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Scientific literacy at a tragic low: A call for more public engagement in science

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SCIENTIFIC LITERACY AT A TRAGIC LOW: A CALL FOR MORE PUBLIC ENGAGEMENT IN SCIENCE

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ABSTRACT

Science is the catalyst for humanity's progress. Without it, we would not understand our world, our universe, even our own bodies to the extent we do now. We would not have the ability to travel, connect, and innovate at the heights we currently enjoy. In fact, many people are alive today only because of scientific discoveries and advancements. Life-saving surgeries, medications, and implants impossible a mere hundred years ago are now routine, thanks to science. It follows that science should be revered, trusted, and understood. Unfortunately, in the information age, communication gets complicated. As with any other topic, there are agitators who aim to tarnish the reputation of science and scientists or spin scientific information for personal or political gain. The public must work against these forces. As long as science remains the best way to make sense of the world and continues to improve and save the lives of millions of people, scientists need and deserve our support. Better engagement on scientific topics among teachers, students, journalists, politicians, scientists, and everyday citizens needs to occur. This thesis examines some of the ways science is communicated, evaluates some examples of science communication, and proposes some improvements. Ultimately, increased scientific literacy brings a brighter, healthier world with greater fulfillment for its inhabitants.

INTRODUCTION

Science is not perfect. Nor does it always provide timely or suitable answers to urgent questions. But the scientific method, with its principal goal of simply arriving at the truth, has given us knowledge and technology on scales unimaginable to previous generations. While many puzzles of modern existence remain unsolved, the system of scientific inquiry works. Science has built-in strategies to check itself, correct itself, and refine information in order to deliver the best answers possible.

Systems of scientific inquiry evolved from our very own human nature, spawned by the natural curiosity stirring within all of us. The elegance of nature and animals, the majesty of the sun, and the mysteries beyond the stars have captivated history's greatest thinkers and laypeople alike since the beginning of civilization. This curiosity about ourselves and our world has fueled our desire to understand and improve our surroundings. Through our imaginations and the implementation of the principles of science, humans created a flourishing world with continuous advancements. Scientists have engineered seeds to withstand devastating weather phenomena, allowing farmers to feed growing populations in developing countries. In industrialized nations, life is easier, richer, and more productive than ever before. Here in America, most daily activities are made possible by science. Every time we hear the buzz of an alarm clock, feel the turbulent breeze of an approaching train, or laugh along with our favorite television show, we should thank a scientist.

It seems logical, then, that people would be grateful for all of these developments and comforts, but instead, they are often taken for granted, and we find ourselves in a time where a new mistrust in science is blossoming. A variety of successful misinformation campaigns spread with the help of social media have sown the seeds of doubt in science (and even education in general, alarmingly) among the general public. Propaganda targeting political parties can significantly influence viewpoints. According to a 2017 Pew Research Center study of over 2,500 Americans, “a majority (58%) of Republicans say colleges and universities are having a negative effect on the way things are going in the country” (Pew). Furthermore, in several chilling recent examples (discussed in more detail below), unnecessary suffering and death in the face of a global pandemic could have been avoided if more leaders and citizens had followed the advice of scientists. Scientific ignorance can bring costly consequences.

Of course we should not blindly trust science. Skepticism is healthy and wise. People should question science because scientists are human–they make mistakes, they harbor biases that could lead to false findings, they may even be corrupt individuals working with bad intentions. What the general public needs to understand is that the scientific process will weed these things out eventually. We must realize the importance of the process and have the patience to allow it to unfold. We would all do well to learn to live, however uncomfortably, with the maxim that it is better to have questions that cannot be answered than answers that cannot be questioned.

A healthy balance between appreciation and skepticism can be achieved with a better overall system for public engagement in science. Traditionally, science learning is spread through educators via educational standards and policies put in place by politicians guided by advisory groups. This places educators as well as politicians as central components to increasing scientific literacy in the general public. Gaps in these structures exist, however, that could and should be filled by scientists themselves and science advocates. All of these groups need to get more involved and be proactive in the areas of outreach and advocacy so that people can appreciate the value of scientific literacy. New alternative science advocacy and education initiatives are popping up that we should embrace and support as well. There also needs to be engagement with the general public in the field of popular science. All of these strategies will be discussed briefly below before taking a deeper dive into science communication in general.

SCIENCE EDUCATION

What exactly is scientific literacy? According to the *National Science Education Standards*, scientific literacy is “the knowledge and understanding of scientific concepts and processes required for personal decision making, participation in civic and cultural affairs, and economic productivity” (22). This book of standards includes a vision for scientific literacy to be implemented in schools across the United States of America. It was written by the National Research Council (NRC) with contributions from the Division of Behavioral and Social Sciences and Education, the Board on Science Education, and the National Committee on Science Education Standards and Assessment as well as support from several prominent groups such as the National Science Foundation, the U.S. Department of Education, the National Aeronautics and Space Administration, and the National Institutes of Health. Although, as history shows, the standards left much room for improvement, the report offers some key observations:

> All of us have a stake, as individuals and as a society, in scientific literacy. An understanding of science makes it possible for everyone to share in the richness and excitement of comprehending the natural world. Scientific literacy enables people to use scientific principles and processes in making personal decisions and to participate in discussions of scientific issues that affect society. A sound grounding in science strengthens many of the skills that people use every day, like solving problems creatively, thinking critically, working cooperatively in teams, using technology effectively, and valuing life-long learning. And the economic productivity of our society is tightly linked to the scientific and technological skills of our work force. (National Research Council, 1996, ix)

While it is true that students can empower themselves through scientific literacy and thereby enjoy a more enriched life, the standards failed to provide a crucial ingredient for the educators: the curriculum. They laid out plans with goals for students and measures to test their learning but no materials besides some examples, some guidelines for rubrics and assessments, and general suggestions.

The standards themselves say that the "organizational schemes of the content standards are not intended to be used as curricula; instead, the scope, sequence, and coordination of concepts, processes, and topics are left to those who design and implement curricula in science programs" (23). However, without content selection guidelines, consistent outcomes can be difficult. As pointed out by science education researcher Iris Weiss, "textbook publishers provide the vast majority of science instructional materials adopted and used in K-12 schools" (qtd. in Ellis, 61). While textbook publishers may have been working with the standards in mind, there was little guidance for them and hence not much consistency among states.

A 1998 study on systemic reform by William Clune of the National Institute for Science Education made some suggestions for science curriculum reform:

> Although it is true that student assessments and teacher networks served as the link between top and bottom in the reforms, that link would have been stronger with a more powerful means of influencing curriculum. The common problem is the focus on pedagogy rather than content. Reforms typically were aimed at classroom processes such as the use of manipulatives, collaborative learning, and inquiry learning. Especially early in the reforms, direct means of influencing curriculum such as model curricula, new materials, and model teaching units were relatively rare. (11)

This was a significant limitation of the standards, but not the only one. In his article in the *Journal of Research in Science Teaching*, Alberto J. Rodriguez argued that the NRC's standards use "a discourse of invisibility to lay out its massive reform for science education in the United States. This invisibility discourse dangerously compromises the well-intended goals of the NRC by not directly addressing the ethnic, socioeconomic, gender, and theoretical issues which influence the teaching and learning of science in today's schools" (19). The lack of discourse in this area affirms and continues to serve those students who are already in privileged groups, whereas a more inclusive discourse could have fostered the idea, as explicitly stated in the standards, that science education and scientific literacy are for everyone.

A new hope arose for yet another reform, the Next Generation Science Standards, introduced in 2013. According to the NRC's book *Next Generation Science Standards: For States, By States*, science education needs to promote STEM:

> The world has changed dramatically in the 15 years since state science education standards' guiding documents were developed. Since that time, many advances have occurred in the fields of science and science education, as well as in the innovation-driven economy. The U.S. has a leaky K–12 science, technology, engineering and mathematics (STEM) talent pipeline, with too few students entering STEM majors and careers at every level—from those with relevant postsecondary certificates to Ph.Ds. We need new science standards that stimulate and build interest in STEM. (xiv-xv)

Reform takes much effort and cooperation on various fronts, but we can be hopeful this new plan–one that focuses more on active learning than rote memorization–gets implemented smoothly and effectively in more states. The goal of producing young adults who can navigate the world with scientific literacy is a noble one and worth the effort. As the NRC standards expressly point out, acquiring scientific literacy enriches many areas of life:

> Scientific literacy means that a person can ask, find, or determine answers to questions derived from curiosity about everyday experiences. It means that a person has the ability to describe, explain, and predict natural phenomena. Scientific literacy entails being able to read with understanding articles about science in the popular press and to engage in social conversation about the validity of the conclusions. Scientific literacy implies that a person can identify scientific issues underlying national and local decisions and express positions that are scientifically and technologically informed. A literate citizen should be able to evaluate the quality of scientific information on the basis of its source and the methods used to generate it. Scientific literacy also implies the capacity to pose and evaluate arguments based on evidence and to apply conclusions from such arguments appropriately. (22)

Fortunately, children are natural scientists. Their brains are wired to learn from their surroundings and gather and process information as their brains develop. It turns out we can help foster their abilities to understand science later on by exposing them to science books during their regular reading time. Professors Jean Parkinson and Ralph Adendorff investigated and compared science books for children to science textbooks and popular science texts. They discuss the results in their article, “Science Books for Children as a Preparation for Textbook Literacy.” They found that science books for children have similar elements as the textbooks, which means if children are exposed to science books when young, their ability to understand science textbooks later could improve. The authors explain that the difference between science books for children and science textbooks is purpose. One is for entertainment, and the other is for education. They also point out the common fallacy that narratives in children's science books make information more accessible than in strictly factual texts. While narratives work well for engaging adults in popular science articles, the genre is not fundamentally easier for children to grasp.

Parkinson and Adendorff looked at university level science textbooks and popular science texts as possible models for science texts for children. In their article, they explain how the textbooks arrange facts in order, separate people from facts, and take knowledge as accepted. The popular texts, on the other hand, sort old from new knowledge, give credit to people (researchers), assess certainty, and show relationships to other texts. The findings were that science books for kids are more similar to science textbooks than they are to popular science texts for adults in terms of register, genre, and values. Their conclusion was that it is essential to add science books for children into their general reading activity because they will prepare them for science in school.

We achieve literacy through communicating. While the public education system has fallen short in many ways with regard to science education, there is a larger group of citizens to examine, notably, the general public. The next sections will focus on how science is communicated in general to the average adult in America. Whether through social media, websites, traditional print newspapers, or magazines, this group tends to consume scientific information through the popular science genre.

It has only been relatively recently that scientific ideas were communicated to the general public extensively through journalism and popular science writing. We think of Isaac Newton or Charles Darwin as household names, yet only a handful of people understood their ideas in their times. However, as far back as the late nineteenth century, a few pioneers recognized the need for scientific ideas to be understood by laypeople. Magazines such as *Popular Science* and *National Geographic* were founded in 1872 and 1888, respectively (PSA). Now, many publications exist in this genre and are circulated to millions. These include general science magazines such as *Scientific American* and *Discover* as well as those focused on specialized areas such as *Astronomy* or *Psychology Today*.

In his book, *Rational Rhetoric: The Role of Science in Popular Discourse*, David J. Tietge (2008) discusses the impact of popular science periodicals. He analyzes two magazines: *Scientific American* and *Popular Science*. One important distinction he found is that *Scientific American* gets its material from actual scientists rather than science writers, which lends credibility to the publication. It also addresses more sophisticated scientific issues. Tietge describes *Popular Science* as more of a platform for the glorification of technological advancements and how it can at times even seem like a catalog of neat gadgets. Tietge mentions the subfield of visual rhetoric as having great potential. This idea will likely continue to be true as more advanced versions of visual representations such as holographic presentations or even interactive virtual reality applications appear in scientific texts.

Tietge discusses some general notes on scientific writing and points out that it has received criticism for its tendency at times to be “impenetrable, esoteric, and jargony” (263). He admits that packaging the often complex issues and ideas of science “in a manner that is both accessible and precise … is no easy task” (262). Tietge examines an example from theoretical physicist Lee Smolin, who discussed quantum gravity and the idea of a unified field theory for physics. He finds the use of literary tropes such as metaphor quite common, which makes sense because laypeople might better understand unknown concepts by comparing them with things more familiar to them. Some authors such as Jeanne Fahnestock (discussed below), however, consider too much use of metaphor as problematic because it might limit the use of other rhetorical strategies that could be equally useful in disseminating scientific information to the public in an understandable way. Moreover, the overuse of metaphor could restrict understanding of the overall concept, which prompted Tietge to ask: “At what level does the metaphor break down?” and “How does the use of metaphor both enhance and restrict our understanding” of a scientific theory? (268). He explored examples from *Scientific American* magazine for some answers and found that the relationship between the idea and the metaphor “has both illuminating and obscuring properties” (275). He hopes that metaphors can, at least, offer a glimpse into complex scientific ideas for some and, perhaps, even complete understanding for others who may already have some familiarity with scientific ideas.

In her article, "Accommodating Science: The Rhetorical Life of Scientific Facts, " Jeanne Fahnestock compared scientific research reports written by scientists with their popular science counterparts. She points out that one of the issues with preparing highly technical information for presentation to the nonscientist public is “the enormous gap between the public’s right to know and the public’s ability to understand” (276). There also exists a difference in the communication styles of scientists and nonscientists in general due to the nature of science itself and its requirements for clarity and detail. In analyzing the accommodating of science writing, Fahnestock found three main points about the conversion of information. One is a genre shift, in which the presentation of information moves from stating and validating truths or results (forensic) to celebrating and praising them (epideictic). This shift occurs more in the fields of biology and medicine than in mathematics, chemistry, or physics. The second point involves finding a way to appeal to the readers through claims of rarity or exaggerations. Fahnestock states that asserting “something is ‘the first’ of its kind is also a way to argue for its significance and value” (282). Popular science writers might also remove qualifications that the scientists used to hedge their claims, resulting in the perception of greater certainty to lay audiences. Fahnestock claims that that such changes and exaggerations can have harmful effects on society such as when a 1980 study about a supposed difference in the mathematical abilities of boys and girls was misrepresented in the media. The third point is that stasis theory from classical rhetoric can help us understand the movement of scientific observations from a scientist audience to a lay audience. She concludes by pointing out that further study is warranted because the issue at hand is an important one: “the machinery and quality of social decision making in an experiment-dominated age” (292).

A few general observations about the way scientists communicate are similar to what Fahnestock brought up at the end of her article regarding writing for specialists and writing for different publics. Scientists usually specialize in specific subfields in which unique nomenclature and abbreviations are developed, used frequently, and understood within small circles. In addition, because the very nature of the scientific process insists on reproducibility of the exact conditions of an experiment in order to obtain results that can be precisely replicated, scientists are trained to always explain things with clarity and detail. This type of communication becomes so commonplace that they can lose track of who understands what vocabulary. They sometimes forget which things they should explain and which things are common knowledge. Scientists can end up doing what Fahnestock says she does not want writing students to do–struggle with "accommodating information for different genres, audiences, and purposes" (294).

Over the years, there have been a few shifts in the approach to science communication and some conflicting ideas. The next sections will examine the ways science is communicated, how public perceives this information, some of the consequences, and where there is room for improvement.

Two conflicting cultures exist in science communication. In her book, *Communicating Popular Science: From Deficit to Democracy*, Sarah Perrault (2013) presents two types of science communicators: the boosters and the skeptics. The boosters see science as wonderful and almost flawless while viewing the public as unenlightened and in need of a cure for their ignorance. The boosters view popular science writing as having a public relations function with the goal of not only passing down information but also promoting science. The skeptics, on the other hand, appreciate science but approach it with a more critical lens. They see popular science writing as an opportunity to engage with the public and ask them to become actively involved in the processes and applications within scientific spheres.

The two cultures have produced different approaches to popular science writing. Perrault analyzed three models of science communication and how they handle the relationship between science and the general public. The boosters follow the approach known as the Public Appreciation of Science and Technology (PAST) model, which views information as having a one-way flow from the scientists to the public. Perrault considers this model as problematic for many reasons. First, she claims it is too simplistic in its view of "science as a black box, a sort of fact-making factory into which go resources, pieces of the natural world, and out of which comes the truth" (12). While coming across as a neat summation of the ideal version of scientific pursuits, in reality, they are much more complex and dynamic. Next, Perrault explains that the PAST model too easily places people into just two groups: scientists and non-scientists. She points out that because scientists are not experts in *all* fields, they become non-scientists in every field other than their own, and therefore, we could all be considered non-scientists. This maxim is not entirely accurate because all scientists are trained as critical thinkers and share a mindset and knowledge of the scientific method. All scientists would be able to understand concepts–even in their non-specialty areas–that the general public may not grasp. Other problems with the PAST model are that it assumes readers of popular science have nothing to contribute to science, that communication is a linear and unidirectional activity, and that because people seem aware and supportive of science already, there is no need for a boost in public support. Efforts would be better spent engaging the people and involving them in the actual science. Perrault briefly presents a model more progressive than PAST, which is Public Engagement with Science and Technology, or PEST. This model, while an improvement, is still problematic because it keeps science and society separate and it "keeps the center of gravity in science" (15). Perrault's criticisms of these two models are sound, and a model that places more responsibility in the hands of the people is called for. Science communication must strive to keep up with the trends and models of modern society, which evolve rapidly and are increasingly interactive.

A more interactive and progressive model, that of the skeptics, is the Critical Understanding of Science in Public (CUSP) model. Perrault explains how this model "recognizes that science communication is multidimensional and contextual" (15) and offers several advantages over the other two. The CUSP model highlights how social and scientific spheres influence each other. It sees non-scientific forms of knowledge as valuable, which is true of course, especially within ethical discussions, for example, where the sometimes narrow point of view of science does not always produce the best choices. Moreover, the CUSP model contains the element of criticism, which is important because although science may provide the preferred way of looking at something, it should not be above criticism. With the emphasis on interaction between science and the public, the CUSP model clearly comes across as superior. All of society should be involved in science because not only do we rely on it for daily activities and conveniences but we will likely be affected by its outcomes. Without input from the public, humanity could head down a dangerous path; potentially harmful technological advances could occur before corresponding ethical considerations are decided upon and enforced, such as what we see happening now with lethal autonomous weapons.

Perrault further examined how practitioners of popular science writing think about their own roles and the role of science in society. She discovered that, in practice, the science communicators, unfortunately, see themselves as still following the PAST model rather than the CUSP model. She found three roles among the popular science writers, which she calls the boosters, the translators, and the critics.

As mentioned above, boosters celebrate the wonders of science and wish to cure a perceived lack in the public. They want to showcase science and present scientists as noble protagonists. Perrault's most important criticism of the boosters is that their method "deflects attention from real problems" and "obscures the aspects and applications of science that are not good" (55). The translators try to take the arcane terminology of science and use fun, flowery language to appeal more to popular science readers. This concern is an improvement over the booster role, but it is still problematic because of its neutrality and lack of a critical perspective. The critics approach popular science writing with skepticism. This strategy seems to be the more critical, as it examines the motivations and backgrounds of scientists and science organizations and empowers readers to ask questions and get involved with science.

SCIENCE COMMUNICATION AUDIENCES

As most writers know, the key ingredient in any communication is the audience. Messages should be tailored to the particular audience in order to be most effective. An engaged reader is more receptive and will retain more information. We engage people by presenting them with information that is relevant to their situation or their lives. At the American Association for the Advancement of Science (AAAS) 2020 Annual Meeting in Seattle, Washington, a Scientific Session titled "Public Trust in Science – Strength and Skepticism" laid out some essential tools for science communicators as well as some obstacles to watch out for.

The first speaker, Cary Funk from the Pew Research Center, gave a talk called "Public Perspectives on Competence, Caring, and Transparency in Science," in which she explained that there are divides in scientific issues. Some are political and others are not. To reach common ground with the public, science communicators have to understand that science is a source of change, and as such, people are emotional about it and often more hesitant than enthusiastic. Their concern is of potential loss of human control, human agency. Messages need to be built in that give the audience a sense of control, particularly ones that align with core human values. Audience mindsets cannot be understood on a binary spectrum of anti- and pro-science. To be effective, messages should be tailored to address the concerns people have (Funk).

The second speaker, Kyle Block, from a market research/data science and analytics company called Gradient Metrics, gave a talk called "Dissecting Americans' Mindset toward Science," in which he described research that sought to categorize people based on their levels of trust in science. The study uncovered six personas, described below from least to most trust in science. By shaping messages to reach these archetypes, science communication can be more effective (Block).

The first group is called “Stories Over Stats” because they tend to find their truth in intuition and anecdotes. They make up 23% of the study participants and are the most difficult group to reach, as they are generally resistant to new information and unfamiliar with science. The people in this group tend to feel uneasy when exposed to new perspectives and believe science education is not helpful.

The second group, making up 21% of the study group, is called “Life is Not a Science.” They have had very little exposure to scientific thinking, believe science is unapproachable, and will tend to trust their experience on matters rather than change their minds when presented with new information. They think more about their immediate world and personal issues rather than society as a whole.

The third group, called “Team Skeptic,” comprises 12% of the study group, and these people place some trust in science itself, but have reservations about the motivations behind scientific institutions. They are curious about the world and even familiar with the scientific method. However, they are very concerned with bias in science and fear that science can be used for manipulation.

Fourth are the “Trust the Experts” group (20%), who trust and value science yet do not believe themselves to be a relevant part of discourse on scientific topics. They have a low to average exposure to science but are open to changing their minds when presented with new information. They are comfortable with not knowing things and will defer to experts.

The fifth persona is the “Natural Observers” group, constituting 15% of the study population, whose members understand and believe in science. They base their decisions on facts, value science as a method to gain knowledge, and adopt scientific thinking into their daily lives. Their exposure to science in school is higher than average, and they believe they are qualified to have discussions about scientific research.

Finally, the sixth group is the "Truth Warriors" (only 9% of the study population), who are staunch supporters of science and believe it can uncover important truths and make a positive impact in the world. They support increasing the role of science in public decision-making. They have the highest exposure to science through education, personal lives, media, and careers and believe it is an ethical position to be informed about science.

How can we best craft scientific communication for popular science media? During a workshop at the same AAAS meeting called "The Science of Communicating about Science," speakers Ann Christiano and Matt Sheehan from the University of Florida explained that there are six imperatives, or core principles, of effective science communication (based on behavioral, cognitive, and social science). They emphasized that just because something is true, it does not mean people will care. People do not necessarily act on information; they act on what they care about.

The six imperatives are:

(1) Know who you are talking to and offer them something of value by:

- Finding the space where values intersect;
- Keeping in mind others' beliefs, identities, and worldview; and
- Remembering that people seek affirmation, not information.

(2) Talk in pictures by:

- Using images and metaphors to convey the message.

(3) Invoke emotion with strategy and intention by:

- Avoiding sadness, anger, and other negative emotions;
- Knowing that people want to feel awe, pride, hope, love, humor.

(4) Make sure calls to action are actionable by:

- Being specific;
- Providing details.

(5) Build curiosity by talking in definitions by:

- Avoiding jargon;
- Connecting to what people already know.

(6) Tell stories knowing that:

- Data without stories can do more harm than good;
- Stories are not the same as marketing messages; and
- Use of the narrative paradigm, story arc, 7 basic plots (comedy, tragedy, the quest, overcoming the monster, rags to riches, rebirth, voyage and return) enhances communication.

These are all points for journalists and science communicators to keep in mind. However, one group has not yet been discussed here and warrants attention: scientists themselves. According to a poll by the Pew Research Center, participants rated scientists as intelligent and assigned them several other positive qualities but rated them as not good communicators (Pew). There is a clear lack of ability in many scientists to engage with the public directly and effectively. One reason for the disconnect is that people who are studying to become scientists rarely receive formal communications training at the undergraduate or graduate level.

According to a 2013 article in the *Journal of Undergraduate Neuroscience Education*, Brownell, et al. observed that:

> While scientists are thoroughly trained in research methodologies, analytical skills, and the ability to communicate with other scientists, they usually receive no explicit training in communication of scientific concepts to a layperson audience. Though most will agree that it is important for scientists to be able to communicate to non-scientists, this is a difficult skill that many practicing scientists lack, likely due to the combination of increased specialization over time and the absence of formal training in science communication." (E6-E10)

Brownell et al. note that "an analysis of the curricula of the top ten neuroscience programs in the United States according to the 2010 *US News and World Report* indicates that none require a course focused on science communication to a layperson audience" (E6-E10). Though focused on neuroscience, similar findings would undoubtedly be found in multiple other fields of scientific specialty. Luckily organizations exist to address this problem:

> Although there are myriad opportunities for scientists to communicate their science to other scientists (e.g., courses with mock grant proposals as the main assignment, lab meetings, departmental retreats, and scientific conferences), there are few avenues for them to communicate, in written or oral format, to a lay audience. One of the few organizations dedicated to improving science communication to the general public is the Alan Alda Center for Communicating Science at Stony Brook University (http://www.centerforcommunicatingscience.org), which offers programs for masters and PhD students in scientific disciplines and a traveling workshop, in addition to internet-based opportunities for scientists to explain fundamental scientific concepts to the general public. The American Association for the Advancement of Science (AAAS) (http://communicatingscience.aaas.org) and the New York Academy of Science's Science

and the City program also offer opportunities for scientists to engage with the public (http://www.nyas.org/WhatWeDo/SciencetheCity.aspx). Importantly, the aim of these programs is not to train future science journalists, but to provide communication skills to research scientists to enable them to better convey the details and impact of their work to the general public. Efforts and resources such as these constitute significant progress fostering a population of scientists with improved communication skills. However, these opportunities cater to a self-selecting group of scientists who must go out of their way to seek communication training. (E6-E10)

While these resources should be applauded and promoted, creating the motivation for science students to invest in science communication skills is a crucial task for leaders in science education. It should be clear to every student that the ability to communicate their research is not only beneficial but essential for society. Since the entire general public is impacted by science, the discourse should not be considered optional. The study of science communication needs to be featured as an important and accessible part of every scientist's education.

One major problem today is sifting through the wealth of information at our fingertips. The era of social media and online news sources coupled with easy access keep us bombarded with new information all the time. We are not wired to navigate through that much material on a daily basis. Even a trained critical thinker can become exhausted trying to sort out true credible information versus “fake news” or pseudoscience. People get their information in a bubble that they have (maybe unknowingly) created themselves by selectively engaging with media that already confirm their beliefs. Unfortunately, one consequence of this information overload is people believing nonsense concepts like “alternative facts” that claim a deadly virus is a hoax.

Very successful misinformation campaigns have derailed efforts by scientists to inform the general public about well-established facts in areas of climate change, genetics, vaccines, and others. Many instances of misinformation have arisen recently as a direct result of the world scrambling to identify, prevent the spread, and manufacture a vaccine for the deadly coronavirus, COVID-19. For example, the hydroxyquinoline debacle of 2020 illustrates several gaps among scientists, leaders, and the general public. This issue was handled so poorly that if people had only examined information carefully before jumping to conclusions, they could have ultimately saved the lives of innocent people and millions of dollars.

Hydroxyquinoline is an anti-malaria drug that the former President of the United States Donald Trump promoted to his millions of followers on social media as a treatment for COVID-19, even though there was no supporting evidence of its usefulness. This action was not only irresponsible, but it also caused mass confusion, division, and mistrust within government agencies and the public, and avoidable deaths of citizens. Eventually, the drug was taken out of use but not without great cost. An evaluation of the timeline of events can shed some light on what went wrong.

In March 2020, former president Trump cited a small French study, “Hydroxychloroquine and azithromycin as a treatment of COVID-19: results of an open-label non-randomized clinical trial” by Philippe Gautret et al. According to the study, “A total of 26 patients received hydroxychloroquine and 16 were control patients. Six hydroxychloroquine-treated patients were lost in follow-up during the survey because of early cessation of treatment,” leaving just 20 patients who actually received hydroxychloroquine. Anyone with a basic understanding of statistics, essential in even the simplest level of scientific literacy, would realize that is not a large enough sample to make concrete conclusions about efficacy. Yet the President of the United States lacked that most basic understanding and tweeted to his millions of followers that because people are dying of this deadly disease, the drug should be used immediately.

In April 2020, the publisher issued a statement that the International Society of Antimicrobial Chemotherapy (ISAC) Board “believes the article does not meet the Society’s expected standard” and that although it is “important to help the scientific community by publishing new data fast, this cannot be at the cost of reducing scientific scrutiny and best practices.” They did the right thing, but the misinformation had already spread. The U.S. Food and Drug Administration (FDA) issued an emergency use authorization (EUA), giving hospitals the green light to distribute it to patients. The FDA revoked this EUA in July, warning that hydroxychloroquine can cause “heart rhythm problems and other safety issues, including blood and lymph system disorders, kidney injuries, and liver problems and failure.”

In a shocking display of scientific ignorance, former president Trump made the following statement regarding hydroxyquinoline at a press conference: “We don't have time to go and say, 'Gee, let's take a couple of years and test it out. And let's go and test with the test tubes and the laboratories,' " (qtd. in Crowley). Three days later, the American Heart Association and the America College of Cardiology issued a statement warning the public that hydroxychloroquine has “potential serious implications for people with existing cardiovascular disease. Complications include severe electrical irregularities in the heart such as arrythmia (irregular heartbeat), polymorphic ventricular tachycardia (including Torsade de Pointes) and long QT syndrome, and increased risk of sudden death. The effect on QT or arrhythmia of these two medications combined has not been studied” (Roden et al.). In an effort to corroborate the president’s claims, under pressure from the most powerful government in the world, the National Institute of Health began a large-scale scientific study to investigate the drug in the fight against COVID-19. Despite warnings issued by the FDA and case studies of deaths resulting from the drug, states stockpiled millions of doses of hydroxychloroquine. These funds could have gone to provide relief for families during the pandemic but were instead wasted because of the president’s rhetoric.

In May 2020, the *Journal of the American Medical Association* published a retrospective study showing that not only was hydroxychloroquine ineffective against COVID-19, but it was also associated with increased incidence of heart attacks (Rosenberg et al.). The NIH and the World Health Organization (WHO) ended clinical trials in June after finding no benefit as a treatment for COVID-19. Now there are millions of doses of an ineffective drug sitting in storage across the country–money spent, perhaps, to win the favor of a corrupt President. Science is political.

Science Magazine reported in June that two papers on hydroxychloroquine, one from the *New England Journal of Medicine* and the other from *The Lancet*, were retracted, yet still cited by over 200 academic articles published in 2020 (Piller). Here, we see a failure by scientists themselves. Perhaps some were motivated by careerism or fell into a quick-fix mindset, wanting to be a hero in a desperate situation. But even in the face of a global emergency such as a pandemic when the public is anxious for answers, information needs to be properly vetted. Science requires peer review, which takes time. It is imperative that both the public and the scientists involved in research employ critical thinking, demonstrate patience, and be especially vigilant in emergency situations where we would be particularly vulnerable to grasping at ostensible solutions.

One organization working to alert people to mistakes in science is the blog, "Retraction Watch." They publish posts and track in a database when science journals retract scientific papers. They note that "mistakes happen. Sometimes these slips are merely technical, requiring nothing more than an erratum notice calling attention to a backwards figure or an incorrect address for reprints. Less often but far more important are the times when the blunders require that an entire article be pulled" (Retraction Watch). The Center for Scientific Integrity is the parent organization of Retraction Watch, and its mission "is to promote transparency and integrity in science and scientific publishing, and to disseminate best practices and increase efficiency in science" (Center for Scientific Integrity). Society would benefit from more organizations like these.

While these organizations are not part of the scientific process, they and others should be embraced as important new components in efforts toward better science and better science communication. Other unorthodox methods of science communication are emerging that have the potential to grow the relationship between science and the general public.

SCIENCE COMMUNICATION: SOME UNIQUE APPROACHES

Recently, there have been several new approaches to science communication. Such worthy efforts to bring scientific literacy to the masses should certainly be supported and promoted. Some were discussed (details below) at the 2019 conference of the National Association of Science Writers (NASW) in a session called “Beyond the press release: New ways to get your research story out” (NASW).

One website, “The Conversation,” contains articles written by scientists aimed at the general public. They operate on a creative commons basis, so others can reprint and share the information. They describe their site as a “nonprofit, independent news organization dedicated to unlocking the knowledge of experts for the public good” (The Conversation). The idea is to make it easy for scientists to pitch ideas and work with staff editors to create news coming out of academia that will spark public interest (NASW).

Another website, “Reddit,” has a page called “AskScience,” which is a direct outreach page from scientists to the public. It is easy to set up and access, and people can ask questions and chat with scientists about their area of research. As of 2019, AskScience had 18 million subscribers (NASW).

Comedian and neuroscientist Shannon Odell communicates science through comedy sketches. She learned from her research that laughter eases stress and creates social bonds, both of which produce an environment conducive to reception and learning. She hopes to teach others about neuroscience through her comedy routines (NASW).

Schools and universities should play a larger role in organizing and advocating for science. Many unique opportunities to engage with the public are currently in the works. As part of Rutgers University's Science Communication Initiative, a webinar on December 8, 2020 called "Communication in the Wild: Engaging Diverse Audiences with Science" discussed a program that places graduate student scientists with local children to teach them about a variety of scientific fields through hands-on activities. The Rutgers Science Explorer, or "Science Bus," is a 40-foot-long bus that travels to middle schools throughout the school year to engage children in STEM areas (Rutgers). According to their website, "this unique interaction between scientists and students is a unique opportunity to foster community engagement and scientific literacy in communities located within a 50 miles radius of Rutgers New Brunswick Main Campus…Our goal is to bring contemporary science and mathematics into middle school classrooms" (Rutgers). The science bus is a noteworthy model for other communities in finding ways to forge connections between scientists and young schoolchildren.

CONCLUSION

We are at an important juncture where we have the opportunity to restore the public's trust in science. It is crucial that we take this opportunity to convey the value of scientific literacy and how it can benefit everyone and the planet.

Parents can begin at home by exposing their young children to science texts. We need to elect politicians who will enact policy with requirements for scientific literacy education. We also need oversight to ensure that the appropriate materials are manufactured to give educators the tools they need to succeed.

Journalists must understand scientific processes and engage with the public in responsible ways. All scientists and science writers should receive better training on engaging with audiences about scientific topics. As the CUSP model indicates, we need to bring the general public directly into discourse about science, as they should be, since it impacts their lives.

There are many creative ways to reach people in our ever-changing world of new forms of media. We need bold thinkers to keep coming up with new ways to reach people because we need an empowered general public that possesses the facility to distinguish between pseudoscience and science, misinformation/propaganda, and truth. Any effort to get scientists out there sharing and discussing their research with citizens is a good one. In addition, science advocates should help promote, organize, and share information.

Not only is all of the above called for, but scientists themselves need to step up too. Science has a reputation for being mysterious, exclusive, and inaccessible, but it does not have to be that way. Scientists have the power and maybe even the responsibility to change that narrative, share their stories, and get people excited about science.

We need a movement to ensure that future generations to come share the value and appreciate all that science does to enhance their lives. If we allow scientific illiteracy to persist, the results could be catastrophic. Now is our chance to rebuild the public's trust in science.

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