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Ten competencies for the science misinformation crisis

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Abstract

Scientific misinformation and disinformation, proliferating via the internet and social media, are now significant problems. Proposed solutions vary substantially. Here, I describe a set of prospective benchmarks—10 competencies—that seem essential for reorienting science education to address the challenge. They include, first, elements of epistemic motivation, including basic epistemological beliefs about "constructed" knowledge, adopting a posture of respect for empirical evidence, and an understanding of our epistemic dependence on experts. Second, the benchmarks include perspectives and skills in interacting with media sources. These include how to identify experts, how to identify credible gatekeepers, how to recognize deceptive strategies, and how to deal with social networks and technology. Finally, the competencies include self-regulation, such as acknowledging the cognitive dispositions that bias our thinking (especially about information that challenges our pre-existing beliefs) and the counter-balancing role of consensus. I hope that these competency goals can function as a concrete target in guiding discussion of perhaps more complete or more nuanced approaches to the current crisis. With such competencies clearly and explicitly articulated, teachers will be better positioned to develop effective classroom strategies to nurture the relevant competencies.

KEYWORDS

consensus, credibility, disinformation, epistemic dependence, expertise, gatekeeping, misinformation, science education

Scientific misinformation and disinformation have reached alarming proportions (e.g., ALLEA, 2021; Amara, 2022; Osborne et al., 2022; Union of Concerned Scientists, 2019). What is the ultimate nature of the problem and how can science education contribute to a solution? The misinformation crisis seems to touch multiple educational efforts—critical thinking, argumentation, media literacy, and nature of science, at least. How should science teachers, specifically, respond? What should science students learn? Currently, no systematically considered standards exist as shared benchmarks.

Here, I focus on *science media literacy*, or SML, as an integral part of functional scientific literacy—empowering students to use science to inform their personal and public decision making (OECD, 2019; Ryder, 2001; Toumey et al., 2010). Namely, the internal scientific processes of research and of reaching consensus are impotent without science communication: a holistic view of scientific information that stretches "from test tubes to YouTube" (see Figure 1; Allchin, 2013, 2020a, 2020b; Höttecke & Allchin, 2020; West & Bergstrom, 2021). The approach is consumer-centered, oriented to the standpoint of the ordinary citizen, who inevitably depends on science specialists and expertise well beyond their own (e.g., Goldman, 2001). I characterize a set of core competencies in

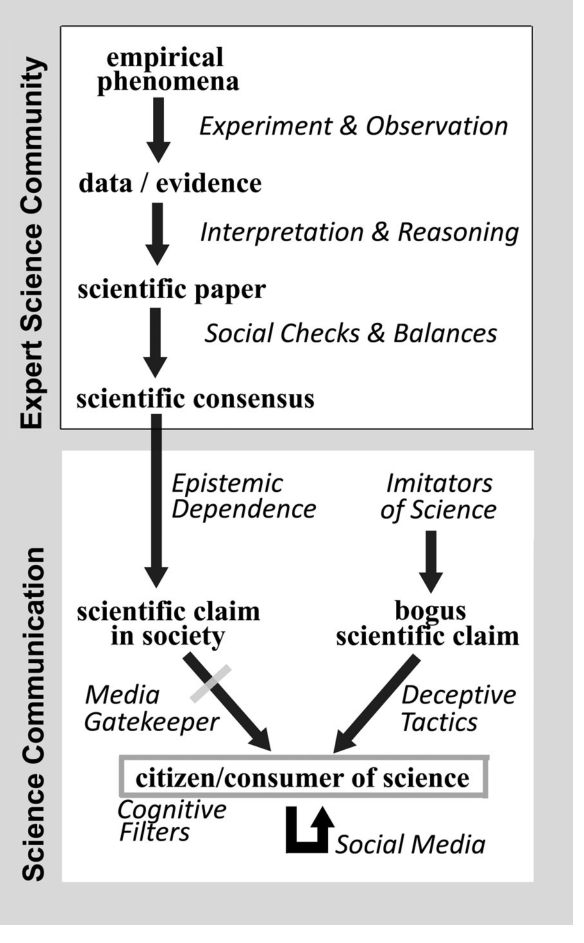

FIGURE 1 Pathway of scientific information, "from test tubes to YouTube," showing the domains of both the expert scientific community and public science communication, as well as the challenge of sources of misinformation and social media (adapted from Höttecke & Allchin, 2021).

SML, and describe how each addresses a different facet of the problem. Most are missing from established or model science curricula.

SML differs from other proposals for engaging science teaching with the news media. One may certainly entertain the prospect of using news media to help teach (a) scientific concepts (e.g., Jarman & McClune, 2007) or (b) the nature of science (e.g., Glynn & Muth, 1994; Norris & Phillips, 1994; Norris et al., 2003). At another level, one may wish to teach the methods and limits of science journalism and how a user can extract relevant information (Reid & Norris, 2016). SML, by contrast, underscores the problematic role of disinformation that has flourished in the age of the internet and social media, with its rapid and widespread dissemination of misleading claims, bogus arguments, and cherry-picked evidence. SML also acknowledges that individuals experience a media environment crowded with both authentic science information and claims by those who mindfully mimic science, hoping to capture its cultural authority (Figure 1). The central challenge of diffusing misinformation is thus not so much to respect science, to understand science, or to reason scientifically, as it is to understand the mediation of expert knowledge. How does one differentiate reports of genuine science from junk trying to masquerade as such (Allchin, 2012a)?

Many characterize the current crisis as a cancerous spread of "science denial" (e.g., McIntyre, 2019; Sinatra & Hofer, 2021), "antiscience" attitudes (Otto, 2016) or lack of trust in science (Hendriks et al., 2016; Oreskes, 2019). However, polls indicate that confidence in scientists remains high—well above journalists and public school principals, say (3M, 2022; Funk, 2020; Kennedy et al., 2022). Indeed, it is not uncommon for purveyors of misinformation—flat Earthers, anti-vaxxers, climate change naysayers, or proponents of "Intelligent Design"—to appeal to science itself. One can find them promoting reliance on your senses and direct empirical observations, awareness of conflict of interest in research, reasoning from data that seems to plainly falsify a hypothesis, or prudent caution in light of insufficient evidence or lack of demonstrative "proof." Ironically, they all seem to trust "science" writ large. But alas, they trust the *wrong* science. The arguments, testimony, and selective evidence that they cite simply do not reflect the consensus of the relevant scientific experts (on consensus as a benchmark, see Oreskes, 2019). They misinform and mislead. There is a world of difference between sound science and "sounds like science" (Michaels, 2008). This blind spot (or short-sightedness) indicates that the problem of misinformation is *not* about respect for scientific reasoning or understanding the nature of science. Instead, it is about distinguishing bona fide experts from imposters (Figure 1). Namely, in the vast reach of scientific information "from lab bench to judicial bench," *who speaks for science?* (Allchin, 2021).

Others view the misinformation problem in terms of technology, especially social media. They seek solutions in the regulation or redesign of the technology. But are new forms of media fundamentally to blame? Sadly perhaps, misinformation has been with us for centuries. For example, as early as 1610 Ben Jonson's stage comedy portrayed two servants who tried to pose as expert alchemists. In the 1950s and 1960s, many cities experienced the protests of anti-fluoridationists (Martin, 1991). In 1990, the whole town of New Madrid, Missouri shut down, and the National Guard was called out, based on a wild prediction from a geological quack about a devastating earthquake (Spence et al., 1993). Admittedly, the speed of electronic communications and the global scale of the World Wide Web, and its penetration into almost every aspect of our daily lives, have all amplified the frequency of misleading reports and the scale of the consequences of deceit. But this differs from the core problem itself, which is primarily about situated, everyday epistemics. Namely, regardless of the medium conveying information, how do we ascertain the reliable science that might inform our personal and public decision making?

The problem of misinformation is multifaceted. Still, science education is situated to have a significant (although not exclusive) role. The aim of this paper is to sketch what that role should entail, based on the nature of the flow of information, "from field sites to websites" (Figure 1).

Various commentators have already proposed solutions. For example, we might exhort students to "be skeptical!" or "think critically!" (e.g., Helfand, 2016; McIntyre, 2019; Shermer, 2017; Sinatra & Hofer, 2021). Indeed, there is a venerable tradition in teaching "critical thinking," an ad hoc nuts-and-bolts approach to informal logic, fallacies, and other cognitive lapses (e.g., Chaffee, 2019; Epstein, 2016; Moore & Parker, 2021). It is premised on an ideal of intellectual independence, and aims to empower students to analyze arguments and make judgments on their own. However, as cogently argued by Stephen Norris in this journal (Gaon & Norris, 2001; Norris, 1995, 1997), this widely endorsed goal is unattainable. Unfortunately, even being well trained in general patterns of reasoning and their flaws is insufficient. Assessing an expert's claim requires at least the same level of expertise. Non-experts cannot replicate the results or attest to subtle technical faults. They cannot know if the evidence is complete, or if experiments are competently performed. Non-experts simply cannot transcend the limits of the "expertise horizon." That is the very reason we turn to scientists: because they know the whole body of evidence in a particular field, the relevant methodological safeguards, the alternative explanations to consider, the many possible sources of error, and so on. *They* are the experts. No one—*no one*—can be expert in all things. No one can be wholly intellectually independent. Even the individual experts who write the IPCC report on climate change depend on each other's expertise to reach their important conclusions. We thus err by trying to be experts ourselves (Nichols, 2017; see also below in Section 2). Critical thinking and skepticism, while immensely valuable for developing general reasoning acumen, cannot fully solve the science misinformation problem.

Alternatively, we may be tempted to steep students in a culture of argumentation, and expect them to assess every claim for its scientific merit, based on the evidence. However, for the reasons just mentioned, we must recognize the limits to achieving full intellectual autonomy and jettison that vision (however, desirable) as unachieveable (for fuller elaboration on the limits of argumentation as a surrogate for science, see Allchin & Zemplén, 2020). So, facility in argumentation or better evidential reasoning—although valuable skills in themselves—are not ultimate solutions to the specific problems posed by scientific misinformation, either (Osborne et al., 2022).

As another educational strategy, we might equip students with the practical tools of quick fact-checking—lateral reading or click restraint, for example, or awareness of such reference websites as Snopes.com or FactCheck.org. Yet while these skills may seem immediately and concretely applicable, they are mostly localized patches and ad hoc fixes. They do not contribute to a general understanding of the dilemma, which will change as the media landscape evolves in the future. Accordingly, consumer-citizens should appreciate the whole trajectory of scientific information "from the lab bench to the judicial bench"—including the mediation of expertise, the role of gatekeepers (or curators or "information agents"), and our own cognitive filters and dispositions (Figure 1; Höttecke & Allchin, 2020).

Among the many proposed solutions to disinformation are recommendations from, ironically, the purveyors of disinformation themselves (e.g., Steve Milloy's *Junk Science Judo*; Murray, Schwartz & Lichter's *It Ain't Necessarily So*; or Berezow & Campbell's *Science Left Behind*). While parading a concern for truth, they promote all the susceptibilities, uncertainties and loopholes that allow the ersatz scientific voices to flourish. For example, they echo the theme of "Do Your Own Research" (D.Y.O.R.), while feeding the reader cherry-picked evidence and incomplete, one-sided arguments. They promote blanket skepticism, rather than measured analysis, with the result that "an ounce of skepticism is worth a pound of doubt." They also tend to dwell specifically on questioning the science related to workplace safety, environmental safeguards, and other challenges to monied or political interests. Sadly, we must confront even disinformation about effectively addressing disinformation. Yet another layer to untangle (see also Section 5 below).

So, the challenge of misinformation—and of SML for science education—is ultimately about *epistemics*, the dynamics of developing or acquiring knowledge. Not being universal experts, how do we gain authentic knowledge? How do we separate reliable claims from error, whether as a scientific researcher or as a consumer-citizen (Figure 1)? How, as imperfect and limited beings—who cannot be expert in everything—do we acquire trustworthy information? Scientific knowledge is distributed across a multitude of experts, cross linked through a social network. The responsibility of science education is, in part, to help students develop the competencies to tap into that knowledge, without succumbing to the wiles of the imposters. To begin, they need practical skills in ascertaining *who speaks for science*.

Each section below describes an essential benchmark. The emphasis is on competencies, with an eye to including them in classroom practice. I frame them objectively in terms of concrete performance, ideally in authentic contexts, even if they depend on concepts, perspectives or cognitive dispositions. Mental constructs cannot be accessed or assessed directly. Hence, each competency is expressed in operational or behavioral terms that can be observed or measured (Pellegrino et al., 2001). Then follows a brief, highly synoptic discussion of the rationale for its relevance. Each implicitly addresses a particular scenario where the absence of the competence opens susceptibility to misinformation. Together, these 10 competencies form a prospective requisite curriculum for SML, or the ability of the ordinary consumer-citizen to interpret the reliability of public scientific claims that can inform their personal choices and our collective decisions.

1 | EPISTEMIC DEPENDENCE

> Explain why scientific experts are important and why non-experts depend on them. Provide examples. Distinguish between trust in empirical science and other forms of trust (contractual, moral, loyalty, promises, sincerity).

Social learning is deeply embedded in our cognitive architecture (O'Connor & Weatherall, 2019; Sharot, 2017). So, too, is the inclination to persuade others (Mercier & Sperber, 2017). In this environment, we must articulate why the verdict of scientific expertse matters more than plausibility, earnestness, or someone's political or celebrity status. As documented by Nichols (2017), respect for experts is waning amid the ready availability of apparently reliable information and the allure of individual autonomy, especially in times of uncertainty. Yet we depend on experts—doctors, lawyers, airplane pilots, bridge welders, and notably, scientists. Our society is now based on specialized knowledge and the division of intellectual labor. *Inevitably*, we must exercise epistemic trust to be fully informed (Hardwig, 1991). Thus, the traditional educational ideal of developing independent thinkers—able to judge the scientific evidence for themselves—is misplaced (Norris, 1995, 1997). Misinformation flourishes opportunistically in the blind spot of ordinary "critical thinking," which mistakenly assumes that anyone can reach expert conclusions even without the relevant expertise. We each need a fully contextualized view of the problem of *epistemic dependence* to understand our predicament and to appreciate the importance of assessing the credibility of purported experts, rather than rely on our own wits to guide us (Höttecke & Allchin, 2020). We need to understand the social architecture of trust, and the roles of both expertise and honesty (Allchin, 2012b; Hendriks et al., 2016).

2 | EXPERTISE

> Describe several important criteria for identifying scientific experts. Describe at least two factors that are often used to gauge expertise but that are unreliable. Demonstrate these principles in analyzing the level of expertise indicated in some sample authentic cases.

What is scientific expertise? Who is an expert? Who is competent to speak for justified scientific knowledge? Research indicates that even individuals well schooled in traditional forms of critical thinking are not proficient in assessing sources for their credibility (McGrew et al., 2018). In addition, individuals tend to calibrate expertise, inappropriately, against their own (nonexpert) knowledge (e.g., Barzilai et al., 2020; Brashier & Marsh, 2020). They may also use social criteria, such as mere reputation (hearsay), authority (power) or likability, that are not related to genuine expertise (Cialdini, 1984). Thus, science educators need to elicit preconceptions and address them. They need to delve into the nature of expertise and the social mechanisms for validating it (Allchin, 2012b; Goldman, 2001; Zemplén, 2009). Authentic cases are essential (Barzilai et al., 2020; Wineburg et al., 2021).

3 | GATEKEEPERS

> Describe several important criteria for identifying a responsible spokesperson for the consensus of scientific experts. Describe at least two factors that are often used to gauge their credibility, but that are unreliable. Demonstrate these principles in analyzing the level of trustworthiness indicated in some sample authentic cases.

Scientific knowledge is inevitably mediated (Höttecke & Allchin, 2020). From the perspective of the science consumer, the most immediate question is "Who speaks for science?" (Allchin, 2021). What is the provenance of a given claim, and does it reflect the consensus of scientific experts? This curricular goal notably contrasts to a focus on scientific reasoning, or even reasoning about expertise, and shifts attention to the challenges of mediation and the nature of science communication. What media outlets, institutions, fact checkers, and other gatekeepers exhibit a track record of reliability—namely, demonstrated expertise in science reporting (Shoemaker et al., 2009; White, 1950)? Do they have a history of journalistic integrity and independence? Are they relatively neutral (or objective), or do they consistently exhibit biases? Do they transparently indicate their sources of information, allowing others to trace the claims or the evidence?

4 | DECEPTIVE TACTICS

> Name several deceptive tactics used to promote unjustified scientific claims. Analyze several sample authentic claims to establish their level of credibility (honesty).

The most egregious cases of scientific misinformation are typically deliberate efforts by monied interests or ideologues (McGarity & Wagner, 2008; Michaels, 2020). Sometimes, only a handful of sources are responsible for widespread misinformation (e.g., Salam, 2021; Shapiro & Park, 2018). Deception (not merely "honest" persuasion) is rampant. The imitators enlist "cheap symbols and ersatz images" to "conjure" an illusion of science and its authority without any actual evidence (Toumey, 1996, p. 6). Such presentations are strategically designed to escape the conventional tools for analyzing arguments and to fool the typical "critical thinker." For the consumer of science, it is usually easier and quicker to identify a lie than an error (e.g., Brandolini's law). It is also easier to detect a suspected liar, than to decisively pinpoint any particular lie. Accordingly, purveyors of misinformation often try to cajole the naive reader with an apparently common-sense feature of "critical thinking":

> It makes much more sense to look at what the researcher's methodology is, not where the money is coming from. The message, not the messenger, is what demands analysis (Murray et al., 2001; p. 159).

They fail to mention that only experts can assess the methodology competently. Namely, if the messenger is not trustworthy, the message itself is worthless. Thus, the interpretation of scientific claims in the media should focus on recognizing conflicts of interest and finding other contexts of deceit and disguise. Another common strategy is to appeal to a philosophical principle of skepticism to leverage scientific uncertainty into outright disbelief—naysayers appropriately dubbed "merchants of doubt" (Kenner, 2015; Michaels, 2008; Oreskes &

TABLE 1 Common deceptive strategies in popular science media, identifed by the acronym "LIARS."

L	Looks	Professional appearance and confident style
I	Identity	Appeal to social bonds as a substitute for epistemic trust
A	Acting	False credentials or irrelevant expertise; disguise
R	Repetition	Flooding the media with the same erroneous message
S	Skepticism	Exaggerating and leveraging doubt for its own sake

Conway, 2010). However, research shows that prior exposure to the deceptive tactics—“inoculation” and “prebunking”—help disarm the impact of such practices (e.g., Cook et al., 2017; Lewandowsky & van der Linden, 2021; Roozenbeek & van der Linden, 2019). Thus teachers and students both need to become fluent in detecting the most common deceptive strategies (see Table 1; Allchin, 2012a; Rampton & Stauber, 2001; Union of Concerned Scientists, 2019). Again, identify the liars, rather than each individual, heavily disguised lie.

5 | ANALYTICAL POSTURE

> Exhibit the skill of “taking one's bearings.” Describe the context of sample scientific claims in the media, especially who is making the claim and why (as a basis for assessing the credibility of the source).

The internet and social media are relatively “hot” media: they elicit emotional engagement and immediacy based on high sensory input (McLuhan, 1964). However, in the context of assessing the reliability of scientific claims, consumer-citizens often need a “cooler,” more deliberative approach (e.g., shifting thinking style from System I to System II in Kahenman's [2010] popular framework). Or, they need to activate a more analytical mode of thinking, cognizant of contexts and of the choice architectures that they encounter (Kozyreva et al., 2020). In short, an online reader needs to “take one's bearings” (McGrew et al., 2018)—as reflected in click restraint, more patient consideration of web search results, thoughtful analysis of the provenance of claims, and of larger-scale contexts and longer-term consequences in general. Consideration of context is an antidote, of sorts, to the cognitive tendency to consider only what is immediately presented to one's attention—what Daniel Kahneman (2010) calls WYSIATI, or “What You See Is All There Is.” Thus, science teachers should foster stepping back and exploring the hidden contexts of scientific claims in the media. Who is speaking, and why? Ultimately, students need to learn how to be patient and methodical *on appropriate occasions*, and know when to summon that behavioral posture to regulate one's semi-automated or default responses.

6 | INTERNET AND SOCIAL MEDIA

> Describe the special challenges of encountering scientific claims on the internet or on social media, using several examples.

Educators now promote, in general, a constructivist approach to learning, whereby students assume an active role in grappling with problematic preconceptions, developing new concepts, and amending their prior knowledge.

Inquiry learning (now widely adopted as an ideal norm) invites students to reflect explicitly on the learning process and thereby build epistemic skills. The advent and meteoric rise of internet accessibility and social media pose new challenges, but not necessarily the need for new basic learning strategies. That is, students should explicitly engage (as before) the epistemic problems and resolve them on their own, with the teacher as a guide (e.g., Allchin, 2020a, 2020b, 2022; Zemplén, 2009). SML needs to be *problematized* for student inquiry, as open questions to be investigated. How do the new media technologies shape behavior and beliefs? How do social networks shape behavior and beliefs?

7 | EPISTEMOLOGICAL BELIEFS

> Describe the circumstances under which competent scientists may justifiably disagree, using a few authentic examples. Describe how they may resolve those disagreements, using at least one concrete historical example.

Research indicates that the persons most susceptible to conspiracy theories tend to exhibit absolutist epistemological beliefs (based on certainty and personal-choice justification; Garrett & Weeks, 2017; Rudloff et al., 2022). By contrast, more effective evaluation of internet sources on socioscientific issues (SSIs)—including click restraint, selecting items past the top web search results, and lateral reading—is associated with a more evaluative epistemological stance (constructivist, consensus-based) (Hämäläinen et al., 2021; Kammerer et al. 2021). To foster these perspectives, science educators should continue to focus on teaching the "tentativeness" of scientific knowledge. But the concept of tentativeness needs to be more clearly articulated, highlighting how or when knowledge is qualified. This includes: (a) error and conceptual change; (b) the limits of observation and statistical uncertainties; and (c) the normality of debate during science-in-the-making (typical for SSIs), along with the community process of resolving disagreement through further data and evidence. Teachers will benefit from the hindsight afforded by historical cases, but also need to show their relevance to interpreting contemporary SSIs and to discrediting misinformed views (Allchin et al., 2014).

8 | CONFIRMATION BIAS

> Describe the problem of individual confirmation bias and how to address it, using a few real examples.

The most pervasive cognitive flaw in reasoning, both among scientists and consumers of science, is confirmation bias: the tendency to reinforce the justification for one's existing beliefs and to discount evidence for alternatives (Nickerson, 1998; Piatelli-Palmarini, 1994; Sutherland, 1992). This is the blind spot of the hypothetico-deductive method, popularly conceived as the scientific method. Ironically, confirmation bias subverts the role of expert knowledge precisely where it may be most needed. It can further bias the assessment of someone else's credibility, eclipsing access to the informed perspectives that might help remedy one's misconceptions. In technological environments, the positive feedback loops of search engines and news feeds can amplify confirmation bias, leading to filter bubbles that (again) insulate individuals from the very information that may be most informative. In social networks, confirmation bias leads to closed, isolated communities (echo chambers) that may foster a sense of false consensus and, ironically, an impression that an incorrect idea*seems* well justified merely because it is shared by the group. By contrast, awareness and appreciation of confirmation bias can contribute to understanding the vital role of corroboration from alternative perspectives and of the system of checks and balances in science that ultimately yields consensus (Solomon, 2001).

9 | COGNITIVE HEURISTICS AND BIASES

> Identify at least three important cognitive dispositions that may facilitate acceptance of unreliable scientific claims, and provide a historical example of each. Identify and explain the flaws in several sample recent contemporary cases.

Educators have long supported the teaching of critical thinking, including common logical fallacies, errors in statistical thinking, and the failures inherent in cognitive heuristics (e.g., Bergstrom & West, 2021; Copi, 1953; Perlmutter et al., 2021). Educators should also recognize, however, the vast repertoire of such errors: WYSIATI, availability bias, positivity bias, anchoring, anecdotal evidence, small sample size, mistaking correlation for causation, appeal to nature, affirming the consequent, and so on (e.g., Kahneman, 2010; Sutherland, 1992)—as well as confirmation bias, noted above. Piatelli-Palmarini (1994) cataloged over 200 such lapses, from the Actor-observer bias to the Zeigarnik effect. Emotions can also bias epistemic judgments—what Kahan (2013, 2017) has called motivated reasoning. In particular, our thinking can be shaped significantly by social relationships (family, local community, identity politics). People may accept *scientific* ideas simply to accord with their group (Kraft et al., 2015). Alas, an exhaustive mastery of cognitive error-types, however ideal, is pragmatically impossible—another ironic manifestation that our brains are not perfect thinking machines. Thus, an appropriate curricular goal in science seems to be introducing a broad *sampling* of such deficits, as illustrations that exemplify a general problem. We can learn how science works by understanding occasions where it fails—and why (Allchin, 2012c). Teachers may then help students become accustomed to relying on experts, who are proficient in the relevant error-types for their particular topic. Such lessons should further foster respect for the communities of experts who cross-check each other's work (Oreskes, 2019).

10 | CONSENSUS/CORROBORATION

> Explain the importance of consensus and of corroboration from independent sources. Describe what makes sources "independent." Identify at least 2 conditions when the "wisdom of the crowd" may be mistaken, and illustrate with authentic examples.

Philosophers now firmly endorse the norms of social epistemology, where trustworthiness is developed through reciprocal critique (peer review, construed broadly at the level of a professional community) and expressed in a general consensus (Merton, 1973; Oreskes 2019; Ziman, 1968). Namely, vetting through multiple perspectives helps keep individual biases in check. Developing an understanding of the role of consensus adds an important further dimension of reliability, beyond empirical evidence, and beyond individual expertise. It is an antidote, of sorts, to epistemic hubris (the tendency for an individual to regard their own personal reasoning as sufficient to justify claims). Science triumphs, in part, because its customary practices include norms for regulating individual errors and reconciling divergent interpretations (Solomon, 2001; Zimring, 2019). How ironic, then, that science education tends to characterize the "scientific method" in terms of experimentation only, and rarely mentions the social practices of mutual criticism, finding technical flaws, exposing biases, or resolving disagreement through additional investigation.

11 | SUMMARY

Many of the 10 competencies may seem familiar or common sense to seasoned thinkers—at least within various subsets of the educational community. But they do not uniformly inform science education. For example, awareness of cognitive biases (including confirmation bias, #8, 9) is common fodder in critical thinking courses. But while these lapses are relevant to scientific reasoning, they generally do not appear in model science curricula, such as the Next Generation Science Standards in the United States. (Conversely, concerns about epistemic dependence, expertise, credibility, trust and deceptive techniques, and so on, rarely appear in texts on critical thinking.) The concept of gatekeepers and the special challenges of the internet and social media (#3, 6) are addressed in some programs in general media literacy, but while they are relevant to scientific misinformation and scientific literacy, the public communication of science (Figure 1, lowex box) is, again, generally considered peripheral within science education. (For their part, media literacy projects rarely address the role of scientific expertise, the special status of scientific consensus, or the consumer's own cognitive context). By contrast, many science educators are already familiar with the challenges of nurturing an analytical posture and developing basic epistemological beliefs (epistemic cognition). Yet these perspectives need to be more fully associated with the problem of scientific misinfomation in the media. Students need to be more keenly aware that (merely) plausible arguments are insufficient and that disagreement and uncertainty do not necessarily threaten the trustworthiness of scientific claims. Most importantly, perhaps, the central topics of epistemic dependence, expertise, honesty/deception, and consensus (#1, 2, 4, 10) are virtually absent from any established science curriculum (just as they tend to be missing from critical thinking and media literacy lessons). These elements are part of (re)conceptualizing scientific practices to include its social dimensions, as much as experimentation and explanation. These four competencies elements form the linchpin of lessons on credibility and are indispensible. Moreover, what has been missing in science education is an effective synthesis that brings these various features together and frames them as explicit, authentic, and behaviorally concrete educational benchmarks.

The 10 competencies are each valuable. But, equally important, they function as an integrated ensemble. At the core, perhaps, is the concept of epistemic dependence: our inevitable reliance on experts as a consequence of the division of intellectual labor in modern culture. We rely on the specialized knowledge of scientists, as much as we do on dentists, accountants, car mechanics, IT techs, and competent high-rise builders. This sets the context for understanding, next, how all that expert knowledge is transferred. How does one ascertain the "signal" of expertise without the "noise" of misinformation and con artists? In the case of many professions, we typically rely on socially established credentials, such as licensing, certification, or having passed a rigorous exam (e.g., bar exam, medical boards) to help exclude imposters and naive would-be authorities. Not so for science. We are on our own to judge whose purported scientific expertise is genuine and respected by peers. So, even if science information is readily available, one still faces the problem of mediation: the epistemic challenge of sorting information from misinformation—or worse, from calculated disinformation designed to fool us.

The lessons of epistemic dependence (#1) are especially important in our contemporary culture where the unfettered access to information (both genuine and bogus) is coupled with an illusion of autonomy and an education system which continues to embrace a model of intellectual independence. The other nine competencies for the most part derive from (or set a context for) this core problem. Namely, once we realize the dependence on experts, we are primed to inquire into the nature of expertise and, more pragmatically, the diagnostic criteria for recognizing who is a genuine expert (#2). We may choose to rely on information "agents" to help us mediate the transfer of expert knowledge: the traditional role of science journalists as gatekeepers (#3). We may recognize that science differs from other sources of information through its social system of checks and balances, which helps filter error and reduce bias: the critical role of consensus in science (#10). But all this will be for naught if the individual is not properly oriented to seeking knowledge (#5) and is aware of the pitfalls in interpreting the testimony of others (#4). One needs to respect the role of evidence, and acknowledge that evidence and knowledge may change and, foundationally, how descriptive accounts differ from normative ones (#7). And one needs to be sensitive to one's own blind spots—confirmation bias and other cognitive dispositions that often allow our desires or social context to overshadow epistemic considerations (#8, 9). Finally, one needs some appreciation of the media themselves, and how they can equally promote or subvert the communication of reliable information (#4, 6).

So, the 10 competencies function critically as an ensemble. Crudely, they operate at three nested levels, addressing (1) epistemic motivation, which allows (2) reasoning about science communication, and then (3) personal interpretations of arguments and evidence (Figure 2). First, science education needs to help motivate a commitment to reliable scientific knowledge in appropriate circumstances (Figure 2, outside frame). For some educators, that may be about characterizing "science as a way of knowing." For others, the focus may be "epistemic cognition" or "epistemological beliefs." Namely, students need to appreciate how empirical evidence offers an objective bedrock for scientific discourse, even if the evidence changes as research investigations proceed (#7). As citizens and consumers, they need to be oriented to science as a source of reliability, knowing when to set aside personal beliefs, desires, or ideologies, and adopt (at least for specific occasions) a more analytical perspective (#5). Having articulated reliable knowledge as a basis for *informing* (but not determining) one's personal choices or public policy, the groundwork is set for understanding the uncomfortable conundrum of epistemic dependence (#1).

Once aware that one relies on others for knowledge and expertise, one is prepared to consider the nature of how that knowledge is effectively shared: the epistemic problems of *mediation* and the *media* (Figure 2, middle frame). That includes knowing how to recognize an expert (#2), possibly using a media gatekeeper as an intermediary (#3). One must be equally savvy to the wiles of those who would deceive us by mimicking experts (or gatekeepers) or just misinform us out of sheer ignorance (#4). Reflection is needed especially on the particular challenges associated with the internet and social media (#6).

Finally, each individual ideally needs to be aware of their own role in information processing, and in possibly filtering claims in ways that do not always preserve their status of reliability (Figure 2, innermost frame). This set of competencies includes noticing and addressing the formidable effect of confirmation bias (#8) and other cognitive dispositions (#9), which plague even the well educated. These potentials for error may also be found among scientists. However, within a scientific community, such biases tend to come to light when scientists review each other's work from their different theoretical perspectives. This process—organized skepticism (or peer review, broadly construed)—leads to collecting additional evidence to help resolve the disagreement. The resulting consensus (#10) is a hallmark of reliability in science and helps explain the extraordinary resilience of its claims over time.

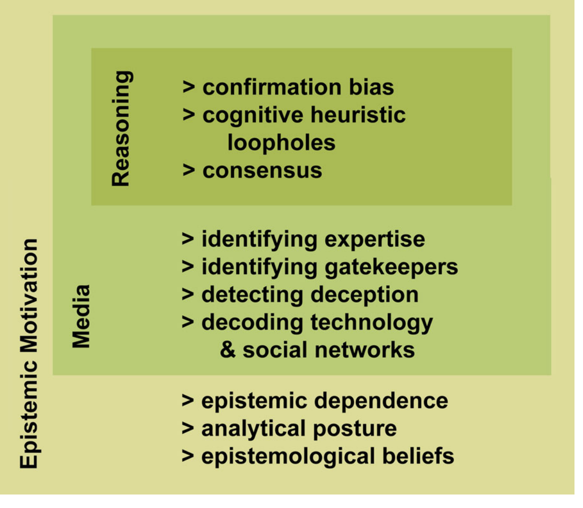

FIGURE 2 Ten competencies for science media literacy, in a nested format

The significance of consensus in science can also serve as a model for how an individual approaches his or her own personal views or interpretations of the "facts." In a sense, it epitomizes the answer to the discomforting dilemma of epistemic dependence. Namely, *find and trust the consensus of the relevant scientific experts* (e.g., Oreskes, 2019). That might be the "simple" solution to the current crisis. But from an SML perspective, it is not separate from ascertaining who is positioned to report the consensus (Figure 1). Ultimately, the remedy to misinformation seems to draw on the whole suite of 10 competencies to be enacted fully and effectively.

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REFERENCES

3M. (2022). State of Science Index 2022: Global Report. https://multimedia.3m.com/mws/media/2183175O/3m-state-of-science-index-sosi-2022-global-report.pdf

Allchin, D. (2012a). Science con-artists. *American Biology Teacher*, *74*, 661–666.

Allchin, D. (2012b). Skepticism and the architecture of trust. *American Biology Teacher*, *74*, 358–362.

Allchin, D. (2012c). Teaching the nature of science through scientific error. *Science Education*, *96*, 904–926.

Allchin, D. (2013). *Teaching the nature of science*. SHiPS Education Press.

Allchin, D. (2020a). The covid conundrum. *American Biology Teacher*, *82*, 429–433.

Allchin, D. (2020b). The credibility game. *American Biology Teacher*, *82*, 535–541.

Allchin, D. (2021). Who speaks for science? *Science & Education*. https://doi.org/10.1007/s11191-021-00257-4

Allchin, D. (2022). The vaccine skeptics of 1731. *American Biology Teacher*, *84*(1), 53–54.

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

Allchin, D., & Zemplén, G. (2020). Finding the place of argumentation in science education: Epistemics and whole science. *Science Education*, *104*, 907–933.

ALLEA. (2021). Fact or Fake? Tackling Science Disinformation [ALLEA Discussion Paper #5]. All European Academies. https://doi.org/10.26356/fact-or-fake

Amara, S. G. (2022). Empower with evidence. *Science*, *375*, 699.

Barzilai, S., Thomm, E., & Shlomi-Elooz, T. (2020). Dealing with disagreement: The roles of topic familiarity and disagreement explanation in evaluation of conflicting expert claims and sources. *Learning and Instruction*, *69*, 101367.

Bergstrom, C. T., & West, J. D. (2021). *Calling bullshit*. Random House.

Brashier, N. M., & Marsh, E. J. (2020). Judging truth. *Annual Review of Psychology*, *71*, 499–515.

Chaffee, J. (2019). *Thinking critically* (12th ed). Cengage.

Cialdini, R. B. (1984). *Influence: The psychology of persuasion*. Collins Business.

Cook, J., Lewandowsky, S., & Ecker, U. K. H. (2017). Neutralizing misinformation through inoculation: exposing misleading argumentation techniques reduces their influence. *PLoS One*, *12*(5), e0175799. https://doi.org/10.1371/journal.pone.0175799

Copi, I. (1953). *Introduction to logic*. Macmillan.

Epstein, R. L. (2016). *The pocket gudie to critical thinking* (5th ed). Advanced Reasoning Forum.

Funk, C. (2020). Key findings about Americans' confidence in science and their views on scientists' role in society. Pew Research Foundation. https://pewrsr.ch/2Hgq31S

Gaon, S., & Norris, S. P. (2001). The undecidable grounds of scientific expertise: Science education and the limits of intellectual independence. *Journal of Philosophy of Education*, *35*, 187–201.

Garrett, R. K., & Weeks, B. E. (2017). Epistemic beliefs' role in promoting misperceptions and conspiracist ideation. *PLoS One*, *12*, 0184733. https://doi.org/10.1371/journal.pone.0184733

Glynn, S. M., & Muth, K. D. (1994). Reading and writing to learn science: Achieving scientific literacy. *Journal of Research in Science Teaching*, *9*, 1057–1069.

Goldman, A. I. (2001). Experts: which ones should you trust? *Philosophy and Phenomenological Research*, *63*, 85–110.

Hämäläinen, E. K., Kiili, C., Räikkönen, E., & Marttunen, M. (2021). Students' abilities to evaluate the credibility of online texts: The role of internet-specific epistemic justifications. *Journal of Computer Assisted Learning*, *37*, 1409–1422. https://doi.org/10.1111/jcal.12580

Hardwig, J. (1991). The role of trust in knowledge. *Journal of Philosophy*, *88*, 693–708.

Helfand, D. J. (2016). *A survival guide to the misinformation age: Scientific habits of mind*. Columbia University Press.

Hendriks, F., Kienhues, D., & Bromme, R. (2016). Trust in science and the science of trust. In B. Blöbaum (Ed.), *Trust and communication in a digitized world* (pp. 143–159). Springer.

Höttecke, D., & Allchin, D. (2020). Reconceptualizing nature-of-science education in an age of social media. *Science Education*, *104*, 641–666.

Jarman, R., & McClune, B. (2007). *Developing scientific literacy: Using news media in the classroom*. Open University Press.

Kahan, D. M. (2013). Ideology, motivated reasoning, and cognitive reflection. *Judgment and Decision Making*, *8*, 407–424.

Kahan, D. M. (2017). Misconceptions, misinformation, and the logic of identity-protective cognition. *SSRN Electronic Journal*. https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2973067

Kahneman, D. (2010). *Thinking, fast and slow*. Farrar, Strauss and Giroux.

Kammerer, Y., Gottschling, S., & Bråten, I. (2021). The role of Internet-specific justification beliefs in source evaluation and corroboration during web search on an unsettled socio-scientific issue. *Journal of Educational Computing Research*, *59*(2), 342–378.

Kennedy, B., Tyson, A., & Funk, C. (2022). Americans' trust in scientists, other groups declines. Pew Research Foundation. https://www.pewresearch.org/science/2022/02/15

Kenner, R. (2015). *Merchants of doubt [film]*. Sony Classic Pictures.

Kozyreva, A., Lewandowsky, S., & Hertwig, R. (2020). Citizens versus the internet: Confronting digital challenges with cognitive tools. *Psychological Science in the Public Interest*, *21*(3), 103–156.

Kraft, P. W., Lodge, M., & Taber, C. S. (2015). Why people "don't trust the evidence": Motivated reasoning and scientific beliefs. *Annals of the American Academy of Political and Social Science*, *658*(1), 121–133.

Lewandowsky, S., & van der Linden, S. (2021). Countering misinformation and fake news through inoculation and prebunking. *European Review of Social Psychology*, *32*(2), 348–384. https://doi.org/10.1080/10463283.2021.1876983

Martin, B. (1991). *Scientific knowledge in controversy: The social dynamics of the fluoridation debate*. State University of New York Press.

McGarity, T. O., & Wagner, W. E. (2008). *Bending, science: How special interests corrupt public health research*. Harvard University Press.

McGrew, S., Breakstone, J., Ortega, T., Smith, M., & Wineburg, S. (2018). Can students evaluate online sources? Learning from assessments of civic online reasoning. *Theory and Research in Social Education*, *46*(2), 165–193.

McIntyre, L. (2019). *The scientific attitude*. MIT Press.

McLuhan, M. (1964). *Understanding media*. McGraw Hill.

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

Merton, R. K. (1973). *The sociology of science*. University of Chicago Press.

Michaels, D. (2008). *Doubt is their product: How industry's assault on science threatens your health*. Oxford University Press.

Michaels, D. (2020). *The triumph of doubt: Dark money and the science of deception*. Oxford University Press.

Moore, B. N., & Parker, R. (2021). *Critical thinking* (13th ed). McGraw Hill.

Murray, D., Schwartz, J., & Lichter, S. R. (2001). *It ain't necessarily so: How media make and unmake the scientific picture of reality*. Rowman & Littlefield.

Nichols, T. (2017). *The death of expertise: The campaign against established knowledge and why it matters*. Oxford University Press.

Nickerson, R. S. (1998). Confirmation bias: a ubiquitous phenomenon in many guises. *Review of General Psychology*, *2*, 175–220.

Norris, S. P. (1995). Learning to live with scientific expertise: Toward a theory of intellectual communalism for guiding science teaching. *Science Education*, *79*, 201–217.

Norris, S. P. (1997). Intellectual independence for nonscientists and other content-transcendent goals of science education. *Science Education*, *81*, 239–258.

Norris, S. P., & Phillips, L. M. (1994). Interpreting pragmatic meaning when reading popular reports of science. *Journal of Research in Science Teaching*, *31*, 947–967.

Norris, S. P., Phillips, L. M., & Korpan, C. A. (2003). University students' interpretation of media reports of science and its relationship to background knowledge, interest, and reading difficulty. *Public Understanding of Science*, *12*, 123–145.

O'Connor, C., & Weatherall, J. O. (2019). *The misinformation, age: How false beliefs spread*. Yale University Press.

OECD. (2019). *PISA 2018 assessment and analytical framework: Science, reading, mathematic, and financial literacy*. OECD Publishing. https://www.oecd.org/education/pisa-2018-assessment-and-analytical-framework-b25efab8-en.htm

Oreskes, N. (2019). *Why trust science?* Princeton University Press.
Oreskes, N., & Conway, E. M. (2010). *Merchants of doubt: How a handful of scientists obscured the truth on issues from tobacco smoke to global warming*. Bloomsbury.
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 the age of misinformation*. Standford University.
Otto, S. (2016). *The war on science*. Milkweed Editions.
Pellegrino, J. W., Chudowsky, N., & Glaser, R. (Eds.). (2001). *Knowing what students know: The science and design of educational assessment*. National Academies Press.
Perlmutter, S., Campbell, J., MacCoun, R., & Lombrozo, T. (2021). *Sense and sensibility [university course]*. University of California. https://sensesensibilityscience.berkeley.edu/
Piatelli-Palmarini, M. (1994). *Inevitable illusions: How mistakes of reason rule our minds*. John Wiley & Sons.
Rampton, S., & Stauber, J. (2001). *Trust us, we're experts: How industry manipulates science and gambles with your future*. Tarcher/Penguin Putnam.
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*, 147–166.
Roozenbeek, J., & van der Linden, S. (2019). Fake news game confers psychological resistance against online misinformation. *Palgrave Communications*, *5*, 65. https://doi.org/10.1057/s41599-019-0279-9
Rudloff, J. P., Hutmacher, F., & Appel, M. (2022). Beliefs about the nature of knowledge shape responses to the pandemic: Epistemic beliefs, the dark factor of personality, and COVID-19-related conspiracy ideation and behavior. *Journal of Personality*. https://doi.org/10.1111/jopy.12706
Ryder, J. (2001). Identifying science understanding for functional scientific literacy. *Studies in Science Education*, *36*, 1–44.
Salam, E. (2021). Majority of Covid misinformation came from 12 people, report finds. *The Guardian*. https://www.theguardian.com/world/2021/jul/17/covid-misinformation-conspiracy-theories-ccdh-report
Shapiro, M. A., & Park, H. W. (2018). Climate change and YouTube: Deliberation potential in post video discussions. *Environmental Communication*, *12*(1), 115–131.
Sharot, T. (2017). *The influential mind*. Henry Holt.
Shermer, M. (2017). *Skeptic: Viewing the world with a rational eye*. St. Martin's Griffin.
Shoemaker, P. J., Vos, T. P., & Reese, S. D. (2009). Journalists as gatekeepers. In K. Wahl-Jorgensen & T. Hanitzsch (Eds.), *The handbook of journalism studies* (pp. 73–87). Routledge.
Sinatra, G. M., & Hofer, B. K. (2021). *Science denial: Why it happens and what to DO about it*. Oxford University Press.
Solomon, M. (2001). *Social empiricism*. MIT Press.
Spence, W., Herrmann, R. B., Johnston, A. C., & Reagor, G. (1993). *Responses to Iben Browning's prediction of a 1990 New Madrid, Missouri, Earthquake. U.S. Geological Survey Circular 1083*. U.S. Government Printing Office. http://pubs.usgs.gov/circ/1993/1083/report.pdf
Sutherland, S. (1992). *Irrationality: Why we don't think straight*. Rutgers University Press.
Toumey, C. (1996). *Conjuring Science*. Rutgers University Press.
Toumey, C., Besley, J., Blanchard, M., Brown, M., Cobb, M., Ecklund, E. H., & Lewenstein, B. (2010). *Science in the service of citizens & consumers: The NSF Workshop on Public Knowledge of Science*. University of South Carolina Nanocenter.
Union of Concerned Scientists. (2019). *The disinformation playbook*. Union of Concerned Scientists. https://www.ucsusa.org/resources/disinformation-playbook
West, D., & Bergstrom, C. (2021). Misinformation in and about science. *Proceedings of the National Academies of Science of the United States of America*, *118*(15), e1912444117.
White, D. M. (1950). The "gatekeeper": A case study in the selection of news. *Journalism Quarterly*, *27*, 383–391.
Wineburg, S., Breakstone, J., McGrew, S., Smith, M., & Ortega, T. (2021). Preparing Students for civic life in a digital age: A curriculum intervention in high school classrooms.
Zemplén, G. Á. (2009). Putting sociology first—Reconsidering the role of the social in "nature of science" education. *Science & Education*, *18*, 525–559.
Ziman, J. (1968). *Public knowledge: The social dimension of knowledge*. Cambridge University Press.
Zimring, J. C. (2019). *What science is and how it really works*. Cambridge University Press.

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