Helping students learn to find trustworthy scientific information and resist misinformation

A toolkit for K-12 science curriculum developers

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A Framework for K-12 Science Education was created to be the "blueprint" for the *Next Generation Science Standards* (NGSS). The goals of teaching science in schools in that document include preparing students to be "careful consumers of scientific and technological information related to their everyday lives" as well as enabling students to "continue to learn about science outside school" (National Research Council, 2012). In addition, the NGSS advocate teaching students to identify and use *reliable* sources of scientific information, noting that science education should reflect connections between science and the real world, help prepare students to make decisions about health and other science-related topics, and prepare students for citizenship.

These goals cannot be achieved unless students are able to distinguish between credible scientific information and false or misleading information. However, research shows that most students struggle to accurately evaluate information found online (Breakstone et al., 2021). Not long ago, information was often curated by qualified gatekeepers, whereas in today's digital world anyone can publish anything on the internet, many influential figures promote bogus scientific claims, and media are replete with misinformation. One of the harmful results of misinformation, for example, was that hundreds of thousands of Americans died unnecessarily during the COVID-19 pandemic (Smith & Plumley, 2022).

Science education has a special responsibility to help students better evaluate information. Why? Because so much of the misinformation people encounter—e.g., about diseases, the efficacy of masks, diets, nutrition, climate change—claims to have a scientific basis. The science, however, can be flawed, misrepresented, or simply wrong. In addition, science has distinctive features that have allowed scientists to uncover reliable knowledge about the natural world and students should learn about them. These include peer review, the importance of syntheses and meta-analyses of studies, the significance of the establishment of a scientific consensus among relevant experts, and the critical roles of key scientific institutions (e.g., the IPCC), among others.

Learning how to find trustworthy scientific information and recognize misinformation requires competencies that need to be learned and practiced over time, just as reading, writing, and mathematics do. While science is not the only discipline concerned with the impacts of harmful misinformation, school science must take some of the responsibility for teaching students the skills and habits of mind necessary to find reliable scientific information in their everyday lives, particularly as finding trustworthy information requires developing an understanding of how science works. Therefore, attention to these competencies across subjects and grade levels is needed, especially in *school science itself*.

Curriculum developers for K-12 science, whether nonprofit or for-profit, can contribute substantially by publishing instructional materials designed to help students develop the capability to find trustworthy information and identify misinformation. Six key themes to consider when developing these materials are described in the following pages.

1. Include illustrative examples of scientific misinformation
2. Include activities that explore how to search for trustworthy scientific information on the internet
3. Address what makes a scientific source trustworthy
4. Explore social and institutional aspects of science, including "scientific consensus"
5. Provide activities that ask students to search for trustworthy scientific information
6. Provide activities that explore common errors in thinking, which can affect scientists and laymen

Figure 1: Six key themes for K-12 science curriculum developers to help students find trustworthy scientific information and resist misinformation

Curriculum developers should think of these six themes as a toolkit of features to be included in any curriculum materials. These elements can be used separately or together in any number of different ways and the order in which they are presented in this document is not essential. Currently these themes are largely absent from the K-12 science curricula.

Many examples of instructional materials that incorporate one or more of the six features listed above are included as illustrations. For that purpose, this paper draws on a searchable catalog of K-12 science resources for teaching students about seeking credible information that was created by Media Literacy Now, with support from the Howard Hughes Medical Institute. That catalog can be found at https://medialiteracynow.org/science-resources. Given that the features highlighted in this document are interrelated, some of the examples used below cut across multiple features. As such, we sometimes refer to examples from previous sections.

Further supporting references are included at the end of the document. While there are potentially hundreds of studies and reports available, we have chosen to highlight only a few important examples.

We hope the ideas in this document prove useful to curriculum developers. It is important to teach students to find trustworthy sources because harmful scientific misinformation has become an enormous challenge in contemporary society in the past decade, one that poses a threat to democratic governance as well as to people's health and well-being. Therefore, any new or revised K-12 curriculum materials for science ought to reflect some or all of these themes.

Include illustrative examples of scientific misinformation

Rationale

Knowing what is wrong, and why it is wrong, is one foundation for knowing what is right. There is a large body of research by Wineburg and his colleagues, van der Linden, and others showing that exposing people to misinformation and explaining how it is deceptive increases their resistance to accepting additional misinformation (Caulfield & Wineburg, 2023; Kozyreva et al., 2024; van der Linden, 2023). For example, students should learn about common techniques used to mislead people (e.g., cherry-picking data; masquerading as an expert; pretending that being a scientist makes one expert in all sciences; claiming that all science is tentative and debatable) so they are better able to recognize these techniques. By carefully using such examples, individuals' capability to identify misinformation can be improved. A wide variety of approaches ("interventions") have been used to reduce acceptance of misinformation. For instance, van der Linden and colleagues conducted studies documenting the efficacy in several countries of using specially designed games to improve people's resistance to misinformation (van der Linden, 2023).

Examples

A common example used for decades in media literacy education is to teach students about methods used by advertisers to mislead or deceive people, with the goal of making them aware of such techniques when encountered again. Studies show that this approach is effective (e.g., Nelson, 2016).

An example of using this approach in science education is a curriculum unit in which students were exposed to a real 30-second video advertisement for a weight-loss product. The Federal Trade Commission found that this advertisement made false claims about scientific evidence and the company was forced to withdraw the ad. In the same unit, students were exposed to ads illustrating that similar misleading arguments have been used to try to persuade people that scientists were unsure about scientific claims on the negative impacts of smoking tobacco, and again more recently to sow doubt about the harmful effects of the release of excessive carbon dioxide into the atmosphere (Zucker, Noyce & McCullough, 2020). Having learned about such deceptive advertising techniques, students were asked to create their own misleading science-related advertisements. The goal of the unit is for students to become better at evaluating the credibility of advertisements and other sources of information that make science-related claims.

Another example of intentionally including misinformation is a lesson asking students to decide whether three organizations are trustworthy sources of information about renewable energy ("Lateral reading about renewable energy"). Two of the three organizations deny that climate change is a problem. Based on students' investigations and on class discussions, this lesson familiarizes students with examples of misinformation and labels them as such. This example, and others in this paper, illustrate that a lesson or unit can explore multiple approaches that enable students to recognize common flaws, find trustworthy information and resist misinformation. In this lateral reading lesson, for example, three of six "tools" were used: examples of misinformation were intentionally provided, students searched the internet themselves to evaluate sources, and characteristics or indicators of credible sources were compared with characteristics of sources that are not based on sound scientific evidence.

Include activities that explore how to search for trustworthy scientific information on the internet

Rationale

Non-experts are generally not qualified to evaluate a complex scientific claim based on the underlying research, such as the finding that common vaccines are safe and effective for almost everyone—a claim that was made by 18 epidemiologists after reviewing more than 1,000 studies (Institute of Medicine, 2012). Their finding is an example of a "scientific consensus." Instead of trying to evaluate the science in claims that are beyond their expertise, such as those they may encounter in advertisements or other media, students should be taught to evaluate the credibility of *sources* of scientific information. Thus, rather than focusing primarily on the claim itself, curriculum materials need to show that it is important to open another browser tab or window to investigate the credibility of the *source* of the claim as well as to find out what other sources say about the claim. This approach is called "lateral reading" (Wineburg & McGrew, 2019).

Experimental studies have shown the efficacy of lateral reading for this purpose (e.g., Fendt et al., 2023). Students are often deceived by superficial characteristics of an internet source, such as believing that all websites ending in ".org" are reliable, or that a person who holds a Ph.D. is automatically a credible source, or that any group identified as an "institute" is trustworthy. Many science teachers know first-hand that students can easily be misled. One student told her teacher she believed all results found by a search engine are accurate, or why else would she be seeing them?!

Examples

One activity from the Civic Online Reasoning project at Stanford (now an independent organization called the Digital Inquiry Group) is called Website Reliability. This activity requires students to conduct an open web search in which they investigate specified scientific topics, including the impacts of carbon dioxide, climate change, and COVID-19. Students learn to look beyond the surface features of a website. A student assessment and rubric are provided for each topic.

The Civic Online Reasoning group found that professional fact-checkers, among others, make regular use of Wikipedia. A short video created by that group, How to Use Wikipedia Wisely, can help science teachers understand what appropriate use of Wikipedia by students should be.

Another example that could be useful to teachers and curriculum developers is an article published in *Science* magazine providing a flow chart of "a fast and frugal heuristic" to evaluate scientific information on the internet (Osborne & Pimentel, 2022). The article advocates teaching students to ask three questions about a claim: does the source have a conflict of interest, does the source have the expertise to vouch for the claim, and is there a consensus among the relevant experts? The flow chart illustrates the reasoning used to reach a conclusion based on answers to these questions.

Other heuristics can also be useful. For example, in the book *Verified: How to think straight, get duped less, and make better decisions about what to believe online*, the authors use the acronym SIFT as a guide to investigating claims. **S** stands for Stop, **I** stands for investigate the source, **F** stands for Find other coverage, and **T** stands for trace the claim, quote, or media to its original source (Caulfield & Wineburg, 2023). The book is filled with examples and with references to research.

Address what makes a scientific source trustworthy

Rationale

The NGSS advocate teaching students to find and use *reliable* information but do not explain what makes a source reliable. That omission is significant because outside of school people are exposed to and seek information from innumerable sources, including YouTube, TikTok, Instagram, Facebook, cable television, newspapers, magazines, and advertisements. Almost everyone can be fooled at times. Nonetheless, schools must help students develop the knowledge, skills, and habits of mind to minimize the odds they will accept false or misleading information supposedly based on science (Zucker & McNeill, 2023).

Trustworthy scientific sources reach conclusions based on good evidence and careful reasoning. They are qualified sources because they are experts in their own field, or are trained to evaluate the credibility of sources, as experienced science journalists do. Students should learn that being a scientist does not make someone an expert in all sciences; even scientists must trust other sources for claims outside their specialty. Trustworthy sources usually have an admirable track record. Trustworthy sources may speak for or represent recognized groups of experts, such as the Food and Drug Administration (FDA). Sometimes the science is not settled so students should also learn about science-in-the-making (as with the first years of COVID-19) when there is no scientific consensus. While research is still under way on a complex topic it is difficult to evaluate which claims and sources are credible.

Conversely, there are certain hallmarks of *unreliable* sources of information and students need to become familiar with some of these. That is like learning about the techniques advertisers can use to mislead people, and several games aim to teach people how to mislead others (in fictitious situations) so that players learn to recognize and resist these techniques in the future. Some fake experts create organizations whose names resemble legitimate scientific groups, some cherry-pick data in ways that non-experts are unlikely to notice or understand, etc.

Examples

An activity called Evaluating the credibility of claims using bellringers provides students with practice deciding whether a variety of claims are based on credible scientific evidence or not. In the process, and with teachers' guidance, students learn about trustworthy sources. Another is a pertinent game called Cranky Uncle. Students are provided with a brief overview of techniques to deny science (fake experts, logical fallacies, impossible expectations, cherry-picking, conspiracy theories). The game is interactive and provides immediate feedback for correct and incorrect answers. The book *Foolproof* (discussed on page 3) includes discussions of experimental research showing the efficacy of several other games in which users learn how to fool others (but intentionally in low-stakes, fictitious situations). One of these is called Go Viral! and another is the Bad News Game.

Activities such as these can support the development of student understanding about the nature of scientists' expertise and other characteristics of sound scientific research. Students especially need *practice* distinguishing trustworthy sources from the ill- or mis-informed, not only textbook explanations. Knowing what is wrong and why it is wrong is just as important as knowing what is right and why it is right. The evidence students gather for or against the trustworthiness of a source can then be used to construct an evidence-based argument for their claims (NGSS practices 8 and 7).

Explore social and institutional aspects of science, including "scientific consensus"

Rationale

Why trust science? The scientific enterprise is not only a body of knowledge and a set of methodological practices but also an institutional system that incorporates specific social practices to ensure that scientific knowledge is vetted to reduce and remove errors. Students need to learn about some of the key features of the scientific enterprise, including the concept of a scientific consensus, where a great majority of qualified experts agree on a conclusion about a scientific claim, based on evidence. It can take many years to reach a consensus, as happened, for example, with the agreement of experts that the continents on Earth have moved in the past and continue to move. Peer review in refereed journals, conferences, and syntheses of research are examples of other important pieces of the scientific process that support the production of reliable knowledge.

Do vaccines cause autism? What causes global warming? Scientific institutions use multiple sources of reliable evidence to answer these and other questions. Students should be given an opportunity to learn about the critical role of key institutions in nurturing the scientific enterprise (Hockfield, 2018). This can include discussions about important institutions like the Food and Drug Administration (FDA), the Centers for Disease Control and Prevention (CDC), or the Intergovernmental Panel on Climate Change (IPCC), to name a few. These institutions help scientists reach consensus, for example by commissioning or convening experts as in the Institute of Medicine example on page 4. They were created specifically to obtain, evaluate, and communicate scientific information (NGSS Science and Engineering Practice #8), including producing reports for policymakers and the public. Of course, no institution is perfect. Curriculum materials should provide opportunities for students to learn about the role of scientific institutions and why they are seen as trustworthy sources of scientific information for public audiences.

Examples

How do scientists come to a consensus about key issues, like climate change? The National Center for Science Education has produced a lesson set to engage students with this question. Students first learn about the dangers of relying on a single study for scientific conclusions and then they review multiple lines of evidence about climate change to reflect on how a scientific consensus is produced.

An article in *The Science Teacher* will be published called "Teaching about the critical role of key scientific institutions" (Zucker & Miller, 2024 [in press]). One recommendation is to include instruction about institutions as part of the existing curriculum. For example, in lessons about vaccines include information showing how the CDC and the FDA use science to reach conclusions about vaccine safety and efficacy.

Some scientific institutions play a role in developing regulations based on science—but regulations also reflect other considerations besides science, including weighing costs versus benefits, feasibility, ethics, and values. Similarly, many personal decisions involving science also reflect other considerations, such as costs and values. One curriculum example is a lesson set focusing on lead pollution in Flint, Michigan (see also Coppens, 2020). The lessons blend science and civics to explore the process of water treatment and the institutions that are involved (e.g., the Michigan Department of Environmental Quality). Another curricular example is a unit published by the Environmental Protection Agency in which students use EPA data to make decisions about where to put a green space in a fictional city.

Provide activities that ask students to search for trustworthy scientific information

Rationale

Sooner or later, everyone will seek trustworthy scientific information needed to address personal or societal concerns (Zucker & McNeill, 2023). Often, this involves learning about topics we have never studied, such as treating diseases (some new, like respiratory syncytial virus, RSV); claims made about nutrition, weight loss, or cosmetics; the safety of air, water, or food; debates about how individuals and society should use new technologies (e.g., artificial intelligence, CRISPR, or green energy infrastructure); and others. To become what some call "competent non-experts" or what others compare to "thinking like a journalist" (Polman et al., 2014), students must be given opportunities to practice finding trustworthy information on the open internet.

By using information sources found online, curricular activities can more closely mirror the "intellectually unfriendly" nature of the internet, where information varies greatly in quality and needs to be evaluated before use (Chinn et al., 2021). As one recent paper notes, science curricula need to attend to "engaging in science as laypeople" (Chinn et al., 2023).

Examples

Several activities discussed in the preceding pages ask students to search the internet for information, including "Evaluating claims using bellringers," and "Teaching about the critical role of key scientific institutions." Curricular materials might incorporate frequent warm-up ("do now") activities that ask students to verify or validate a claim related to topics or phenomena that they are investigating in class.

In addition to these shorter activities, curriculum designers can also provide more elaborate sets of activities or routines modeled on the practices of science journalists, such as producing reports based on multiple credible sources, searching for accurate information, and corroborating information across sources (Polman et al., 2014). Polman and colleagues (2014) developed a set of activities where students learned to "pitch, research, draft, and… revise original news stores" about science-related topics, which were reviewed and published on the internet for real audiences to view (see www.scijourner.org for examples).

In a unit created by BSCS, called Making Evidence-Driven Decisions in a Media-Driven World, students are tasked with finding health information online and, based on what they find, collectively constructing a rubric to evaluate the credibility of the various sources that they find. During discussions about rubric-construction, the unit also incorporates instruction about how students can improve the efficacy of their online searches (using ideas discussed above under 'Show students how to search for scientific information on the internet' on page 4).

In addition to searching on the internet for information, students can also be prompted to reflect on the personal networks they use, or would use, to find trustworthy scientific information in their lives (Feinstein & Baram-Tsabari, 2024). For example, materials can prompt students to brainstorm which people and sources of information they would turn to for information about a science-related question and then evaluate the strengths and limitations and consider potential adjustments they might make in their own personal networks to improve the quality of the science-related information they seek.

Provide activities that explore common errors in thinking, which can affect scientists and laymen

Rationale

Curriculum materials with a focus on these topics provide opportunities for students to build their capacity to reason about and reflect on what they believe and become more aware of their own thinking processes. Activities can support students' understanding that there are many ways in which people—both experts and non-experts—may be mistaken, sometimes due to the influence of confirmation bias, motivated reasoning, mistaking correlation for causation, peer pressure, or relying only on anecdote (Allchin, 2022). For this purpose, activities can help students develop an appreciation for the idea *"Don't believe everything you think."*

A focus on errors in human thinking is important for science education in at least two ways. First, by including information about cognitive heuristics and biases, curricular materials can help students learn how scientific processes work to mitigate these influences (albeit imperfectly). For example, the peer review process used in science can limit the impacts of confirmation bias. Second, students can practice identifying the ways that these biases show up in their own uses of information, for example, when deciding whether to share or "like" information that aligns with prior beliefs on social media before vetting it. By helping students understand the limits of human thinking, curriculum materials work to foster their *intellectual humility*, which is associated with a host of benefits, including the tendency to make more well-informed decisions (Porter et al., 2022).

Examples

One curriculum unit that addresses the topic of misinformation in science focuses partly on how Linus Pauling, a winner of two Nobel prizes, was mistakenly convinced that large doses of Vitamin C could cure or prevent a variety of diseases, including the common cold (Zucker et al., 2020). Pauling did not have sufficient evidence to support his claims, nor was he an expert in science focused on nutrition or disease. Providing examples illustrating when and how scientists have made errors can help students understand that one reason the scientific process is important is precisely that it is designed to catch errors. Eventually, a consensus of experts rejected Pauling's assertions. Similarly, a case study about understanding the disease beriberi discusses the many incorrect hypotheses scientists generated before discovering the actual cause of the disease.

Common Logical Fallacies in Science is a set of lessons introducing inductive and deductive reasoning, strategies to help prevent bias, and understanding the difference between correlation and causation. Spurious Correlations is a website that includes examples of correlations that have no relation to causation, some of them humorous.

Another approach is to include activities allowing students to experience the effects of a cognitive bias first-hand. In one lesson about confirmation bias, students are tasked with figuring out a number rule by proposing a series of three numbers and learning whether that sequence adheres to the rule or not. Another example activity uses the popular Müller-Lyer Illusion to support students in understanding flaws in human perception. In both cases, students can discuss the focal bias, how it impacted their thinking, what the implications are for evaluating scientific information, and how scientific processes are designed to minimize those effects when producing trustworthy knowledge about the natural world.

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