(Mis)informed about what? What it means to be a science-literate citizen in a digital world

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Science literacy is often held up as crucial for avoiding science-related misinformation and enabling more informed individual and collective decision-making. But research has not yet examined whether science literacy actually enables this, nor what skills it would need to encompass to do so. In this report, we address three questions to outline what it should mean to be science literate in today's world: 1) How should we conceptualize science literacy? 2) How can we achieve this science literacy? and 3) What can we expect science literacy's most important outcomes to be? If science literacy is to truly enable people to become and stay informed (and avoid being misinformed) on complex science issues, it requires skills that span the "lifecycle" of science information. This includes how the scientific community produces science information, how media repackage and share the information, and how individuals encounter and form opinions on this information. Science literacy, then, is best conceptualized as encompassing three dimensions of literacy spanning the lifecycle: Civic science literacy, digital media science literacy, and cognitive science literacy. Achieving such science literacy, particularly for adults, poses many challenges and will likely require a structural perspective. Digital divides, in particular, are a major structural barrier, and community literacy and building science literacy into media and science communication are promising opportunities. We end with a discussion of what some of the beneficial outcomes could be—and, as importantly, will likely not be—of science literacy that furthers informed and critical engagement with science in democratic society.

science literacy | digital literacy | science knowledge | misinformation | science communication

In recent years, calls for increased science literacy have received additional fuel, motivated by growing concerns about the spread of misinformation and conspiracy theories that contradict established scientific findings. The common but as yet untested assumption is that greater science literacy could help stem the believability and spread of science-related misinformation and ultimately help improve informed decision-making at the individual and collective levels. This context prompted the National Academies of Sciences, Engineering and Medicine to conduct a consensus study in 2016, culminating in the report *Science Literacy: Concepts, Contexts, and Consequence* (1), which highlighted the major gaps remaining in science-literacy scholarship.

According to the above cited report, science literacy broadly refers to "familiarity with the enterprise and practice of science" (1). But although there is widespread agreement that a science-literate citizenry should be the norm in modern democracies, scholars have yet to clearly articulate what it concretely means to be science literate in the 21st century. In other words, what skills should a science-literate individual master, and for what end? How can these skills stay relevant in everchanging science and media environments? As a result, we have little understanding of how science literacy would help people be informed about science and protect themselves against misinformation, nor what kinds of skills science literacy would have to include to do so.

In this report, we address three larger questions to outline what it should mean to be science literate in today's world: 1) How should we conceptualize science literacy? 2) How can we achieve this science literacy? and 3) What can we expect science literacy's most important outcomes to be?

We start with a simple, yet important, premise. If science literacy is to truly enable people to become and stay informed (and avoid being misinformed) on complex scientific issues, it has to encompass knowledge and skills that go beyond understanding what we traditionally think of as the world of science. Instead, science literacy has to consider the entire "science information lifecycle." This includes how the scientific community produces science information, how media repackage and share the information, and how individuals encounter that information and form opinions on it.

There are, however, many challenges for how this 21st century science literacy can be achieved in an equitable way among the American public, and we take a structural perspective to examine some of the ways we could accomplish this. In particular, we focus on digital divides as a structural barrier and discuss how realistic our vision of a science-literate America really is. We see some promise in community literacy, which we believe constitutes a structural opportunity to achieve an ambitious goal. We also see potential to build science-literacy lessons into media and science communication.

We end our report by returning to the question posed in the title: (Mis)informed about what? We describe how science literacy as we have outlined it could address the different ways people tend to be (mis)informed across science-related issues. We discuss not only what greater science literacy among the American public could accomplish but, as importantly, what greater science literacy will likely not accomplish.

A Definition of Science Literacy Should Encompass Knowledge and Skills Relevant across the Science Information Lifecycle. Modern science-related issues—such as the COVID-19 pandemic, climate change, vaccinations, gene editing, and artificial intelligence—are complex and dynamic, with profound implications for individuals,

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communities, and societies. Much of the science on these issues moves rapidly through information environments rife with incorrect, confusing, and quickly changing information. People will pay attention to some of this information and will interpret it based on their values, while discarding others based on complex cognitive processes. Depending on all of these factors, individuals may (or may not) become polarized on these issues as the issues develop in society.

Science literacy should therefore help people effectively navigate these complex, dynamic science issues. People should feel equipped to access and use trustworthy science-related information when needed for informed decision-making, both in their everyday lives and as citizens. They also need to be able to gain additional skills as needed to navigate (mis)information and potentially highly polarized or contentious opinions across different issues and information sources.

Science literacy, then, is best conceptualized as including three dimensions of literacy that span the lifecycle of science information (Fig. 1). Of course, the schematic cycle we describe does not take into account all of the complexities of science knowledge production and popularization (2) and the potential mutual influences between the different dimensions presented in the figure. However, it does provide a framework for identifying the abilities that are necessary components of science literacy today. These abilities include: 1) Understanding how science is produced, and what that means for how science relates to broader society, or "civic science literacy"; 2) understanding how science information appears and moves through media systems, or "digital media science literacy"; and 3) understanding how people interpret science information when they come across it, or "cognitive science literacy."

Civic science literacy. The first stage of the science information lifecycle relates to the production of scientific knowledge and the creation of scientific facts; an understanding of that is captured in civic science literacy.

The concept of civic science literacy was originally put forward a few decades ago as encompassing the skills necessary to understand and evaluate the main points behind arguments in policy disputes involving science and technology. This was motivated at a time by issues such as biotechnology that were starting to generate controversy. Civic science literacy was initially presented as a multidimensional concept, encompassing: 1) Mastering a vocabulary of basic scientific constructs, 2) understanding the processes of science, and 3) some understanding of science and technologies' impacts on individuals and on society (3).

The items researchers originally used to capture these dimensions, however, were heavily criticized for being too narrow. The measures seemed to reflect "knowledge deficit thinking" that overestimates the influence of knowledge of a particular scientific fact on attitudes and behaviors toward a science issue (4, 5). The conceptualization also focused too narrowly on science's impacts on society, without including how societal contexts impact science itself. As a result, the original concept of civic science literacy missed how interactions between science and society shape the type of scientific research that is conducted, who supports it, and the potential implications of its applications.

Since then, many scholars have highlighted the importance of including the understanding of scientific processes in conceptualizations of science literacy, and started to do some work toward measuring the extent to which those literacy skills are attained or not by Americans (e.g., refs. 6 and 7). Very little work, however, takes a sufficiently broad approach to these conceptualizations, or tests how these skills actually would work in practice for achieving a greater ability to navigate complex science-related issues in society.

We therefore argue that civic science literacy should go beyond the extant conceptualizations and should also capture the elements that shape science and how science fits into society. In other words, civic science literacy should include some understanding of the many elements that shape the production of scientific knowledge, such as the people, institutions, training, resources, methods, and norms of science.

We do not claim that Americans need to become specialists in sociology of science. But since all of the elements listed above are inherent to discussions about science across many issues nowadays, it is time to think about integrating them into conceptualizations of science literacy. It is also clear that individuals cannot be expected to follow current mediated discussions about scientific issues without understanding some of the nitty gritty aspects of modern science. Indeed, maybe aspects of science that are seldom included in the formal education of individuals who are not pursuing scientific fields do appear very often in the public discourse. For example, individuals encountering science information pertaining to burgeoning science topics (such as COVID-19) and other developing science issues should have a broad understanding of the following related aspects: 1) The incremental production of scientific knowledge and why one single study can seldom uncover the mechanisms behind one phenomenon; the issues of reproducibility and replicability in science; the notion of uncertainty in science contexts and how it

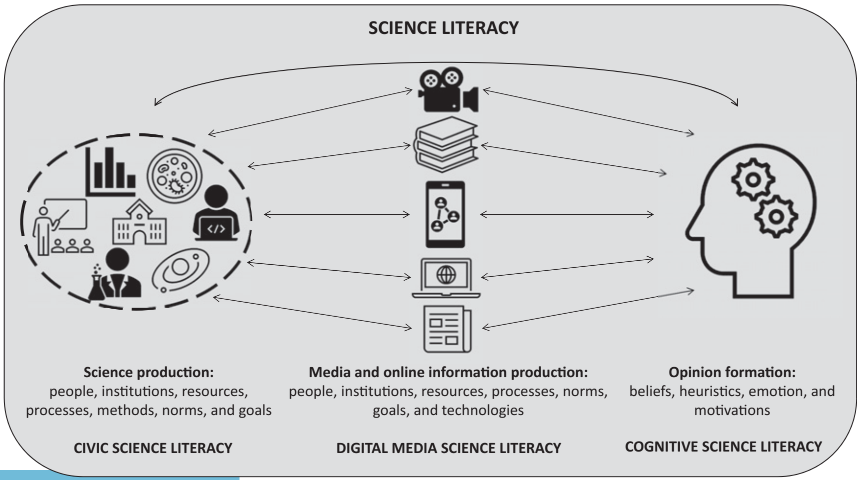

Fig. 1. A representation of the dimensions of literacy necessary for science literacy, across the schematic lifecycle of science information in society.

differs from uncertainty in lay contexts; the processes related to scientific publishing, including peer review, retractions, and what makes a scientific journal trustworthy; and how scientists and the institutions and methods they rely on provide checks on their own and each other's research.

Of course, understanding the production of science knowledge does require some understanding how science relates to society. Societal factors—such as economics, politics, societal priorities, and other societal elements—shape who is doing science in what areas at any given point (e.g., refs. 8 and 9), just as the information and technology that come out of science shape what choices and decisions we face in society. The civic science literacy dimensions of greater science literacy, then, should mean individuals are aware, to a degree, of these processes. Most interesting from our perspective, especially in the context of addressing misinformation, is that knowing these elements and relationships that shape what makes something "scientific" will also mean knowing what is not scientific. In other words, individuals need to be able to understand what science can tell us or what kinds of questions it can answer.

Digital media science literacy. The nature of media environments (mainly online today), shape what information people can access, how they see it, and what conclusions they may then draw from it (10). Because most people learn about science and science information through mediated sources (11, 12), science literacy has to include being able to navigate and evaluate mediated science information. The abilities needed to be science literate in this next stage of the lifecycle of science information are represented by digital media science literacy.

Digital literacy and media literacy are two overlapping concepts in existing literature, and each has been given a wide range of definitions and assumed goals (13, 14). Broadly, digital literacy refers to abilities to participate in society through opportunities enabled by digital technologies, such as the internet, personal computers, and smartphones (13, 15). It typically includes being able to both consume and produce information online (13). Media literacy, on the other hand, broadly refers to the ability to access, understand, and critically assess media and media content, as well as the ability to create media content (16). Many empirical studies assessing media literacy focus on the ability to critically evaluate single media messages, such as advertisements. This ability includes skills in questioning why producers make particular media messages, what techniques they use, what viewpoints or information are included or left out, and how different people could interpret the same message (17, 18).

We combine media and digital literacy here into one necessary dimension of science literacy because it is difficult—and not particularly useful—to disentangle media and digital literacies, particularly for science information. Although one can be digitally literate without being media literate, one cannot realistically be media literate today without being digitally literate to a degree as well. There are many media that exist only online and are accessible through digital technologies, but increasingly fewer media that exist only offline, especially among media sources that feature prominently in people's media diets. Even books that exist only in physical copies in libraries are often found through digital technologies, such as digital catalogs or search engines.

As described in Fig. 1, digital media science literacy includes understanding the elements that shape online information: How people and institutions create that information, with particular norms and goals, and how digital technologies shape what information appears and how. Because of how these factors interact, digital media science literacy will likely need to include at least three skill areas: 1) The ability to access science information, particularly in online environments; 2) an understanding of how science information travels through media systems, particularly online; and 3) the ability to evaluate individual pieces of science information in media messages (based as well on the skills captured in the civic science literacy dimension).

Media literacy can be an important factor for avoiding believing misinformation. Much of the research on media literacy concerning science-related issues has focused on health information and how to avoid advertising messages that can be harmful to health (such as for cigarettes or junk food). This research consistently finds benefits from even basic levels of media literacy in terms of positive health outcomes. Media literacy skills, such as greater knowledge of media, awareness of its influences, and understanding of what features shape a health-related media message, lead to healthier behaviors, such as healthier food consumption and reduced intention of risk-taking behaviors (17–19). Research is starting to expand into broader science-related contexts as well, and emerging findings suggest that those who have greater media literacy can be more resistant to the influence of misinformation online (e.g., refs. 20–22).

Moving forward, research should examine what digital media skills give individuals the tools they need to access and use sound science information for informed decision-making at the individual and collective levels, beyond health-related issues. Elements that could be examined as components of digital media science literacy include the following.

First is how journalists, (social) media companies, and others produce media content and media technologies and for what purposes. This includes: 1) Who creates and disseminates science-related information and why, and how trustworthy they are; what science information does the information producer highlight and what might be missing; how media produce science headlines, and the extent to which the headline matches the content of the story; what are science facts versus opinions in media stories; and why individuals share science stories or piece of information on social media.

Second are the features and limitations of online search. This includes: 1) What was the original source of the information, or who wrote or produced it; how could one find additional information to add context and additional perspectives; how might the terms in the article shape what appears and does not appear in search engine results when searching for more information; and how could one find more general words to use in a search to get possibly a less narrow search result?

Cognitive science literacy. Ultimately, however, civic science literacy and digital media science literacy together are not sufficient for people to find and use science information to make informed decisions. Individuals need some level of cognitive science literacy as well, or an awareness of their own biases as they evaluate science information and media.

Research on cognitive literacy, also called metacognition (23–25), refers to the awareness of one's own processes for thinking through information and how those processes shape resulting conclusions (24). The assumption is that if one understands that these processes are at work, one will then be more likely and able to regulate them (26). It is becoming clear that high cognitive literacy can improve learning and problem-solving across contexts in both children and adults (27). Cognitive literacy can also facilitate information searching and can improve critical thinking and reading (26, 27). More importantly, cognitive literacy appears to be a skill that can be developed in adulthood (27).

It is well established that having access to reliable sources of science information does not mean that information will be critically evaluated and in an accurate or relatively nonbiased way (28–33). In the context of controversial science, such as fracking and genetic engineering, having more information about these issues may just mean the individual is more extreme in their opinions (32, 34). This is partly because individuals rely on their beliefs and values as mental filters to process, and accept or dismiss, information. For example, we all use directional motivated reasoning, in which we pay more attention to and give more weight to information that is congruent to our beliefs and are more critical of information that seems incompatible with them (28, 35). Even when we are not motivated to shore up our held beliefs, we are motivated to save time and use heuristics, or mental shortcuts, that help us quickly reach conclusions on complex issues (36–38). We do so, however, at the risk of falling prey to biased and, more crucially, unquestioned thinking.

Because of these tendencies, our preheld beliefs, values, and cognitive shortcuts and biases also make us especially susceptible to the influence of misinformation. Research suggests that people are generally very capable of practicing "epistemic vigilance," or being on guard for misinformation from others (39, 40). A review of the effects of a variety of propaganda, advertising, and misinformation campaigns found that communication was not particularly influential for changing people's minds about a specific topic in most cases (39). But, when that propaganda or misinformation fit with the individual's preexisting belief, vigilance was much less present and people were more likely to accept the information at face value (39). The problem, then, is not that people are widely gullible, it's that we are selectively gullible. Because individuals are better at recognizing biases that don't resonate with their own than they are at catching those already in their heads (6, 35, 39), cognitive literacy could be especially vital for counteracting that tendency.

The body of research on cognitive literacy is still small but growing, and much of it focuses on developing cognitive literacy skills in formal education settings (23, 24, 26, 41). We can safely assume based on that body of work, however, that greater cognitive literacy could help people better navigate and use information on science-related issues in society. If people are aware of their cognitive processes and are able to regulate and adjust them as they encounter science information in media contexts, they would be less likely to fall into the trenches of misinformation that fits their worldviews and opinions, and that further polarizes.

Fig. 1 presents in broad terms some of the many factors that may shape reasoning and that people should ideally be aware of when they are processing science-related information. These factors exist to some degree in all of us. We tend to have poor statistical sense and give more weight to information that is salient or readily available in our minds (e.g., ref. 38). Additionally, our emotions shape our reasoning in predictable ways, such as becoming overly certain when we are angry, which can make us hasty in our conclusions (42, 43). Through motivated reasoning, we also all tend to judge less critically information that confirms our beliefs about the world and to more quickly apply stereotypes to discount information from those who seem different from us, and then use motivated reasoning to hold those stereotypes in place (e.g., refs. 30 and 44).

Developing literacy of these processes might be more difficult to achieve for some of the sources of biases than others. For example, addressing poor statistical sense will require some degree of understanding of how statistics work, why sampling is important, and what conclusions can be drawn (or not) from some statistical results. But many other biases could be easier to convey, such as being aware of the effects that emotions can have on reasoning. That being angry or feeling defensive will make one more certain and blind to alternatives is something we can all likely relate to.

It will be worth testing a broad range of simple messages or lessons that could help improve cognitive literacy across these different biases, and examining how understanding of these biases matter specifically in the contexts of science-related information. Some examples of what cognitive science literacy could encompass include understanding: What motivated reasoning is and the basics of how it works; why we tend to overweight rare and sensational cases; why it is uncomfortable to hear information we think disagrees with our view, and what our defensive tendencies are; how fear and anger shape our thinking, and what we can do to avoid their negative effects; how we might overweight something lots of other people seem to be paying attention to; and why we might ignore something that someone says if we assume that person isn't like ourselves.

It will be important to stress not just the processes individuals rely on to form opinions based on science information and why default processes might mislead them, but also what the benefit is to knowing that these processes are at play. As the work cited above on epistemic vigilance points out (39, 40), none of us like to be perceived as gullible, and we all are more than capable of not being gullible. We just need to be better equipped at extending that vigilance toward our own thinking.

So, How Could We Achieve Greater Science Literacy, Especially for Adults? In sum, being science literate will require combining the three dimensions of literacy skills that shape how people access and use science-related information: Civic science literacy, digital media science literacy, and cognitive science literacy. Of course, each of these encompass skills that would be applicable beyond science-related information. We have focused on highlighting some promising concepts and research directions that could enhance our theoretical understanding of these dimensions as they matter for being informed about science issues.

The crucial question remains, however, on how to actually achieve this greater science literacy in the American society, and if it even is attainable. Can adults realistically gain the skills necessary to become science literate in the United States nowadays and be better equipped to navigate online discussions of science? If the answer is yes, and we believe it is, then how?

Many aspects of science literacy we discussed in this report could (and should) be achieved through K-12 education and other formal education settings. The good news is that work on science literacy among students in formal education programs is promising, and we are seeing successes in developing skills in digital media literacy in particular. Indeed, students can learn to critically assess what they find online and digital tools helping develop these skills can be integrated in school curricula (45). Additionally, interesting work in library sciences is focusing on ways to develop cognitive literacy in students. This work is highlighting the importance of cognitive literacy for critical thinking and for developing the ability to find and navigate information online (26, 41, 46). In other words, the important overlapping benefits between cognitive literacy and digital media literacy are beginning to be documented (24–26, 41, 47). Of course, more research that tests how these skills matter for science issues and experiments with ways of incorporating them along with civic science literacy in formal education will be extremely valuable.

Enhancing these different dimensions of science literacy in adults outside of formal education settings will be more challenging, and research in that context is less developed (see ref. 48 for an example of some of these challenges for media literacy). What is clear is that for both children and adults in the United States, achieving science literacy will not be possible without also taking a structural view of literacy.

A structural view of science literacy focuses on how structures shape the distribution of literacies (and differences in opportunities to gain such literacies) across individuals and communities (1). These structures provide both barriers and opportunities. They also, therefore, indicate necessary areas for research. We highlight three pathways that seem especially promising or necessary: Addressing digital divides, building in literacy content across information sources, and better understanding "community literacy" (1)

Literacy that overcomes digital divides. Disparities in society shape who is science literate or not and "digital divides" (representing who has access to online tools and information) are one of the many ways these disparities play out (49). Those who are white, male, wealthy, and well-educated in the United States are more likely to create online content and to be able to access and benefit from online technologies and information (41, 50). And digital divides are particularly pernicious in that they do not automatically disappear with equal physical access to digital technologies. Even when people have physical access to online resources, those who are already advantaged in society have different levels of access to and different patterns of use across online information platforms and often can gain the most from informational resources (15, 51, 52).

For example, digital divides exist in who seeks out news versus entertainment, and who seeks out different types of entertainment. Digital divides exist in whether or not someone is likely to have offline and online social networks they are interested in or that they identify with "science." Digital divides also impact what terms people are likely to use as keywords when using search engines, and therefore what information they are likely to come across as a result. All of these divides occur along socioeconomic, racial, and other demographic lines in the United States and all translate into barriers in gaining science literacy (15, 51, 52).

Digital divides, in that sense and like many other areas of systemic inequity, breed further inequity. And because literacy also begets literacy, inequities in literacy will beget greater inequities in literacy, unless we work to ensure that opportunities for literacy are equitable and based on where a person is in terms of what they have access to and want to achieve. Achieving science literacy, therefore, requires continued research on how to overcome the digital divides that affect whether people are able to develop and use literacy skills.

Literacy through media. This brings us to the next broader question, and one which could help overcome some of the barriers posed by digital divides. How can we work with diverse groups to build literacy materials into the media people already rely on? As we have mentioned throughout this report, media are people's primary sources for science information. So perhaps media themselves offer promising resources for people to develop literacies.

By using media for increasing science literacy, we do not, however, mean using fact checks or warnings that information might be false or misleading. Relying on corrections and fact checks for misinformation, especially online, is unrealistic because of the vast resources it would require if we were to keep up with the breadth of information available online (53). And more importantly, fact checkers are only successful when people trust the fact-check source (54). Additionally, fact checks do not help people gain the skills they need to evaluate science information for themselves and in the many information settings where fact checkers do not exist.

There could, though, be promising opportunities to build in science literacy throughout the science information lifecycle in ways that transfer through media to individuals. For example, applied science communication training for scientists and journalists could encourage them to include science-literacy aspects in their stories. Design features on social media sites could also include some of these elements. The idea would be that when people access science information, they are also accessing science literacy-increasing information.

For example, some interesting open research questions, grouped by where they would fall along our schematic science information lifecycle, are at the science-producer stage, at the media-producer stage, and at the consumer stage.

The science-producer stage. What aspects of civic science literacy are missing from scientists' training that would help them speak more effectively about their own work, either through journalistic pieces or directly through online and in-person media?

The media-producer stage. Do journalists providing contextual and process-focused information help people gain science literacy? Can we include components of civic science literacy in science journalism training for journalists to use in their own writing?

Can components of digital media literacy dimension be included in media stories? What happens at the audience level when journalists or news sources incorporate descriptions of how they produced a story?

Rather than just corrections or fact-checking, can social media sites provide science-literacy information? What would that look like, and would they (or someone else) be trusted as sources for that information?

What happens at the audience level if depictions of the processes of science are included in entertainment media, as the true-crime nonfiction series *Forensic Files* (55) does, or fiction or dramatizations, such as pandemic film *Contagion* (56) or the TV drama *Manhunt Unabomber* (57) do?*

The consumer stage. How do and could people learn science literacy from others in their social networks, on- and offline?

Finally, at what levels of science literacy does skill increase become self-sustaining? Or, how much literacy does someone need to be able to continue to gain literacy skills on their own?

Developing community literacy. Connecting to these last questions, a related and potentially promising structural view of literacy is represented by the idea of community literacy. Community literacy refers to how the shared literacy in a social network or community is greater than the aggregate literacy of each person in the network taken into account individually (1). This phenomenon has consequences and great potential for how we think about achieving greater science literacy. Is greater literacy for individuals the sole goal, or should we think of community science literacy as well?

The combined literacy of the community can go beyond what the aggregated literacy of the individuals in the community would be because of the properties and knowledge that emerge from the interactions in the community (1). Certain community members hold more of a particular type of knowledge or the literacy skills to gain more information on a specific science topic. They then exchange and combine information with other community members in ways that create new connections, knowledge, and broader skill sets that likely could mean greater literacy across the community.

It is clear that communities have used the combined literacy of individuals in their community to overcome challenges or address concerns relevant to their specific context. This includes making decisions on environmental contaminants (58) and other local health-related or environmental concerns, such as oil and gas production (59) and flood risks (60), that impact the community as a whole.

The idea of a shared or community literacy raises interesting questions about achieving literacy for adults that need to be pondered and addressed in scholarly work. Some of these questions include:

In what ways would community literacy compensate for lower levels of literacy in individuals in the community?

What baseline level of literacy would be needed in individuals, and how would literacy skills need to be distributed?

How could community literacy overcome or still be hindered by digital divides?

Then, given how we answer the questions above, in what cases is it more realistic to aim for community literacy, rather than targeting individuals? What would that mean or look like in terms of methods for increasing science literacy?

In short, these questions could be summed up the following way: To what extent do individuals need to be science literate themselves, and to what extent could they instead combine forces with their friends, neighbors, and influencers in their community?

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*An idea inspired by the work of producer Adnaan Wasey, who is experimenting with incorporating science literacy information in fictional entertainment on television.

What Does Success Look Like? We have put forth that science literacy is best seen as skill-building that can help people navigate diverse science-related issues across the science information lifecycle to avoid misinformation and make informed decisions at the individual and collective level. To better understand what outcomes such literacy could bring, we now return to the question we posed in the title of our piece: (Mis)informed about what? We focus on how the science literacy we describe could help alleviate some of the different ways people could be misinformed about science issues.

Beyond misinformation, we then describe some of the limits and promise for decision-making involving science issues more broadly that our approach may produce. In particular, and perhaps counterintuitively, greater science literacy (as proposed here) could likely make people both more skeptical and more supportive of science.

(Mis)informed about what? Better understanding the potential and bounds of science. People spread misinformation for many reasons, but the science literacy that we have outlined assumes that at least some of the cross-cutting reasons for misinformation spread are because people are misinformed or uninformed broadly on how science works. Interestingly, many misinformation examples put forward by scientists seem to involve overestimating the power of science, whether by misunderstanding the power of one scientific study or set of studies, or misunderstanding the ability of science in general to answer our most pressing questions.

Misinformed about what answer a scientific study, or selection of studies, answers. As we see with controversies over vaccinations or genetically modified organisms, often a single, retracted study is held up as evidence of links between these technologies and autism or cancer, respectively (61, 62). Some of the skills civic science literacy includes could be particularly useful for better assessing such information, such as how norms and practices in science and scientific institutions shape what a single study stands for and what it means when a study is retracted.

More broadly, civic science literacy skills could mean people can better discern when (mis)information portrays science information as more (un)certain than it actually is or cherry-picks information. Digital media science literacy will be an important dimension here as well, for helping people navigate how and why different media sources portray (mis)information in different ways and find additional information to gain an informed understanding of the issue. The dimension of cognitive science literacy will then be key for people to recognize when they might be cherry-picking or overgeneralizing the results of specific science studies, as well.

Misinformed about how (quickly) science answers questions. In many cases, however, misinformation also arises where there is not yet a clear right answer for a scientific question. People in these cases seem to misunderstand both what makes a piece of information scientific and the ability of science to quickly answer scientific questions. The COVID-19 pandemic is a case in point, when misinformation about what could treat the virus abounded in 2020 and scientific information did not yet exist for answering many questions. In such instances, people might be misinformed partly because there is no good existing scientific information that answers their specific concerns: Fast-produced science information or outright made-up misinformation that provides a seemingly credible answer and that might be discounted later on as not valid fills the void (63).

Here, literacy as understanding what makes something scientific and nonscientific, including what value that has for broader society, becomes particularly important. For example, science moves relatively slowly in finding answers, and it updates and changes its answers over time because it is trying to find better, less biased, more accurate answers. Science literacy could help people better understand why complex uncertainty exists in science and what scientists do to better address that uncertainty. In addition to helping people identify misinformation, such literacy skills could perhaps also make misinformation providing false, short-lived certainty less appealing.

Misinformed about what science can answer. Finally, in many cases misinformation arises from conflict between diverse, relevant, value-laden viewpoints and concerns tied to a science issue that go beyond questions that science alone can answer. In climate change, for example, these include: What are the respective roles of government and markets in shaping energy use? In vaccinations, what are the rights of parents in their children's health care, and what do we do when those rights run into other's rights and broader public health concerns? Who will benefit from artificial intelligence technologies, who will not, and who gets to decide that distribution of risks and benefits?

Here as well, science literacy as we have outlined would be especially valuable. People are often misinformed in these issues because the misinformation aligns with their values and goals. Being informed in such science issues, therefore, will especially depend on cognitive literacy to check when our own preexisting thoughts and feelings shape how we perceive these issues based on related values. Otherwise, more information gathering can just mean more polarization.

But individuals and broader public discourse on these issues also are often misinformed or misrepresent what problems science can solve in such cases. Disagreements about broader normative goals end up sidelined into unproductive disagreements about a particular scientific fact. In other words, we fall into the "evidence trap" (64). People try to amass more science (mis)information rather than debating the value-based considerations involved. We end up with more confusion and make effective, informed decision-making even more difficult and unlikely.

Being informed, therefore, will also require civic science literacy and digital media science literacies to assess what claims different actors make and separate to some degree more value-based claims from the particular scientific evidence people use to support them. Together, these dimensions of science literacy could mean we are all better at assessing the situations for which science is particularly helpful, and those for which science cannot answer, or fully answer, the question at hand.

The limits (and dangers?) of science literacy: Continued disagreement and increased skepticism. However, while science literacy will likely be vital for reducing the impact of misinformation, science literacy cannot be the magic wand that reduces all of our societal disagreements and confusion about science issues. Important for guiding any measure of success in any of the areas we describe above is having a realistic picture of what science literacy could do, for better and worse and, as importantly, what it cannot or likely should not do.

As the persistence of the knowledge-deficit model thinking illustrates, it is often tempting to hope—especially when faced with people who disagree with us—that science literacy will lead to support for a particular normative claim or societal path. This is not only unrealistic but not democratically or practically desirable. There will always be uncertainties in science and society that we have to navigate, and science will likely continue to become more complex and with high stakes for society. As scientific processes themselves illustrate, disagreement, paired with collaboration, is necessary to advancement. Even among the highly science literate and strong supporters of science, one could expect reasonable and valuable disagreements about how public funds should be used (e.g., space exploration versus medical research) and about how to continue improving scientific institutions.

It is also possible, however, that higher science literacy could create new negative outcomes and challenges, at least in the intermediate term, especially by creating greater skepticism. Across the different literatures, especially on digital and media literacy, interesting patterns emerge. Digital literacy research tends to focus on empowerment and equity: How to ensure that digital technologies and opportunities do not just further inequities in economic and social opportunities (e.g., refs. 15 and 51). Media literacy, meanwhile, tends to focus on increasing skepticism, usually of advertisements, but also of media overall (e.g., refs. 16 and 53). Science literacy, however, usually hasn't explicitly focused on equity or skepticism. Instead, it tends to approach science literacy as a way to reduce controversies related to science and increase support for science.

In reality, though, if science literacy as we have defined it here is accomplished, the abilities to access and interpret science-related information will necessarily mean greater equity and, very likely, greater skepticism, including of claims and processes within science. Literacy is inherently democratic in that individuals can use it to equip themselves with information and empower themselves to act on that information. That means that greater science literacy should include greater ability to use, shape, and criticize certain aspects of how we produce and use science. It will mean greater critical thinkers, in the long-term, which could also mean we have more disagreements going forward. We already mentioned that we think some level of this disagreement is democratically and practically necessary. But it is also why democracy—and science for that matter—is often slow to reach conclusions.

In the intermediate term, however, a potentially dangerous effect of increasing science literacy could be an increased skepticism leading to greater relativism. Research on epistemic beliefs—or what people believe about the nature of knowledge—describes how our beliefs about knowledge go through stages as they change through education and experience. We tend to start with absolutist beliefs (e.g., truth is universal and easily known), then advance to relativist beliefs (e.g., more chaotic absolutism in which everything is relative; we cannot really know anything), and finally to the "sophisticated beliefs." Sophisticated beliefs assume that there is a reality that we all share and can know and that we should interpret information and knowledge by the context and processes in which and from which it appears (65–67).

Science literacy would ideally mean reaching more sophisticated beliefs about the nature of scientific knowledge. But that means it is very possible that developing greater levels of science literacy could require that at some point people are in the relativism stage. We see this anecdotally in statements like, "you can't trust anything you see in media," from people as they start to become aware of biases in media production. We also see evidence of this in misinformation research, as well. People who receive a reminder to be on guard against misinformation do become less trusting of misinformation, but in part because they become less trusting of all, including true, information (68).

Some interesting questions for research, then, are the following: 1) To what extent does a better understanding of the processes of science make people more skeptical of misinformation and/or information more broadly? and 2) Is there a particular level of science literacy necessary to overcome this relativism stage, or other negative effects of greater literacy?

Science literacy could still mean greater support for science. Ultimately, however, greater science literacy as we have outlined in this article could still end up furthering the original goal of science literacy, generating support for science. By support for science, it is important to note that we mean epistemic support, seeing science as a legitimate form of understanding the world (at least as an ideal, even if not perfect in practice). This kind of support aligns with the concepts of "belief in the authority science" and the "cultural authority of science." These refer to how individuals and cultures grant authority to science as a distinct and valuable way of collecting knowledge (69, 70). Understanding and believing in the value of what scientific processes, and therefore scientific information, can offer us in particular decision-making contexts could mean that people value and defer to science in situations in which science can offer useful answers (70, 71).

Understanding the limitations of science in decision-making is important for maintaining broad support as well. Deferring to science in decision-making can also become akin to authoritarianism if it misunderstands the extent of what science can tell us in societal decision-making: For example, by thinking that a particular scientific fact makes it a given that we will take a particular action in society (70, 72). We described how this misunderstanding can make misinformation pop up. Overclaims of what science can offer could also reduce trust in the value of science and hinder our ability to discuss across diverse viewpoints. It could spur counter reactions in which people rightfully, even if not explicitly, recognize that science does not have the answer to their concerns.

It remains an open question, however, how and if science literacy as we have outlined it helps people better navigate issues that are not only scientifically but also ethically and socially complex, and what that means for their views of the issues and of science more broadly.

Science Literacy Won't Be a Panacea, but It Is Vital for Today's World. Our goal in putting forward these and other promising avenues for research on science literacy is to generate ideas and to spur future conversations, collaborations, and experimentation. We need to expand our conceptions of what it means to be science literate in today's environments of complex science, social issues, and information networks. The stakes for decision-making are high, and the potential benefits of science literacy to help us do so are as well. It is crucial to think of science-literate citizens (and perhaps of science-literate communities) in ways that account for the realities of our modern, digital world, across the lifespan of scientific information as people access and act on it. This will only be possible if we address civic science literacy, digital media science literacy, and cognitive science literacy.

At the least, science literacy as captured through these three overlapping dimensions should mean that more people are able to access information they need, avoid misinformation, and better contribute to informed discourse and decision-making involving science. It could mean that individuals and communities are better able to identify and make explicit the logic in their own and others' thinking. It could also likely increase trust in or support for science, while also likely meaning being better able to identify—and therefore possibly fix—the weaknesses in how we do or use science. It might mean we are all better able to understand nuance and communicate with each other as we decide how to move forward in science and society.

In short, there is ample opportunity for expanding our understanding of what it means to be science literate today. Being able to navigate scientific processes, science issues as they interact with broader society, how we all receive mediated information, and how we form opinions on that information are all crucial for that literacy. There are reasons to hope that gaining these skills in society means we will then be better able navigate complexity in science and society and be clearer about what our goals are and on what rationale we base them. That would be no small success. Given the range of complex, dynamic issues and divisions we face today, there is also profound urgency in helping people develop the skills science literacy encompasses. Only then will science be able to help build a better, more just society.

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