Can science literacy help individuals identify misinformation in everyday life?

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Abstract

Certain science-related topics elicit persistent public controversy, such as routine childhood vaccinations and anthropogenic climate change. Many people are misinformed about the scientific facts underlying these issues. In response, science educators have called for improvements in the public's science literacy, but it is not clear which components of science literacy would help individuals identify misinformation. In this position paper, we examine this issue and make two arguments. Firstly, we unpack the construct of science literacy to the seven components identified by the National Academies, and argue that four of these components are most likely to help individuals identify misinformation in everyday life: (1) Understanding of scientific practices; (2) Identifying and judging appropriate scientific expertise, (3) Epistemic knowledge, and (4) Dispositions and habits of mind, e.g., inquisitiveness and open-mindedness. We also show that three of these four components are not commonly used in definitions of science literacy. Secondly, we posit that two opposite reasons explain why misinformation is so intractable: on the one hand, that individuals uncritically accept most information, even if it is false, and on the other hand, that they reject information that contradicts their worldview, even if it is true. Consequently, we argue that inculcating intellectual virtues, such as open-mindedness, should be central to imparting science literacy, and propose some implications for educational practice. Lastly, we point out some limitations of our arguments and offer recommendations for further research.

Can science literacy help individuals identify misinformation in everyday life?

Individuals and groups need to make decisions in everyday life that involve scientific knowledge. For example, some parents may be unsure whether vaccines are safe and effective for their child, a small town mayor may face demands by members of her constituency to stop the fluoridation of local drinking water, and voters may be called upon to vote on issues related to the role of human activity in climate change.

For decades, ever since the term "science literacy" (or "scientific literacy"; hereafter SL) was coined in 1958, science education scholars have been discussing what people need to know and be able to do in order to make such everyday decisions, both on the personal and social levels (National Academies of Sciences Engineering and Medicine, 2016). Despite efforts to promote SL through science education, concerns about the usefulness of science education in everyday contexts persist. For example, based on a substantial body of research, Aikenhead (2006) concluded that "most students tend not to learn science content meaningfully (i.e., they do not integrate it into their everyday thinking)" (p. 27). Similarly, a review of the literature by Weeth Feinstein, Allen and Jenkins (2013) asserts that aside for small and confined increases in conceptual knowledge, it is not clear whether long-standing efforts to impart SL have enhanced people's ability to make sense of science in daily life.

Recent debates have continued to focus on the issue of reasoning with and about scientific evidence across disciplines and contexts. Some lingering questions are: Can educators help students reconcile scientific ways of understanding an issue with other ways of understanding phenomena? If so, how? In this journal, Osborne (2019) points out that common-sense ideas often fail to explain canonical phenomena such as the sphericality of the Earth, heliocentrism, and floatation, and asserts that science educators should therefore "introduce students to the unfamiliar, and to the strange and novel ways that science offers of understanding the material world" (p. 1281-1282), so that they ultimately "build an understanding of […] the consensually agreed scientific explanation" (p. 1282).

In response, Hammer and Manz (2019) write that everyday thinking about the natural world is dynamic and contextual, and a great deal of it *does* align with canonical science. They point out that "intellectual progress often involves drawing connections across different aspects of knowledge and experience" (p. 1290). They also contend that students should emulate scientists' practices to monitor the intelligibility, plausibility, and fruitfulness of scientific explanations, and seek coherence across contexts of experience. These criteria mesh well with criteria for explanations previously suggested by other scholars, including empirical accuracy, scope, consistency, simplicity, and the precision of predictions (Brewer, Chinn, & Samarapungavan, 1998).

In the context of this discussion, we have a somewhat different focus. While Osborne, Hammer and Manz discuss these issues in the context of canonical science, we are more interested in socio-scientific issues, and especially those involving risk, such as vaccination, climate change and water fluoridation. It has been claimed that vaccines contain "toxins" and cause autism; that water fluoridation causes cancer; and that climate change is a hoax. Assessing the intelligibility, plausibility, and fruitfulness of such instances of "science denial" (Darner, 2019) is different than assessing claims about heliocentrism and floatation. It necessarily involves "acknowledging and dealing with the uncertainties of scientific knowledge" and engaging with "the power and limitations of science in social contexts" (Christensen, 2009, p. 207).

Of course, there is always a chance that denialist claims might turn out to be true, since scientific findings are always provisional. But, in the words of sociologist Harry Collins, "we cannot live by skepticism alone" (Collins, 2009, p. 30), as skepticism offers very little practical guidance for decision-making in real-life situations. Like Collins, we are concerned about the possibility that for too many people, in too many contexts, "[t]he founding myth of the individual scientist using evidence to stand against the power of church or state [...] has been replaced with a model in which Machiavellian scientists engage in artful collaboration with the powerful" (p. 31).

The climate change dispute in the U.S. and other developed countries serves as a useful example of the effects of science denial in the public sphere. Between 90 and 100 percent of all climate scientists agree that there is a 95-100% probability that the Earth is warming due to human influence, and evidence supporting this claim is available in the public domain (IPCC, 2013). (IPCC Assessment Reports that synthesize knowledge on climate change are published once every 5-6 years, with the next installment due in April 2021.) However, persistent political campaigns supported by the fossil fuels industry have made climate change a contentious issue in the U.S. and elsewhere (McCright & Dunlap, 2003; Michaels, 2020). While 70% of U.S. adults believe that global warming is happening (for natural or anthropogenic reasons), 14% disagree (Leiserowitz et al., 2018). Similarly, only 65% of U.S. adults believe that scientists have formed a consensus on global warming (Dunlap, McCright, & Yarosh, 2016). In France, Germany, Norway and the UK, only 54-64% of adults believe that over 50% of scientists agree on this topic (Steentjes et al., 2017). No longer on the political fringes, climate change denial is now a view held by high-ranking U.S. politicians and government officials. This has resulted in policy changes including cutting over seventy percent of the U.S. Department of Energy's funding for clean energy research, as well as cancelling satellite missions designed to measure atmospheric carbon dioxide and other factors that affect the Earth's climate (Burdick, 2018).

In response to recent political developments, the science education community has paid increased attention to SL. For example, SL was the topic of the NARST 2018 Annual International Conference entitled "Re-Centering on Scientific Literacy in an Era of Science Mistrust and Misunderstanding." Across the Atlantic, Costas Constantinou, former president of ESERA, argued that a lack of SL explained the U.S. withdrawal from the Paris Agreement in his speech at the ESERA 2017 conference in Dublin, Ireland. Additionally, at least three recent frameworks of SL have referred to the problem of misinformation: A consensus report on SL by the National Academies of Sciences, Engineering and Medicine (2016; hereafter the "National Academies report"); The U.S. *Framework for K-12 Science Education* (National Research Council, 2012; hereafter the "NRC framework"); and the PISA 2015 Science Framework (OECD, 2016). The National Academies report provides a review of the literature on SL and makes recommendations for the improvement of public understanding of science in the U.S.; The NRC Framework is a U.S. document that "articulates a broad set of expectations for students in science" (National Research Council, 2012, p. 1) which serves as the basis for the Next Generation Science Standards; and the PISA 2015 Science Framework is a "basis of the instrument to assess scientific literacy" used in the 2015 version of the Programme for International Student Assessment study (OECD, 2016, p. 2).

By and large, all three documents envision students as future citizens who are "critical consumers of scientific and technological information related to their everyday lives" (National Research Council, 2012, p. 9); expect them to have "[t]he knowledge and ability to detect 'bad science'" (National Research Council, 2012, p. 71); and to develop a "skeptical attitude towards all media reports in science" (OECD, 2016, p. 25) (Table 1).

(Insert Table 1 here)

At first glance, promoting SL makes intuitive sense as a remedy to the challenge of misinformation. However, upon reflection, one finds that SL is not a straightforward concept that can be readily used for designing curriculum, instruction and assessment. Rather, it is a construct that is made up of different components, and it has been argued that each of these components may become more or less important in different contexts (National Academies of Sciences Engineering and Medicine, 2016). Thus, in order to design effective curriculum and instruction, one would need to know which components of SL are most relevant in this context and why. In this article, we set out to elucidate this matter, and offer some principles for dealing with the problem of misinformation.

To be sure, misinformation is hardly the only problem in this context. Open debate in the public sphere invites political actors to disseminate questionably relevant information and half-truths alongside claims that are demonstrably false. For simplicity's sake, we focus this paper on helping individuals identify the latter, although many of our claims apply more broadly.

Overview of the article. This article is a position paper with two main sections.

Firstly, we unpack SL to the seven components identified in the National Academies report, and argue that four of them are most pertinent to identifying misinformation in everyday life: (1) Understanding of scientific practices, (2) Identifying and judging appropriate scientific expertise, (3) Epistemic knowledge, and (4) Dispositions and habits of mind, such as inquisitiveness and open-mindedness. We also point out that three of these four components are not commonly used in definitions of SL.

Secondly, we argue that two opposite psychological phenomena drive much of the intractability of misinformation about science-related controversies: on the one hand, default trust towards most information, even if it is false, and on the other hand, rejection of information that contradicts one's worldview, even if it is true. Consequently, we argue that intellectual virtues, such as open-mindedness, should be placed in the center of science education. We then propose ways to teach intellectual virtues explicitly in science classrooms, based on existing scholarship from science education and other relevant fields.

Lastly, we point out some limitations of our argument, and offer recommendations for further research.

Argument #1: The components of SL most pertinent to identifying misinformation in everyday life are mostly overlooked in the SL literature

Identifying misinformation as a matter of trust. One of the most basic challenges in identifying misinformation is that it can pertain so many different specialized domains of scientific knowledge: for example, in the case of vaccines, these would include epidemiology and immunology, as well as the mathematical modeling of disease. In the case of climate change, these would include climatology and other earth sciences. As Norris (1995) maintained, the body of scientific knowledge is complex and specialized, and this limits the scientific knowledge and understanding that can realistically be expected from any individual.

In fact, even individual scientists need a great deal of knowledge to evaluate scientific claims within a domain, as Chinn and Golan Duncan (2018) maintain, based on historical, philosophical, psychological and sociological studies of scientists. These scholars posit that this task requires (1) knowledge of theories, concepts and principles; (2) knowledge of a large body of empirical findings; (3) knowledge of research methods specific to a domain or a topic, such as scientific apparatuses and statistical methods; and (4) knowledge of the history and sociology of the field, to assess whether someone is a trustworthy expert in that field.

Moreover, scientific knowledge is constantly growing and changing. This is the reason even scientific experts depend on the knowledge of their peers to conduct their research, especially in interdisciplinary research, but even within a single discipline, such as mathematics. Hence, *a fortiori*, a "cognitive division of labor" is needed between scientists and publics as well (Hendriks, Kienhues, & Bromme, 2016).

Thus, identifying misinformation is often a matter of trust. For reliable knowledge about vaccines, parents should turn to pediatricians, and health authorities should turn to medical specialists like immunologists and epidemiologists; to read reliable knowledge about climate change, one should turn to reports written by climatologists; and if French farmers working in a field near CERN's Large Hadron Collider hear misinformation that it could form a black hole, they should rely on the testimonies of particle physicists and safety experts to evaluate that claim, since they have little relevant content knowledge to be able to gauge this risk on their own (Baram-Tsabari & Osborne, 2015).

Science literate individuals as competent outsiders. One useful theoretical concept, deriving from a similar line of reasoning, defines science literate individuals as "competent outsiders" (Feinstein, 2011). These are individuals who can, firstly, recognize when science is relevant to their needs and interests, and secondly, adaptively "interact with sources of scientific expertise in ways that help them achieve their own goals," or to "enrich their understanding of their own lives" (p. 180) by connecting scientific information with their own lived experience. Weeth Feinstein used the word "outsiders" to signify that these individuals remain situated within their existing social contexts. For example:

> A rural resident worried about pesticide contamination must learn to express his concerns in questions that science can answer: What pesticides, at what doses, are most

> harmful? Are there reliable tests for pesticides in my children’s air or water? These questions lead to answers that must then be translated back into local reality: Who will help me test my water? What can I do to mitigate the risks? The decision-making process incorporates both scientific and nonscientific information. (Weeth Feinstein et al., 2013, p. 315)

Competent outsiders, Weeth Feinstein maintained, can "[start] on the outside of a problem, without much background […] plunge into the deep water of conflicting expertise and emerge with something resembling an answer" (Feinstein, 2011, p. 182). In sum, according to this argument, if we wish to prepare students to reasoning with and about scientific evidence in everyday life, we must teach them how to depend on scientific expertise.

Problems with dependence on scientific experts as a learning goal. Before we discuss the implications of this argument to SL, we wish to qualify the promotion of depending on scientific experts as a learning goal by pointing out five problems with it. The first problem is normative. As Hendriks at al. (2016) put it succinctly, "there is some tension between trust and the core idea that Science is a means for freeing people from only relying on authorities to understand the world" (p. 151), such as clergy or government officials. Similarly, Norris (1997) suggested that science educators promote an ideal that is "somewhere between [two] unacceptable extremes" of believing whatever scientific experts say and believing nothing (p. 253). This middle-ground stance has been termed "epistemic trust" (Hendriks et al., 2016), "epistemic dependence" (Norris, 1995) or "intellectual dependence" (Norris, 1997).

The second problem is that laypeople need some prior knowledge to interact with sources of expertise meaningfully. Although it is not clear what qualifies as a "meaningful" interaction with expertise, it is reasonable to assume that as a person can ask more relevant questions, that person is more likely to obtain more relevant answers from their interaction with sources of scientific expertise (Tseng, 2018). For example, Ryder (2001) suggested that individuals who can ask questions about certain domain-general aspects of science such as "the spread in a data set, the distinction between correlation and causation, time horizons, the assumptions within a model, and the funding sources of scientists" are better prepared to engage with science in everyday life (p. 37).

The third problem is a lack of consensus among experts. This widespread problem led sociologists of science Harry Collins and Robert Evans (2007) to formulate the "fifty year rule," which stipulates that "scientific disputes take a long time to reach consensus and thus there is not much scientific consensus about" (p. 144). They also claimed that since political decision-making usually takes place at a faster rate, science can play only a limited part in science-related decision-making on public affairs. Although consensus among scientists can emerge on timeframes shorter than fifty years, laypeople find themselves in a difficult position in the interim, unsure which side is favored by the weight of the evidence. This difficulty is often exacerbated by news media, which are prone to portray a "false balance" between opposing sides of an issue, even if one of them is based on dubious or false evidence, just to create the impression of objectivity and impartiality; this has been observed both in the context of vaccine safety and in the context of climate change (Bennett, 2016).

The fourth problem is that experts' interests might not be aligned with those of the individuals and publics who depend on them. Examples include physicians who falsely claim that there is a link between vaccines and autism (Deer, 2011). Moreover, the book *Merchants of Doubt* (Oreskes & Conway, 2010) documents several other contributions of scientists to misinformation campaigns regarding tobacco, acid rain, the ozone hole, global warming, and DDT. Additionally, a more recent account of campaigns conducted in the same vein is found in the book *The Triumph of Doubt* (Michaels, 2020), with chapters focusing on opioids, alcohol, sugar, and more. Put together, these books show us how time after time, "experts for hire" helped thwart regulatory actions that were proposed on behalf of human health and environmental protection. This unfortunate track record lends credence to the belief that indeed, sometimes "Machiavellian scientists engage in artful collaboration with the powerful" (Collins, 2009, p. 31).

The fifth problem pertains scientists' responsibility to earn trust from publics on a more sociological level. An instructive case study of this is Brian Wynne’s research on the interactions between scientists, government officials and sheep farmers in northern England. In this case, the farmers faced a soil contamination caused by the nuclear fallout from the Chernobyl disaster in 1986, and scientists were asked to provided expert advice to protect the food supply. Unfortunately, as Wynne (1989, 1992) shows, their handling of the situation undermined their own credibility, breeding social alienation, ambivalence and mistrust. Specifically, the scientists and officials ignored the local farmers' extensive knowledge of the local environment, of sheep behaviors and of sheep farming practices, thus threatening farmers' social identities. By and large, the scientists and officials also neglected to admit errors, omissions and oversights to the farmers, as well as the limitations of their own knowledge; this attitude caused the farmers to mistrust expert advice and have contempt towards experts. In particular, Wynne (1989) singled out the U.K. Ministry of Agriculture, Fisheries and Food for criticism for its "centralized, hierarchically structured and geographically and culturally remote" communication of scientific expertise, which proved to be a poor fit for the task at hand (p. 38). Thus, to build on Wynne's argument, if scientists (or the institutions that employ them) behave in ways that come across as untrustworthy in a certain context, it is difficult to blame laypeople for mistrusting their knowledge in that context. This argument is also supported by survey data, which point to high variation of trust in scientists depending on the scientists' employers and on the topic under discussion (Krause, Brossard, Scheufele, Xenos, & Franke, in press).

First-hand and second-hand evaluation. Scholars have offered a strategy to cope with the problems of reliance on expertise: to consider both "what is said" (a "first-hand" evaluation of the scientific claims) and "who said it" (a "second-hand" evaluation of the trustworthiness of the source) (Bromme & Goldman, 2014; Hendriks et al., 2016). For example, for the first-hand evaluation, Scharrer and colleagues suggested that laypeople make some basic assessment of information "for its logical coherence and its consistency with their own prior knowledge" (Scharrer, Rupieper, Stadtler, & Bromme, 2017, p. 1005). However, the authors added that laypeople should be sure to do so with caution, especially if that prior knowledge is limited – thus, a rudimentary first-hand evaluation can only supplement, but not replace, deference to experts (second-hand evaluation).

The "Grasp of Evidence" framework proposed by Ravit Golan Duncan, Clark A. Chinn and Sarit Barzilai offers a similar approach for preparing students for reasoning with "the complex, varied, and contentious evidence encountered in popular media or in advanced education" (Golan Duncan, Chinn, & Barzilai, 2018, p. 907). On the one hand, it promotes lay reasoning as a "competent outsider," by "figuring out […] what is the scientific community's stance about the issue of interest, whether there is consensus about it or not" and other criteria that assist second-hand evaluation of evidence (p. 928); and on the other hand, it advocates fostering students' appreciation of "how and why scientists are able to produce reliable knowledge" in the first place (p. 910). The framework proposes doing so by promoting an understanding of "how scientific evidence is generated and used in the scientific community," by having students work with evidence "in much the same ways as scientists do" (p. 928), that is, by conducting first-hand evaluations of evidence.

These two aspects are represented in the framework by five evidentiary practices: one represents laypeople's use of evidence, and the other four represent experts' practices when using evidence: analysis, evaluation, interpretation and integration. The framework identifies these practices based on studies of science scholarship in philosophy, history, anthropology, sociology, psychology, and education. It also defines epistemic components that are entailed within each practice based on the AIR model of epistemic cognition (Barzilai & Chinn, 2017).

Using the Grasp of Evidence framework to analyze conceptualizations of SL. Let us now examine the components of SL based on the National Academies' report (2016); For reference, we will also show the equivalent components from the NRC Framework (National Research Council, 2012) and the PISA 2015 Science Framework (OECD, 2016) as two other examples of recent SL literature (Table 2). The National Academies' report (2016) asserts that "there is no clear consensus about which aspects of science literacy are most salient or important" and that "different aspects may be more or less important depending on the context" (p. 2). Based on this assertion, we argue that certain components of SL are more likely to help individuals identify misinformation in everyday life, and that these are mostly overlooked in the SL literature. We will analyze these components using the Grasp of Evidence framework to establish this claim. We chose this framework because it is recent and up-to-date with current educational theory, it integrates the notion of science literate individuals as "competent outsiders," and it is based on a diverse theoretical base, drawing upon "science scholarship in philosophy, history, anthropology, sociology, psychology, and education" (Golan Duncan et al., 2018, p. 914). The analysis will be based on two criteria derived from Grasp of Evidence framework: Firstly, does the component directly relate to laypeople's evidentiary practices?

Secondly, does it directly relate to experts' evidentiary practices? If a component of SL satisfies at least one of these criteria, we deem it relevant to identifying misinformation in everyday life.

(Insert Table 2 here)

The National Academies' components of SL. Based on a review of the literature, the National Academies' report lists seven commonly hypothesized components of SL. All of these are restricted to the *individual* level, rather than the levels of communities and societies. The components are:

(1) foundational literacies, such as numeracy and textual literacy;

(2) content knowledge, such as scientific terms, concepts, and facts;

(3) understanding of scientific practices, such as collecting and analyzing data, interpreting scientific findings, and procedures such as double-blind trials, controlling variables, and peer review;

(4) identifying and judging appropriate scientific expertise;

(5) epistemic knowledge; i.e., understanding how scientific claims are supported by scientific procedures, "why uncertainty is an inherent aspect of science, how […] peer review sustains objectivity, how to recognize the boundaries of science and scientific knowledge, and the ways in which scientific knowledge is constructed by a community over time" (p. 33);

(6) cultural understanding of science; i.e., acknowledging "the interrelationships of science and society," understanding "the tremendous epistemic achievements of science" and appreciating "the beauty and wonder of science and the contributions of science to society" (p. 33);

(7) dispositions and habits of mind, such as inquisitiveness and open-mindedness, which "shape how people engage with science in a wide range of circumstances and may be necessary preconditions for the use of other sorts of skills and knowledge" (p. 33).

According to the National Academies' committee, three of these seven components are "common to most applications" of the term SL (p. 2); namely, content knowledge, understanding of scientific practices and cultural understanding of science. The other four are "less common" in the literature but "provide some insight into how the term has been used" (p. 2). The three common components are labeled with stars in the first column of Table 2.

Similarities with the NRC Framework and the PISA 2015 Science Framework. Additionally, it is worth noting some points of similarity between the National Academies' components with the two documents mentioned earlier: the NRC Framework and the PISA 2015 Science Framework (see corresponding columns in Table 2). The comparison with these documents helps understand how conceptualizations of SL guide curriculum amd assessment. The SL components that the NRC Framework and the PISA 2015 Science Framework share in common with the National Academies' report are: (2) content knowledge, at two levels of abstraction ("cross-cutting concepts," e.g., "cause and effect" and "structure and function", and "disciplinary core ideas," e.g., "all living things are made up of cells"); and (3) scientific and engineering practices, such as planning and carrying out investigations and analyzing and interpreting data. A third SL component, shared with the PISA 2015 Science Framework, is epistemic knowledge, which PISA 2015 defines as understanding "the constructs and defining features of science," such as observations, facts, hypotheses, models and theories, and "the role of these constructs and features in justifying the knowledge produced by science" (OECD, 2016, pp. 27-28). The comparison reveals that the common components across the three documents include both content knowledge (component 2) and "knowledge about science" in the form of procedural and epistemic knowledge (components 3 and 5), suggesting that the authors of these documents wished to promote a systematic introduction to the scientific enterprise both in terms of its products and in terms of its processes.

Let us now examine which of these seven components can help individuals identify misinformation in everyday life.

Components Relevant to Identifying Misinformation in Everyday Life. We claim that components 3, 4, 5 and seven in the NRC Framework can help laypeople identify misinformation in everyday life, by helping them interact with sources of scientific expertise, per the Grasp of Evidence framework. We firstly discuss components 3 and 5, which relate to "first-hand evaluation" of scientific evidence by experts, and then component 4, which relates to "second-hand evaluation" of evidence by laypeople. Finally, we discuss component 7 and relate it to both first-hand and second-hand evaluation.

Understanding of scientific practices. The third component, "understanding of scientific practices," corresponds with experts' evidentiary practices such as analyzing and evaluating evidence. Experts must understand "how and why data were generated, how the data are represented, and how they fit together" (Golan Duncan et al., 2018, p. 917), and also "critically examine the quality, reliability and validity of [the] evidence" (p. 918); In turn, teaching this component of SL this should help students appreciate that scientific misinformation may derive from poor *quality* of evidence (in terms of reliability and validity). Laypeople who are familiar with this component of SL are able to apply this in two ways. Firstly, they can apply standards of evidence quality in their first-hand evaluation of knowledge-claims. Secondly in time of need, they are able to ask experts questions about the quality of evidence available on a topic of interest.

Epistemic knowledge. The fifth component, "epistemic knowledge," at least partly corresponds with experts' evidentiary practices of evidence interpretation and integration, such as "evaluating evidence strength" (p. 921) and discussing questions such as "what predictions each model under consideration would make, how each model can account for findings, and which evidence fits with predictions of the different models" (p. 921). Although epistemic knowledge is arguably a broader concept, here we focus on the parts of epistemic knowledge that relate directly to coordinating claims with evidence, along the lines of the PISA 2015 Science Framework (OECD, 2016), as well as to coordinating between bodies of evidence.

Teaching this component of SL should help students appreciate that scientific misinformation may derive from the poor *strength* of evidence, or from poor reasoning with bodies of evidence. As Golan Duncan et al. explain, there is a difference between evidence quality and evidence strength: strength is evaluated in terms of its connection to models or theory. Thus, even high-quality evidence "may be irrelevant to the models or theory in question," and conversely, a poorly conducted study may yield evidence of low quality that is nonetheless highly relevant to the same models or the same theory (p. 920). Laypeople who are "competent outsiders" would be able to assess some aspects of evidence strength as part of their first-hand evaluation of knowledge claims, and also ask experts about the strength of particular pieces of evidence and the state of the body of evidence.

Identifying and judging appropriate scientific expertise. The fourth component, "identifying and judging appropriate scientific expertise," corresponds with lay evidentiary practices proposed by Golan Duncan et al. (2018) and by others, e.g., Ryder (2001), such as examining experts' credentials and track records, checking reports' publication venues and their editorial policies, and gauging the degree of the scientific consensus around claims. All of these are strategies that laypeople can use for the second-hand assessment of knowledge claims, instead of, or in addition to, first-hand assessment of those claims.

Dispositions and habits of mind. Lastly, the seventh component, "dispositions and habits of mind," does not appear per se in the Grasp of Evidence framework, but it is part of a construct underlying the entire framework, namely "apt epistemic performance." This term refers to the ability "to reliably succeed, through competence, in epistemic activities such as forming accurate judgments or evaluating arguments, across a range of situations" (Barzilai & Chinn, 2017, p. 10). Both experts' evidentiary practices and laypeople's evidentiary practices presuppose some "virtuous epistemic dispositions," such as "wanting to know, endeavoring to get it right, pursuing understanding, preferring beliefs that are based on good reasons, and being intellectually careful" (p. 19). Enacting these dispositions through evidentiary practices increases the layperson's likelihood of success in identifying misinformation. For example, "preferring beliefs that are based on good reasons" (p. 19) is more effective than preferring beliefs that are comforting and reassuring.

Missing components. Three components of SL are missing from our interpretation of the Grasp of Evidence framework, due to their complex links to the topic at hand: components 1, 6 and two.

The first component, "foundational literacies," is required to assess any type of written evidence across all subject domains, including graphs and charts, and is not unique to science (National Academies of Sciences Engineering and Medicine, 2016).

As for the sixth component, a cultural understanding of science, as Feinstein (2011) and others have argued, teaching science as a cultural resource is not likely to be useful for applying scientific knowledge for practical ends. For example, appreciating that we owe our collective knowledge of the etiology of infectious diseases to scientific methods can be a source of joy and reasurance. While it can provide a general sense of trust in science and its processes, it is not directly useful for a parent trying to assess whether the Polio vaccine is safe and effective.

The second component, "content knowledge," has a complicated relationship with everyday life reasoning tasks. On the one hand, scientific content knowledge is necessary for scientific reasoning. In fact, a large body of research on scientific experts shows that their ability to solve new problems is facilitated by a coherent body of knowledge constructed around domain-specific "big ideas," such as Newton's second law of motion (in physics) or evolution (in biology) (National Research Council, 2002). Moreover, "[s]tudents who learn general scientific reasoning strategies in the context of one topic can often transfer that knowledge to reasoning about other topics, including topics in other domains" (Chinn & Golan Duncan, 2018, p. 79). Thus, for example, if individuals have a deep understanding of mathematical modeling of ecology and evolution (e.g., bacterial growth curves or predator-prey equations), then, arguably, they are able to use that understanding to evaluate claims about the spread of infectious diseases in human populations.

On the other hand, the transferability of scientific reasoning depends on the specific task a person is transferring to. Much of the existing evidence of successful transfer come from studies conducted on "toy tasks, simple tasks, and simulated tasks" which provide "friendly constraints and scaffolds that facilitate successful transfer" (Chinn & Golan Duncan, 2018, p. 91). These constraints and scaffolds include a reduction of the amount and complexity of information available, as well as cues such as "the use of terms in prompts and materials (evidence, models, argument)" that suggest which strategies or practices should be used (p. 90). Although it is not known to what extent the tasks individuals face in real life are "friendly" as opposed to unfriendly, it seems likely that there is a large variance. For example, the first-hand assessment of the claim that "the MMR vaccine causes autism" can be conducted in different ways: An investigation of a proposed biological mechanism would require in-depth, specialized knowledge of vaccines, domains relevant to the study of autism, domain-specific research methods, and more. By contrast, making sense of an epidemiological study (e.g., Hviid, Hansen, Frisch, & Melbye, 2019) is a more straightforward task, which does not require in-depth knowledge of vaccines or autism, but rather a good grasp of research methods and statistics. In turn, reading an epidemiological study is still much more demanding than reading a news article on the topic, in which most of the epistemically relevant complexity is usually stripped away. Hence, it is unclear how much scientific content knowledge helps perform first-hand assessment tasks in the wild.

Thus, we consider this issue to be a grey area. While science content knowledge must be taught in the science classroom for students to be able to identify misinformation, the transferability depends on several factors, including the degrees of content knowledge needed the degree to which the task facilitates transfer. Hence, it is difficult to predict which science content knowledge is most likely to be useful to identify misinformation in everyday life.

Summary and conclusion. To recap, we have argued here that four components of SL are most pertinent to identifying misinformation in everyday life. We wish to point out that three of these four components are not commonly used components in the SL literature. The other three components have a more complex connection to this task. Future work could focus on elucidating the role of scientific content knowledge in scientific reasoning in everyday life. Finally, we suggest that scholars in science education and other stakeholders be more precise when proposing SL as a remedy for misinformation – and specify which components of SL they refer to.

Argument #2: Intellectual virtues, such as open-mindedness, should be placed in the center of science education

In the previous section, we argued that identifying scientific misinformation requires several evidentiary practices, dispositions and habits of mind. In this section, we argue that the intractability of misinformation derives from two opposite errors outsiders make when they rely on sources of scientific expertise (National Academies' component 4). One is trusting sources of scientific information too much, to the point of accepting false or highly dubious knowledge claims. The other is rejecting sources of scientific information offhand or trusting them too little, to the point of rejecting valid knowledge claims. (This distinction is akin to Type I and Type II errors in statistical hypothesis testing. Type I errors refer to false positive inferences, which happen when a researcher concludes that there is a significant effect when in fact it occurred by chance. Conversely, Type II errors refer to false negative inferences, which happen when a researcher concludes that there is not a significant effect when it truly exists.)

We argue that dispositions and habits of mind (National Academies' component 7) – and particularly open-mindedness – should be placed in the center of science education to help learners identify misinformation in everyday life. Based on this argument and on research findings from several scholarly fields, we then propose several educational implications.

Accepting false information. As regards the problem of accepting false information, Tseng (2018) reviews several studies which collectively suggest that students tend to trust scientific information too much, such that "even high school students are likely to accept some information without evaluation and overestimate the certainty of claims in media about science" (p. 251). Her study calls attention to the need to teach students to be more vigilant towards science-related information, and to provide more opportunities for critiquing scientific knowledge claims in science classrooms (see also Henderson, MacPherson, Osborne, & Wild, 2015). Similarly, Allchin (2012) argued for teaching students to appreciate the "need to analyze claims for specific errors" (p. 916).

Rejecting true information. As for the problem of rejecting true information, Eun Ah Lee and Matthew J. Brown (2018) review several examples of studies in which students made decisions about socio-scientific issues "based primarily on non-epistemic values and either did not rely on inquiry-based learning or *cherry-picked scientific knowledge through the lens of personal, social, and cultural values*" (p. 65, emphasis added). For example, Yeung Chung Lee (2007) studied students aged 15 to 16 who participated in inquiry-based learning activities about the health effects of smoking. The activities included conducting simulations and experiments as well as conducting statistical analyses of relevant public health data. The students then participated in a discussion about a proposed smoking ban in restaurants. Unexpectedly, although the students did gain conceptual knowledge about smoking from these inquiry-based learning activities, many of them did not use the obtained evidence in their decision-making process. These students claimed that ventilation systems in restaurants effectively handled second-hand smoke, even though the inquiry-based activities provided clear evidence to the contrary.

Similarly, Sadler and Zeidler's (2005) study of college students' informal reasoning about socio-scientific aspects of genetic engineering found that whenever students employed "intuitive" reasoning, it "always preceded other reasoning patterns and was frequently the primary determinant of the decisionmaker's ultimate decision" (p. 131).

Both studies point to similar implications. Lee and Brown call for teaching students to "explore different values, epistemic and non-epistemic, embedded in socio-scientific decision-making to make informed decisions" and "to be consciously aware of their own personal, social, and cultural values" (E. A. Lee & Brown, 2018, p. 68). Sadler and Zeidler (2005) add a call for practitioners to challenge students to explore their own informal reasoning and consider the basis of their reasoning patterns.

Insights from research on public engagement with science. Why do students make decisions based on non-epistemic values and cherry-picked scientific knowledge? Studies in adults have explored these phenomena, and some of the most relevant of these come from the scholarly field of public engagement with science, rooted in a larger and older field, usually called "Science and Technology Studies," which lies at the intersection of history, sociology, philosophy, and other fields. In recent years, scholars have advanced a distinct subfield, whose outputs include publications such as the *Oxford Handbook of the Science of Science Communication* (Hall Jamieson, Kahan, & Scheufele, 2017), which focuses on the ways individuals process complex scientific information despite their limited, or "bounded," understanding of science. Key to this process is relying on mental shortcuts, or heuristics, that are characteristic of the human cognitive processing system in general (Bromme & Goldman, 2014). As Sinatra, Kienhues and Hofer (2014) succinctly put it, our cognitive processing system has a "default mode" that is difficult to overcome, that has "developed over the course of millennia to think and react quickly, to avoid threats, to value ideas from our ingroup more so than those from outgroup members, and to maintain our current conceptions if they have proved useful to us" (p. 125).

Accordingly, studies in public engagement with science have repeatedly shown that people tend to reject scientific information that threatens their positions, identities or world views, and accept information that coheres with them (Kahan, Jenkins-Smith, & Braman, 2011; Lewandowsky & Oberauer, 2016; National Academies of Sciences Engineering and Medicine, 2017). For example, when people are exposed to news reports about the risk of the Zika virus spreading to their area, their assessment of the risk depends on how the health threat was presented to them. If the Zika virus is presented as a threat because it could enter the country as a result of unlawful immigration, people are more concerned about the risk if they belong to a social group that tends to oppose unlawful immigration. By contrast, if the Zika virus is presented as a threat that could spread to their area because of climate change, people are more concerned about the risk if they belong to a social group that tends to be worried about climate change (Kahan, Jamieson, Landrum, & Winneg, 2017). The social groups that determine these perceptions of controversial issues are defined by values and cultural world views. Some of these world views are based on constructs such as "hierarchy" versus "egalitarianism," or "individualism" versus "communitarianism," and are measured using a battery of questionnaire items.

This biased interpretation of scientific evidence is called "motivated reasoning," and is considered to be the human tendency to selectively "seek, evaluate, evaluate, and recall information" that supports prior beliefs and commitments (Drummond & Fischhoff, 2017, p. 2). Evidence suggests that it derives from automatic, uncontrolled processes in the human mind, and it requires conscious effort to override their later effects on opinion formation (Kraft, Lodge, & Taber, 2015).

Alarmingly, motivated reasoning seems to affect the second-hand assessment of claims in several ways. For example, one study found that egalitarian- and communitarian-leaning participants found fictional experts' opinions on global warming more trustworthy if they argued for a high risk of global warming, whereas the hierarchical- and individualist-leaning participants found the experts arguing for a low risk more trustworthy (Kahan et al., 2011). A similar pattern emerges with the second-hand assessment of scientific consensus. When presented with evidence supporting a high risk of global warming, people who have egalitarian and communitarian world views are more likely to believe that there is a scientific consensus about anthropogenic global warming, whereas people having hierarchical and individualist world views are more likely to believe that the scientific community is divided on this issue (Kahan et al., 2011).

Ironically, recent findings suggest that educational attainment seems to exacerbate the problem rather than mitigate it as regards certain ideologically driven science-related issues, such as climate change and human evolution. When plotting the opinions of different social group members towards certain science-related issues on a graph against general educational attainment, educational attainment in science, or achievement on a science knowledge test, a "funnel pattern" emerges. As the values of these three variables increase (on the horizontal axis), the opinion gap between opposing groups widens (on the vertical axis), creating a funnel shape (Drummond & Fischhoff, 2017).

Anthropogenic climate change again serves as a useful example of this phenomenon. Kahan et al. (2012) found that science knowledge and numeracy (the ability to comprehend and use quantitative information) affected the perceived risk of climate change in ways that depended on participants' cultural world views. Among U.S. adults with egalitarian, communitarian world views, concern with climate change risk *increased* with scientific knowledge and numeracy ($r = 0.08$, $p = 0.03$). However, among U.S. adults who subscribe to an individualistic, hierarchical world view, concern *decreased* with scientific knowledge and numeracy ($r = -0.12$, $p = 0.03$) (Kahan et al., 2012).

In other words, in certain controversial contexts, as educational attainment increases, so does political polarization. This evidence suggests that education does not bring individuals with opposing worldviews closer to a common understanding of scientific issues, but rather drives them farther apart.

According to Drummond and Fischhoff (2017), the "funnel effect" can be explained in three different ways. The first explanation stems from motivated reasoning and maintains that better-educated people are also more skillful at evaluating, interpreting, and recalling information in ways that support their pre-existing positions. The second suggests that those who are more educated may tend to be more aware of how a certain topic is perceived in the political and religious groups they belong to. The third is related to over-confidence and considers that people who are more educated are more confident in their assessments on science-related issues. Using Norris' (1997) terminology, according to the third explanation, better-educated people are more likely to exercise their intellectual independence – sometimes while overestimating their knowledge and understanding of the issue at hand. This is also known as the "Dunning-Kruger effect," named after the authors of a study which found that people who do relatively poorly on tests of humor, logic and grammar also overestimate their abilities in those areas (Kruger & Dunning, 1999).

This body of evidence shows that individuals are predisposed to believe misinformation that aligns with their pre-existing values and to trust sources of expertise that align with those values as well. Conversely, when they encounter evidence that contradicts with their values, they tend to discount it. Alarmingly, this style of motivated reasoning increases with educational attainment and with science knowledge and numeracy, and it recurs across several contexts.

Taken together, these findings should give pause to the science education community. It is possible that current educational practices promote an overly strong version of intellectual independence, and that this inadvertently predisposes people to believe misinformation, so long as it is congruent with their pre-existing worldviews. This evidence should be taken into consideration when preparing students to be "competent outsiders" with respect to science.

Laypeople need to be open-minded to identify scientific misinformation as competent outsiders. This disposition, or intellectual virtue, appears as part of National Academies' component 7; Similar claims have been made in Harry Collins' promotion of elective modernism (Collins, 2009; Collins, Weinel, & Evans, 2010) and Jacob Bronowski's works advocating values as central to scientific activities (Bronowski, 1965). Thus, if we wish to impart SL, it is time for virtues, such as open-mindedness, to take center stage. If we want students to become "competent outsiders," intellectual virtues should be taught explicitly in science classrooms.

Implications for Science Education

These findings call our attention to the ways we can learn to "live with scientific expertise" (Norris, 1995): How can we teach students to seek out expert testimony and rely upon it, while maintaining skepticism as appropriate? Conversely, how can we teach students to be open to evidence that may oppose their worldviews, but not be overly credulous? The tension between these dispositions can be traced back to *Project 2061* of American Association for the Advancement of Science (AAAS) (Rutherford & Ahlgren, 1990), which called for a developing a "healthy balance […] between openness and skepticism" (p. 186).

No doubt promoting such dispositions and habits of mind in the science classroom, and balancing between them, is easier said than done. Here we propose an approach that, hopefully, can help guide research and development to this end. A reliable process for identifying misinformation as "competent outsiders" would avoid two opposite extremes: On the one hand, it would avoid excessive deference to scientific expertise, but on the other hand, it would also avoid excessive vigilance towards those sources, especially if that excessive vigilance is driven by motivated reasoning. This should be emphasized in SL instruction to all students, including those who advance to higher educational attainment levels, who seem to be more predisposed to motivated reasoning.

The literature uses different terms for this stance, including the term "epistemic distance" mentioned above (Norris, 1997), as well as "open-mindedness" (Taylor, 2016). We find the term "open-mindedness" more appropriate and useful, especially as conceptualized by Taylor (2016) and Battaly (2016). Taylor (2016) defined open-mindedness as a "virtue that is a[n Aristotelian] mean between the opposing vices of closed-mindedness and credulity" (p. 609). Similarly, Battaly (2016) argued that open-mindedness is a "mean between the vices of dogmatism and naïveté," and that an open-minded person "considers some alternatives, but ignores others" (pp. 166-167), if they are irrelevant to the given context. Here, we use the term "open-mindedness" in a narrower sense than other scholars have defined it, e.g., as a willingness to consider different narratives about the self (Bommarito, 2018).

Taylor specified that open-mindedness requires (1) intellectual humility (the ability and willingness to judge one's own fallibility), (2) intellectual courage (the willingness to take risks in the pursuit of knowledge despite threats to one's identity), and (3) intellectual diligence (the willingness to persist in pursuing knowledge and understanding). By definition, laypeople who display these three virtues are able and willing to consider scientific evidence that does not sit well with their world views, and they are inclined to seek it out persistently. This improves their chances of identifying misinformation (Barzilai & Chinn, 2017).

There is also some empirical evidence that supports this claim. A recent study explored the relationship between science curiosity and political information processing. In this study, science curiosity was operationalized as an inclination to seek out and consume information in science films. The study ultimately found that individuals with higher science curiosity engage more open-mindedly with information that contradicts their political predispositions (Kahan, Landrum, Carpenter, Helft, & Hall Jamieson, 2017).

There is also evidence showing that open-mindedness can be taught, although it is usually framed as a part of critical thinking skills (including self-regulation) and dispositions (including open-mindedness). A meta-analysis of quasi- and experimental studies shows that students can be taught such skills and dispositions, as evidenced by significant effects observed at different educational levels and across different disciplines. On average, teaching critical thinking in the context of one discipline "spills over" to general measures of critical thinking, although the effect size is small (Hedge's $g = 0.3$) (Abrami et al., 2015).

To outline our vision of how intellectual virtues such as open-mindedness should be taught in the science classroom, we draw on three sources. Firstly, we draw on the nascent intellectual virtue education literature, which draws on Aristotelian ethics (Baehr, 2013; Battaly, 2016; Porter, 2016). Secondly, we draw on relevant research-based practices from the field of moral character education (Lapsley & Yeager, 2013), which studies the characteristics of instruction that "motivate and enable students to function as a competent moral agent," such as by resisting temptations to cheat or steal (Berkowitz & Bier, 2014, p. 250). Thirdly, we draw on theories from epistemic education, which studies the characteristics of instruction that assist students in "developing their thoughts about the nature of knowledge and the process of knowing" (Muis, Trevors, & Chevrier, 2016, p. 331).

Direct instruction. The first practice mentioned in the intellectual virtue education literature is direct instruction on the nature and importance of the virtues, that is, explaining what "open-mindedness" and other intellectual virtues are, why they are valuable for both scientific experts and laypeople engaging with science (including policymakers), and what actions, emotions and motivations are associated with them. Evidence suggests that direct instruction about character and values promotes character development (Berkowitz & Bier, 2014), suggesting that this practice could be effective for inculcating intellectual values as well.

A word of warning is in order, however, as many well-intended attempts to educate moral character through direct instruction were found to be ineffective or even harmful; for example, instruction intended to reduce bullying in schools frequently makes bullying happen more often (Lapsley & Yeager, 2013). One explanation for these effects is that when adolescents are provided with direct instruction on moral habits, this may come across as threatening their autonomy or as stigmatizing, "if it implied they are in need of a change in their moral behavior" (p. 168). One workaround could ensure that the instruction on this topic is framed positively or neutrally. To that end, teachers could inform students that since cognitive biases are a universal feature of the human mind, scientists and policymakers have cognitive biases as well. Hence, like a scientist or a policymaker, they are also expected to actively maintain open-mindedness.

Exposure to exemplars of the virtues. The second practice is exposure to exemplars of the virtues, that is, presenting students with examples of real or fictional people coping with decisions in virtuous ways. Ideally, teachers can model intellectual virtues, such as open-mindedness, when interacting with sources of scientific expertise. They can do so by patiently considering a variety of expert opinions on an issue or a variety of alternative solutions for a problem. However, modeling can also be done by others in the community, and intellectual virtues can be learned from studying historical figures and fictional characters, as well as from scientific and popular texts. The fictional character Dr. House from the television drama series *House, M.D.* has been suggested as an exemplar of virtuous actions for his relentless pursuit of correct diagnoses (Battaly, 2016). Similarly, scientific experts' enactments of intellectual virtues can be derived from the history of scientific errors and the ways they were found and remedied (Allchin, 2012). Another source of useful texts for reflecting on virtues can be the adapted primary literature, which is intentionally designed to be accessible to students and help them understand scientific argumentation (Yarden, Norris, & Phillips, 2015); such literature could be purposively designed to be more open-minded or more closed-minded and then critiqued in class.

However, for the purposes of preparing students to become competent outsiders, perhaps people making decisions in personal or civic capacities would serve as more fitting exemplars. For example, students could be exposed to stories of individuals coping with personal health decisions, or of policymakers and communities grappling with local environmental issues as "outsiders." They could learn how these individuals and communities relied on different types of expertise to make sense of their problems and devise action plans, and discuss how well they conducted both first-hand and second-hand evaluations of scientific evidence. Additionally, historical examples of the practices of science journalists and health journalists as "outsiders" can be discussed in the classroom. Outsiders' historical errors, such as journalists' coverage of the fraudulent study that caused a worldwide scare over the MMR vaccine, can be particularly instructive (Allchin, 2011). Similarly, authentic or adapted science-related news articles can be used in class. Some items could serve as exemplars of open-minded reporting, whereas others could serve as exemplars of missed opportunities to perform virtuous actions, by cherry-picking scientific evidence or portraying false balance (see McClune & Jarman, 2010; Reid & Norris, 2016). The use of modeling for character development is well supported by evidence from character education research (Berkowitz & Bier, 2014). This suggests that exposure to exemplars of the virtues could promote intellectual character development as well.

Practicing virtuous behaviors. The third dimension is to encourage students to practice virtuous behaviors and to learn to engage in virtuous dispositions. This is perhaps one of the most difficult dimensions to apply, but it can be integrated into class discussion and argumentation. These activities provide students with opportunities to "interact with others who may see the world quite differently than they do," weigh evidence, and learn to be tolerant and value other points of view (McAvoy & Hess, 2013, p. 19). Thus, these activities could help counteract the socially embedded problems on judgment and decision-making. It has been argued that teaching using the socioscientific issues framework, which puts an emphasis on student discussion and argumentation, "develops students' open-mindedness, ability to detect bias, and capacity to critically reflect on science-based issues" (Zeidler, 2014, p. 715) and can cultivate "character traits like empathy, caring, responsibility, and willingness to take action on issues" (p. 719).

One promising teaching method could be preparing a news article, as part of a learning activity modeled after practices of professional science journalists (Hobbs, 2016; Polman, Newman, Saul, & Farrar, 2014) and fact-checkers (Caulfield, 2017; Wineburg & McGrew, 2019). Alternatively, a similar method could be a "health educator" activity, in which students compile evidence and health advice on authentic issues of interest for the local community. In any of these contexts, engaging with an authentic media landscape rife with both scientific and pseudo-scientific claims and evidence can provide much-needed opportunities for critique and for reflection (Golan Duncan et al., 2018; Tseng, 2018).

When conducting these activities, it has been argued that teachers must make desirable epistemic beliefs explicit, and show students "the complexity and tentativeness of knowledge as well as multiple and active ways for its justification and evaluation" (Muis et al., 2016, p. 350). Again, the language and concepts of intellectual virtues should be explicitly incorporated as well. One way of doing this is by asking students to take note of intellectually virtuous actions they performed, or of missed opportunities to perform such actions (Battaly, 2006).

Enculturating virtue. The fourth dimension, crafting environments that enculturate virtue, refers to making intellectual virtues part of cultural interactions in school life, as "character education is, in large part, fundamentally organizational/institutional reform" (Berkowitz & Bier, 2014, p. 251). This would entail a systematic endorsement of intellectual virtues as part of the school's identity, as well as enacting teaching and assessment policies that promote understanding and critical thinking (Baehr, 2013). Generally, the principal must competently lead character education efforts (Berkowitz & Bier, 2014; Berkowitz, Bier, & McCauley, 2017), and this is probably the case for intellectual character education as well. While the literature seems to focus on the individual school level, it should be emphasized that schools need these efforts to be supported by school systems and by local and national governments through curriculum reform, by providing pre- and in-service teacher professional development programs, and more. For further discussion of the structural factors that impede the inculcation of science literacy in general, see Aikenhead (2006).

Since the field of intellectual character education is still in its infancy, it is not yet known which instructional methods are most appropriate for which developmental stages, and why. Thus, the most effective instruction might be indirect. In addition, relevant assessment tools for intellectual character education are still few and far between. These are promising areas for further research, with the fields of moral-character education and epistemic education offering many starting points.

Summary and Concluding Remarks

At the beginning of this article, we inquired whether SL can help individuals identify misinformation on science-related issues in everyday life. In the first argument, we posit that the answer is yes, but not in the way SL is commonly conceptualized; the most pertinent components relate to evidentiary practices and to intellectual virtues. In the second argument, we argue that intellectual virtues, such as open-mindedness, intellectual humility, intellectual courage, and intellectual diligence, are needed to identifying misinformation in everyday life as a competent outsider. We therefore contend they should be central to science education.

Our position paper has three main limitations. The first stems from the unit of analysis considered in this article, which is the individual; it ignores group-level effects, such as the sharing of misinformation by trusted peers within internet discussion forums, and structural effects, such as the changing role of mass media as a potential gatekeeper against misinformation (Scheufele & Krause, 2019). Future work could examine the constraints and affordances communities provide for individual SL, specifically in the context of identifying misinformation (National Academies of Sciences, Engineering and Medicine, 2016).

The second limitation has to do with external validity, as many of the findings cited derive from studies conducted in laboratory-experimental settings in participants from WEIRD ("Western, educated, industrialized, rich and democratic") societies. A more diverse evidence base is needed to make more general claims about SL and public engagement with science. Additionally, it is never easy to determine what children and adolescents need to know and be able to do based on studies conducted in adults. Nor is it easy to predict future trends based on contemporary personal and social challenges.

The third limitation is conceptual, and derives from a general problem with the "science of science communication" approach. As some researchers have pointed out (e.g., Lewenstein, 2017; Mellor, 2018), this approach frames social controversies as an obstacle for the implementation of policy, and identifies a lack of rational capabilities among lay publics as the culprit of the problem. This framing ignores the ways scientists and the institutions of science may inadvertently contribute to public mistrust and social controversy. For example, some parents hesitate to vaccinate their children not because of ignorance or a blanket resistance to science, but because they perceive the risks of vaccination in different terms than scientific institutions and health authorities, and sense that these institutions are out of touch with their concerns. While health authorities perceive adverse events as a reasonable risk on the population level, this often fails to persuade parents who look at the question of vaccine safety in terms of their particular child (Goldenberg, 2016). To provide another example, climate change skepticism can be traced to the protection of values such as individualism and free enterprise (Kahan et al., 2011). Future work could examine the institutional structures of science, how they could better "accommodate the cultural values that are essential to the proper functioning of civil society" (Mellor, 2018, p. 751), and consider how science education can promote mutual understanding between these institutions and publics. Erduran and Dagher (2014) and Christensen (2009) are a good starting points for this discussion.

Despite these limitations, this position paper offers a way to cope with misinformation in everyday life. It is based on theory and findings from science communication, epistemic education and intellectual virtue education. No doubt, it is a tall order to "put the values that underpin scientific thinking back in the centre of our world" (Collins, 2009, p. 30), but we, as science educators, share the burden with scientists, journalists and many other sectors of society. Although we are not able to complete the work, neither are we free to desist from it[1]. For our part, we must encourage students to seek out and depend on scientific knowledge and expertise, even if it may contradict their pre-existing worldviews. At the same time, we must encourage students to critique scientific knowledge claims as needed. In short, we must impart open-mindedness in science classrooms. It is crucial for helping our students become "competent outsiders."

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Table 1. Comparison of three recent conceptualizations of science literacy by the expectations they set for students' future engagement with science and by their stances towards misinformation

		National Academies' Consensus Report	**NRC Framework**	**PISA 2015 Science Framework**
1.	**Expectations for Students' Future Engagement with Science**	No normative statement on this topic	By the end of 12th grade, all students should have "sufficient knowledge of science and engineering to engage in public discussions on related issues [and] to be critical consumers of scientific and technological information related to their everyday lives" (National Research Council, 2012, p. 9)	"Scientific literacy is the ability to engage with science-related issues, and with the ideas of science, as a reflective citizen. A scientifically literate person is willing to engage in reasoned discourse about science and technology" (OECD, 2016, p. 20)
2.	**Stances towards Misinformation**	Expresses both optimism that the public has increased access to reliable scientific information and concerns about the public's increased access to misinformation; Science literacy requires the "ability to integrate and interpret information, as well as the time and ability for reflection and evaluation" (National Academies of Sciences, Engineering and Medicine, 2016, p. 23)	Scientists and citizens must "make evaluative judgments about the validity of science-related media reports," have "[t]he knowledge and ability to detect 'bad science'" and be able to identify the "strengths and weaknesses" of media reports of science or technology (National Research Council, 2012, pp. 71, 73)	"Students need to understand the importance of developing a skeptical attitude towards all media reports in science" (OECD, 2016, p. 25)

Table 2. Comparison of dimensions of science literacy across three conceptualizations of the construct, and their correspondence with dimensions of the Grasp of Evidence framework

	Conceptualizations of Science Literacy			**The Grasp of Evidence Framework**	
	National Academies' Consensus Report	**NRC Framework**	**PISA 2015 Science Framework**	**Experts' Evidentiary Practices**	**Lay Evidentiary Practices**
	(1) Foundational literacies, e.g. numeracy and textual literacy				
★	(2) Content knowledge	(2) Crosscutting concepts (3) Disciplinary core ideas	(1) Content knowledge		
★	(3) Understanding of scientific practices	(1) Scientific and engineering practices	(2) Procedural knowledge	✓	
	(4) Identifying and judging appropriate scientific expertise				✓
	(5) Epistemic knowledge	Mentioned as a goal of reflecting on the scientific and engineering practices	(3) Epistemic knowledge	✓	
★	(6) Cultural understanding of science				
	(7) Dispositions and habits of mind, e.g., inquisitiveness and open-mindedness			✓ (as part of apt epistemic performance)	✓ (as part of apt epistemic performance)

★ Common to most definitions of science literacy, according to the National Academies' Consensus Report

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[1] This sentence was derived from an adage from the *Mishnah* attributed to Rabbi Tarfon, a Jewish sage who lived in the first century A.D.: "It is not your duty to finish the work [of perfecting the world], but neither are you at liberty to neglect it" (M. Avot 2:16).