel, 2023, p. 12).

While scientific findings are primarily disseminated through peer-reviewed journals, the general public largely learns about science through media communication, which often presents "science-in-the-making" rather than the fully established knowledge presented in school science textbooks (Kolstø et al., 2006). Therefore, engaging students with news reports in the classroom helps bridge the gap between formal science education and real-world science. Wellington (1991) was among the first to suggest using news reports in science classrooms, arguing that formal education should prepare students to critically analyze science-related media content beyond their schooling years. Incorporating science news into classrooms aligns closely with scientific literacy goals and helps make "the school walls (more) permeable" for students to see science as an evolving field rather than a static body of facts (McClune et al., 2012, p. 17).

A scientifically literate student understands scientific methods and the inherent interconnectedness between science, the environment, technology, politics, business, and society. Therefore, scientific media literacy has considerable implications for teaching and assessment. The ability to critically evaluate media reports of scientific research reflects proficiency across these areas, making news articles a valuable tool for instruction and assessment. Teachers can use current events to stimulate an interest in science, encourage students to report on science news through assignments and classroom discussions, appreciate the significant role of science in society, and accept that science is in a state of continuous change. This type of healthy skepticism balances being open to new perspectives and questioning those that lack credible evidence. Students learn to apply evidence-based arguments to issues involving extraordinary claims, distinguishing between scientifically valid assertions and those that do not hold up under scrutiny.

Implementing these goals, however, presents several challenges that must be addressed. Teachers' resistance to change and their comfort with traditional methods must be acknowledged to encourage a shift toward teaching scientific media literacy. Some consider media literacy part of civic education, while others view it as an additional burden that cannot be realistically managed Jenkins (1996). This is not a critique of teachers' professionalism but rather an acknowledgment of the complexity of the task Monk and Dillon (2000). Scientific media literacy may also require a significant shift in teachers' familiar, tried-and-true methods. Applying new strategies that deal with complex, controversial issues that lack clear-cut or universally agreed-upon solutions is challenging. Science teachers may feel uncomfortable venturing beyond their established areas of expertise, presenting scientific media literacy as a professional challenge. Moreover, high-quality media education requires teachers who possess a solid understanding of various media genres, the nature of science, science processes, and how these elements interact. As a result, science teachers may need pre-service and ongoing professional development to effectively integrate scientific media literacy into their instructional plans. Finally, teachers must have designated time and a lighter teaching load to collaborate with colleagues on new methods of teaching critical media skills and prepare media-related materials.

In formal science education, assessments are often in the form of standardized multiple-choice tests that measure a student's ability to memorize and recall scientific facts and theories. While these tests may help evaluate a student's knowledge of institutional, cultural, and economic aspects of science, they fall short when determining whether a student can effectively apply this knowledge when engaging with science in the media. Short extracts, possibly modified, from newspapers could be used to assess students' understanding of the scientific content presented, the quality of the evidence supporting the claims made, their capacity to offer thoughtful responses regarding the risks to themselves or others, and their ability to provide an informed opinion on actions that should be taken by individuals, the government, or other organizations (Reid and Norris, 2016). Open-ended or constructive-response questions may be better suited to testing more complex skills, such as interpreting media representations of science (Aikenhead and Michell, 2011).

Conclusion: a call for action

Science does not operate through snap judgments or fixed answers. While textbooks focus on established facts, much scientific work involves inherent uncertainty, unresolved questions, competing hypotheses, ongoing debates, and conflicting models. These aspects of science may also feel unfamiliar for students, educators, and parents, as they were not emphasized in their education. This dynamic nature of science can be confusing and perceived as political manipulation, as experienced during the COVID-19 pandemic.

The decoupling of formal and informal science education necessitates a significant shift in focus. Schools have a pivotal role in the development of an informed citizenry capable of engaging with science and technology throughout their lives, regardless of whether students pursue careers in the field. Even though most people's everyday lives do not require extensive scientific knowledge, a scientifically literate public is essential for the functioning of a democratic society. A profound shift in the goals of science education is necessary to prepare students for the misinformation era.

The situation is critical. It is easy to be discouraged by the prevalence of misinformation, and pretending these issues can be easily addressed within the curriculum would be misleading. While offering significant benefits to society, science can only fulfill its potential if individuals can access and identify trustworthy scientific information. The science that matters to individuals, whether for personal reasons or public decision-making, is often new, complex, and sometimes incomplete. When credible scientific research is dismissed for the wrong reasons, science and public trust in it are at risk.

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