BRAINIACS
BRAIN IMAGING AND COMPUTING SCIENCES

2021 Volume 2
Issue 1 Edoc M85EC99EE

Truth in Science*

S. Koby Taswell, Anousha Athreya, Madhavi Akella, and Carl Taswell†

Abstract

Truth, honesty, and integrity remain crucial to the pursuit of science as a self-correcting discipline to explore, discover, and process information about the world around us. When following the scientific method, we hypothesize, experiment, and repeatedly retest our results, investigating whether or not those results can be confirmed as reproducible and valid. Conducting this process rigorously with unbiased and objective investigations enables greater confidence in obtaining results we consider more reliable and trustworthy. Such truthful information can be used to avoid harm and prevent injury by those who may wish to apply it in their daily lives in the form of a medicine, machine, or method of some kind. However, in recent years, some scientists and lay persons have violated these tenets of truth in science to further their professional or personal agenda by spreading false information in scientific literature and on social media. This misconduct can be evaluated by assessing the authors' awareness of the document's truthfulness prior to publishing it and their willingness to correct the mistakes and false information when brought to their attention. Identifying these key characteristics about incidents of scientific misconduct enables analysis and introduction of a consistent collection of definitions and criteria for the terms *mis-information, dis-information, anti-information, caco-information, and mal-information*. Clarifying different categories of misconduct in this manner should enable more effective interventions to remediate and/or prevent each one appropriately. Without adequate safeguards to maintain reproducible science as a self-correcting endeavor with retractions of publications when necessary, false information will continue to pollute the published literature and threaten the core of science.

Keywords

Scientific reproducibility, research integrity, mis-information, dis-information, anti-information, caco-information, mal-information.

Contents

*Document received 2020-Dec-28, published 2021-Dec-31, revised 2022-Jan-19.
†All authors affiliated with Brain Health Alliance Virtual Institute, Ladera Ranch, CA 92694 USA; C. Taswell also with University of California San Diego School of Engineering; correspondence to CTaswell at Brain Health Alliance.

What is 'Truth' in Science?

Truth is a simple concept to understand; yet it poses challenges. The Merriam-Webster.com dictionary gives four different definitions with multiple variations [1], while Dictionary.com gives six different versions [2]. According to definitions at both sites, truth generally refers to the state of something being factual and in accordance with reality. On the surface, the truth seems simple enough, but when digging deeper, one notices the underlying issue: humanity. Every human has a different perspective with which they view and understand the world. Hopefully, this perspective is based in reality, but it is occasionally constructed by imagination, delusion, misperception, or misunderstanding of reality. To further complicate matters, when we as humans try to define and discuss truth, we often do so from the perspective of a certain occupation or personal belief structure, including religion, philosophy, science, and many other alternatives. In most definitions, truth is an unchanging absolute, written and carved into stone for all time. An idea that was, is, and will always be true, but one perspective stands out from the others: science.

In science, truth is a changing, growing, and evolving creature which we could best define as a rational understanding of the world justified with the collected evidence currently available to scientists. We discover truth by employing a set of standardized procedures called the scientific method. By following variations of the scientific method, we can find the essence of science: reproducibility. The scientific method begins when a scientist formulates a hypothesis and then tests it with

experiments. Once sufficient evidence has been found to prove this hypothesis right or wrong, the investigating scientist accepts this hypothesis as either true or false in accordance with the evidence they have gathered. This methodology provides a practical working understanding of reality, or alternatively proves that a certain hypothesis is most assuredly not true based on what is currently known about reality. Later, when a colleague retests that experiment to verify the results, the 'truth' of the concept is put to the test yet again, and perhaps again by other scientists, until the scientific community has accepted the results to be representative of the underlying truths of reality. If a test fails, the researchers might test it further with more scrutiny and care, changing the experiment slightly, to see if past research misunderstood results or if the failure was a mistake itself. These repeated experiments may yield results of today that support a newly modified truth in place of the previously accepted truth, thus further shaping what is understood about the universe and paving the way to new discoveries of tomorrow.

Thus, our goal in the pursuit of scientific reproducibility should be to forge a self-correcting path which repairs its mistakes over time via repeated experimentation, validation, and verification with factual reporting of observable evidence as part of the simultaneous pursuit of scientific truth. This experimentation is not willy-nilly playing around; rather, a researcher must follow certain methods and meet specific requirements to be considered and accepted as credible. In 1620, to move away from guessing and citation of authorities as means of constructing scientific truth, Francis Bacon wrote the *Novum Organum*, laying the foundation for the scientific method scientists know and use today [3]. With these basic techniques, scientists conduct experiments to test, evaluate, verify, re-examine, and reverify hypotheses, investigating them in controlled environments where a researcher can be certain that nothing else could cause the observed behavior.

The real world consequences that result from failures represent another important distinction that derives from the scientific perspective of truth in contrast to other perspectives. If a historian hypothesizes about past events from millennia ago, there is little possibility for direct and immediate life threatening consequences; however, that is not the case in science. A new medication has both the capacity to heal or hurt, a new car has the ability to transport someone either to their destination or death, and new agricultural techniques can help feed millions or cause famine. By testing and investigating every aspect of a hypothesis, science can help ensure the safety of these inventions and reduce the likelihood of injury or harm caused by them. This discussion assumes that every scientist conducting scientific investigations engages in honorable conduct with transparency, honesty, and integrity when adhering to and following the guidelines and practices of the scientific method and scientific reporting in their entirety. This assumption also requires that if and when mistakes do occur, then the scientists who made those mistakes must be willing, ready, and able to correct their mistakes if and when brought to their attention. However, in the real world, human nature and behavior cause unpredictability in science when various factors influence a person's desire and ability to respect and maintain adherence to research integrity and scientific truth.

Threats to Truth

Truthfulness in science, technology, engineering, and medicine, or lack thereof, has become a perplexing problem due to a decline in transparency and a reluctance by some investigators to maintain reproducibility in the scientific community. Unfortunately, the scientific community has experienced a worsening history of fraud in the past decade which has caused public perceptions of dishonesty. Indeed, these perceptions by the public may in and of themselves provide indications of the extent of fraud within the scientific community itself. Fraud in science can take many forms, whether it be ethics violations, plagiarism, censorship, falsification, fabrications, and falsehoods or other forms of deceptive misrepresentations of the truth. High profile cases of fraud have identified scientists who falsified results in favor of their tested hypothesis. Often, the motivation behind cases of fraud includes seeking attention and recognition in order to 'publish or perish' in the race with others to retain academic positions or obtain grant funding in a ruthlessly competitive environment. Experimental variables are manipulated with the intention of producing positive results, eliminating the possibility of reproducibility for these studies.

Some scientists may even try to misrepresent the work of others as their own in order to receive credit and acclaim in a wrongful manner that harms the victims of their plagiarism. The responsibility to manage complaints reporting allegations of falsifications, fabrications, and plagiarism often passes through professional member organizations, publishers, journals, and into government or academic 'integrity offices' which then 'pass the buck' between each other in an impossible 'Catch 22' no-win scenario [4]. These 'integrity offices' seem all too willing to bury complaints about violations, using sham processes that fail to review the complaints and that otherwise dismiss them 'sweeping them under the rug' while also silencing and censoring the concerns of the complainant [4]. This pursuit of 'fame and fortune' by persons and organizations which prioritize 'grants and glory' over scientific truth must be contrasted with the moral and ethical pursuit of scientific truth with research integrity by those persons and organizations committed to upholding truth and integrity in the conduct of research investigations, especially in medicine where the Hippocratic Oath should be honored and respected.

The most prominent threat to truth includes the abuse of science in politics to propagate falsehoods, causing harm to numerous groups of people. Within the USSR, new political leaders emerged in support of communist-era policies, including Trofim Lysenko, a Soviet biologist. Lysenko believed firmly in the communist revolution and corrupted the standards of science and biology in order to serve communist ideology. His work directly conflicted with tenets of Mendelian genetics, going so far as to deny that genes even existed because he considered them to be fixed without a capacity for change. To prove his claim, he ran poorly designed experiments and often falsified his results in order to obtain praise and acclaim. The recognition he received then allowed him to acquire political power with Stalin who admired his work.

With apparent misunderstandings of and confusions between phenomena related to genetics and epigenetics, Lysenko promoted the Marxist idea that if a plant is exposed to the right environment and stimuli, then it can be remade in future generations. Lysenko began to apply his claims to Soviet crops, attempting to have them sprout at different times of year by soaking them in freezing water at some points and heating up the crops at others. He proclaimed that the plants would pick up environmental cues and inherit the beneficial traits, promising to boost crop yields across Russia. Soviet leaders, including Joseph Stalin, forced millions of people to join state-run farms in support of Lysenko's experiments, even when they resulted in severe crop failure [5]. Lysenko's methodology caused a widespread famine

Table 1: Definitions of different types of false information

	Aware of falsehood?	Conduct is benign?	Description
Mis-information	not aware	benign	mistaken publication of false information while agreeable to correct the content
Dis-information	aware	benign	publication of false information while agreeable but unable to correct the content until a later time
Anti-information	not aware	not benign	mistaken publication of false information, but refusal to correct the content due to political, financial, social, and/or psychological factors
Caco-information	aware	not benign	intentional and malicious publication of false information with explicit willful refusal to correct the content

Table 2: Comparison of false information types

	Benign	Not benign
Aware	**Dis**-information	**Caco**-information
Not aware	**Mis**-information	**Anti**-information

that killed over 7 million people, prolonging the crisis and limiting the USSR's food supply for years. His actions demonstrated how the falsification of scientific data, combined with the abuse of political power, caused signficant harm to many people in the USSR.

The history of the misuse of psychiatric diagnosis to further the Soviet Union's political power and ideology also demonstrates the past abuses of science in the former USSR. In the 1970s, the Soviet Union considered those who opposed their regime to be "mentally ill." As a result, hospitals saw an increase in the diagnosis of sluggish schizophrenia and individuals with "reform delusions" and "struggles with the truth". These diagnostic labels were used as pretexts to hospitalize over 1000 dissenters. At the time, literature and knowledge about psychiatric disorders were only available to the Communist Party elites of psychiatry who were often the persons ordering the hospitalizations. The lengths of hospitalization for these patients correlated with the same amount of prison time an offender would receive as a sentence for the corresponding crime [6]. Using psychiatric diagnosis, the Soviet Union was able to hide thousands of imprisonments under their medical abuse.

History has also observed this pattern, with the refusal to recognize science and instead the misuse of science, emerge in the past leadership of South African president Thabo Mbeki. When the Acquired Immune Deficiency Syndrome (AIDS) epidemic ravaged South Africa, causing around 900 deaths per day, Mbeki turned away from the scientific community. At the time, Western researchers had tested and proclaimed that AIDS was a curable virus with the use of expensive and sophisticated medication. Instead of acknowledging the presence of medication and scientific innovation, Mbeki brought AIDS denialists from California to discuss the cause of the disease and publicly reject present scientific wisdom. His understanding of HIV and AIDS was that poverty caused the disease, leading to the collapse of the immune system [7]. Later, he rejected offers of free medication from Western nations and took a vow of silence, refusing to further discuss the issue and his actions. As a result of his inaction, 330,000 people died over this period and 35,000 HIV-infected babies who could have potentially been protected from the virus were born [8]. Ultimately, the South African government failed to prevent the transmission of AIDS by actively refusing tested and available medication that was proven to reduce HIV/AIDS virus transmission. The political abuse of scientific methodology has been present throughout history. Each group used a combination of fake news and false information in order to convey their ideas to the public and maintain political power. This use of propaganda, fake news, and false information has given power to those individuals who sought to further their political gain by abusing scientific standards and undermining truth.

Different Kinds of Information

To combat the spread of fraudulent information, UNESCO published the 2018 handbook entitled "*Journalism, Fake News & Disinformation: Handbook for Journalism Education and Training*", where the authors [9] define three different versions of warped information which can be described by the following:

- **Misinformation**: false information not based on reality, that is believed by the author to be true;
- **Disinformation**: false information not based on reality, that is spread by the author who knows it to be false;
- **Malinformation**: true information based on reality, that is deliberately spread by the author with the intent to harm other persons and society rather than benefit and serve the public interest.

To clarify further with examples, a whistleblower who reports violations of regulations required by law cannot be considered malinformation because it serves justice for public safety, whereas someone releasing private information about their competitor's personal life only serves the author as an ad hominem attack on their competitor. Another nuance to consider: With the advent of social media, disinformation spread intentionally may be propagated as misinformation by others who assume it to be true. Thus, the nature of the information may change contextually depending on who authors it whether the originating authors or the propagating authors. Therefore, with these UNESCO definitions the line distinguishing between disinformation and misinformation may be ambiguous and result in situations wherein one accused of spreading disinformation may claim they merely misunderstood in an attempt to whitewash themselves of responsibility for the falsehoods.

In each scenario of UNESCO's definitions for misinformation, disinformation and malinformation, the consequences are somewhat similar, resulting in at least the disenfranchisement, if not harm (social, physical, or psychological), of a group or individual. The importance

of identifying the differences between misinformation, disinformation, and malinformation is that it enables an upholder of truth to handle the situations differently as appropriate to each case. For the simplest scenario of misinformation, one can combat it by spreading true information within a social community and attempting to remove the offending misinformation. Disinformation can be combatted with a variety of different methods combining personal, social, and legal interventions depending on the case. For instance, slander and libel with propagating lies could be stopped via either social intervention or the legal action of cease and desist requests, while propaganda with falsified allegations to incite violence will more likely end in a civil lawsuit if not a criminal lawsuit.

Although the UNESCO definitions have been useful for discussing issues related to publishing malicious and/or false information, they do not adequately address concerns about both (a) the authors' awareness of the false nature of the content published and also (b) their subsequent responsiveness to requests for correction of mistakes in the publication. Whereas UNESCO's definitions of misinformation and disinformation have been based solely on the author's awareness of the falsehood prior to publishing it, a more effective approach supporting intervention and remediation should consider how the author responds when the falsehood is brought to their attention. Defining and *inferring* benign versus non-benign motive, intent, and purpose by divining what thoughts may have been in the authors' minds *before* publication remains a difficult and opinionated debate. In contrast, *proving* benign versus non-benign motive, intent, and purpose by observing the authors' actions *after* publication becomes a very simple and easy task. Publishers can readily document the authors' responsiveness, willingness, and agreement to correct their mistakes, including both omissions and falsehoods, in their own published documents. If authors and/or their representatives fail to respond and correct their mistakes, then publishers can document the authors' failure to respond appropriately and to correct what can shown to be provably false claims in the published documents.

Therefore, to provide our set of definitions for fake and false information, we extend the UNESCO definitions to include four categories of false information with the addition of **anti-information** and **caco-information** as follows:

- **Mis-information**: the authors were **not aware of the falsehood** before publication, and **agree to correct** the published literature after the mistakes are brought to their attention;
- **Dis-information**: the authors were **aware of the falsehood** before publication, but due to possible extenuating circumstances were unable to make corrections prior to publication, and then later **agree to correct** the published literature when given the opportunity to do so;
- **Anti-information**: the authors were **not aware of the falsehood** before publication, and the authors **refuse to correct** the published literature after the mistakes are brought to their attention;
- **Caco-information**: the authors were **aware of the falsehood** before publication, submitted the false information with purposeful intent to spread it, and the authors **refuse to correct** the published literature when given repeated opportunities to do so;

where the latter prefix *caco-* has been chosen consistent with its origin and etymology: "from Latinized form of Greek kakos 'bad, evil' ... the ancient Greek word was common in compounds; when added to words already bad, it made them worse" [10].

These new definitions refocus an analysis of fake and false information with a more rigorous and explicit set of criteria for four distinct categories of incorrect, invalid, and/or otherwise provably false information that is not based in reality. This new analysis supports the information and library sciences community with better tools to characterize the behavior and misconduct associated with the spread of false information, in contrast to a simpler set of terms with definitions that mixes and confounds both false and true information in a classifying categorization. By better stratifying and identifying different kinds of false information, the peer review community can address these concerns whether they arise in the scientific literature or in social media and spread as false information either by professional scientists or by lay persons, each with different kinds of awareness, motives, and observable behavior both before and after publication. Our redefinition of the term *dis-information* according to the criteria summarized in Tables 1 and 2 does allow for inclusion in this category of those authors who some may call "deliberate liars" as long as these authors who published the false information "agree to correct their mistakes". In this regard, our redefinition of *dis-information* differs from the past UNESCO definition for *disinformation* [9]. However, our new set of definitions for the four categories of false information does avoid any conflict with various interpretations of the past UNESCO definition for *malinformation* [9], which we paraphrase and alternatively redefine here with the following statement:

- **Mal-information**: the use with malicious intent of true or partially true information that may be based in reality, but abused in violation of laws, regulations, or codes of conduct, and then published with the purpose of harming other persons, groups of individuals, or the common good of society and public benefit.

For clarity and consistency grouped as a collection of five terms according to our definitions and criteria for usage, we will write all five words with the hyphens as *mis-information, dis-information, anti-information, caco-information, and mal-information* separating the prefixes *mis-, dis-, anti-, caco-, and mal-* from the term *information*. In contrast, when discussing usage according to the UNESCO collection of three terms [9], we will write their three words without the hyphens as *misinformation, disinformation, and malinformation*.

The new definitions that we have introduced for different categories of false information should each be handled and applied appropriately to the relevant scenarios by all parties involved in each scenario. In both lay media and scientific literature, benign forms of false information can be easily corrected by the cooperation of the original authors combined with the support and assistance of the publishers. Authors may readily show with their actions after publication that their mistakes were benign by demonstrating their responsiveness and willingness not only to admit their mistakes but then to correct those mistakes and repair any harm caused. Unfortunately, non-benign forms of misconduct with false information pose greater difficulties when authors either remain reluctant to respond, fail to respond, or otherwise respond with a repeated refusal to cooperate and correct their mistakes. Without the cooperation of authors in correcting the published record of scientific literature, publishers must then resort to the use of enforcement interventions including when necessary and appropriate the retraction of the paper regardless of the author's wishes. In fact, rates of retraction by non-authors have increased in recent decades

[11] and further increased in recent years during COVID-19 [12]. In the event that the authors' non-benign false information leads to injury or loss of life, legal actions in courts of law may be pursued by the victims' survivors resulting in the authors' loss of funding, employment, or other forms of more strict censure and/or legal consequences.

Case Examples

In the history of science and medicine, let's ask a hypothetical question about the Greek physician, surgeon, scientist, and philosopher Galen [13] as the example case: Should the published work of Galen, accepted as truth at the time he authored and published his research, now be considered mis-information according to the definition explained in the previous section? Our definitions classifying an author's published writings require evaluation of the author's awareness and understanding both before and after publication if and when mistakes in the author's writings are brought to the attention of the author. Does the author or the author's representatives agree to correct or refuse to correct any mistakes or misunderstandings of the available evidence at the given time and place for the given situation and publication?

Galen is no longer alive. Who should be his living representatives to answer these questions on his behalf? If Galen misrepresented a misperception and misunderstanding of observed evidence about the world around him, and if magically Galen could be brought back to life to answer our questions now given more recent discoveries and facts about the world around us in the present, would he agree to correct any mistaken claims or would he refuse to update and change them? In contrast, questions by living publishers and editors to living authors with observation of responses from those non-deceased authors about their writings and behavior can in reality be reported in a non-hypothetical manner. In other words, living authors — who are not yet dead but who have made mistakes — can either agree to correct their mistakes or not correct them, especially when those mistakes can be proven to have misrepresented the observed realities of the world around us. Then the publishers and editors of medical-scientific journals can decide to retract or not to retract those published papers containing false information depending on whether the author's conduct after publication clarifies which of the four kinds of false information the author published in the editor's journal.

Unless one believes in magical resurrections, this question about Galen remains entirely hypothetical and neither consistent nor compatible with our current definition for mis-information unless either his descendants, his students or other historians step forward to argue on his behalf. However, in this scenario, a modern-day ethicist might also question whether or not Galen authorized any of his representatives to speak on his behalf. Applying the principle that 'discretion is the better part of valour', we conclude that the question remains moot in this case considering the theoretical possibility of mis-information by Galen and thus impossible to answer. Therefore, we state simply that evaluation of mis-information cannot be determined nor declared and applied retroactively to the published research of Galen.

As a contrasting example of a case beyond the realm of medical-scientific literature, but rather one involving modern-day publishing in other spheres of life such as politics, definitions for the four kinds of false information also require an analysis of the author's conduct both before and after publication. Analysis of modern-day life and behavior of politicians as authors should be especially easy, convenient, and verifiable in digital environments for which mistakes in published content can be corrected almost daily if not hour-by-hour by reporters in the news media. As public figures holding public office, these politicians speaking, writing, and posting publicly cannot claim privacy, confidentiality, or secrecy of any kind regarding their published mistakes. Indeed, many web-enabled news sources have been updating their published articles with corrections as soon as mistakes are made known to the editors and correction of those mistakes have been approved by the editors and publishers. In the current free-for-all information wars of the social media world, where information spreads quickly and has often been proven to be wrong, incorrect, or invalid, some companies are now attempting to crack down on this propagation of false information. Usually, these interventions have been achieved with remediation simply by deletion of the offending post, and depending on severity of the incidents involved, possible suspension or deletion of the author's account.

Most famously, this sequence of events occurred with former US president Donald Trump shortly after the 2021 January 6 insurrection for which Trump's Twitter posts incited violent riots at the nation's capitol. Two days later, Twitter deleted both Trump's posts and his account, discussing their reasoning in a 2021 January 8 blog post [14]. The published policies called simply "The Twitter Rules" prohibit Twitter customers from using Twitter social media services to affect elections, to violate copyright and trademark laws, or to spread synthetic or manipulated media likely to cause harm [15]. Twitter's moderation of the content on its own platform remains legally permissible (regardless of calls for alleged 'free speech') because Twitter is a company unto itself and users must agree to the company's terms and conditions if they wish to use its services. Despite the rules that Twitter attempts to impose on moderation of content, Twitter has been ranked very low on cracking down on false information, because it has focused more on stopping the spread of obscene content and hate speech [16] rather than all kinds of false information.

Contributing Influences

The deficits of truth in the scientific community have resulted not only in a loss of trust in science, but also in the loss of lives in our communities. Hence, we are faced with the questions: 'What are the influences that contribute to these deficits of truth and loss of trust?' and 'What are the incentives and disincentives that can be correlated with the presence or absence of an individual's or organization's willfull disregard for truth in science?'

Scientists face increasing competition for research funding and academic positions with reviews that may use bibliometric measures such as citation counts of published papers to evaluate the success of their career. This pressure can ultimately undermine the truth due to confirmation bias. Scientists are more likely to favor information that they believe will enhance their professional or personal goals. In the court of public opinion, researchers hope that their results will be trusted, accepted, and reproducible. Standards should be upheld in scientific research to assure the validity of methodology, data, and results. When different kinds of bias or discrepancies appear in the conduct of science, ideally researchers turn to existing standards in order to acknowledge these differences in results and be as transparent as possible in scientific reporting. However, the phenomenon of confirmation bias can get reinforced when scientists assign a greater weight to evidence

that confirms their original hypothesis, especially when insufficient attention has been addressed to the alternative hypothesis [17], [18]. When confirmation bias has not been acknowledged and addressed appropriately, this failure to maintain an impartial objective investigation demonstrates another way in which truth can be lost when deviating from standards of truthful reporting of methods and analysis.

A similar bias can be present with positive reporting, where researchers only pursue 'publishable' results or those results deemed *significant*. Negative results frequently do occur when following the scientific method, and may lead scientists to revisit procedures, results, and methodology before conducting the experiment again. Although they may not immediately benefit that particular investigator according to traditional patterns of recognition for scientists, nevertheless, these negative results benefit the community when published to identify those approaches and methodologies that resulted in apparent failures, thus enabling all to consider course corrections on research agendas for all colleagues working in the field of inquiry where the failure occurred. Unfortunately, that has not tended to happen, and negative results, regardless of their*significance* may not get published. Papers are less likely to be published if they yield results that fail to support the tested hypothesis. Instead, these publication pressures have increased this positive bias by favoring scientists who submit only their positive results in competitive academic environments. Indeed, positive bias reporting often leads to one of two outcomes: either researchers will submit only their positive results, or researchers fall victim to falsification and fabrication as the means of manipulating data in favor of the positive results. Both confirmation bias and positive reporting bias result in positive feedback from the scientific community. Because papers that report positive results attract more interest and funding, peer reviewers and journal editors tend to favor them for acceptance to publication [19].

After spending years investing time, energy, and effort on a specific research project, it can be difficult for some investigators to accept unsatisfactory results. Sometimes this contributing influence, a psychological factor involving human emotion, can mislead investigators. In their desire to achieve a goal, individuals may experience a psychological rationalization to manipulate their experiments fraudulently in order to sustain and fund their research agenda. Such manipulation could occur especially when the investigator misperceives barriers blocking or preventing the continued pursuit of that particular research agenda in the future. If a researcher encounters consistent negative results in their dedicated projects, then they might seek to manipulate data in order to sustain their personal pride and public reputation. If a researcher faces a potential loss of position or resources due to of a variety of factors, including a lack of current results, then they would be more inclined to take the risk of research misconduct out of desperation to maintain their current position [20].

Political motivations can also contribute to a desire or intent to commit scientific fraud. In John F. Kennedy's book *Profiles in Courage*, he outlines two political pressures faced by politicians: the pressure to be liked and the pressure of the constituency and interest groups [21]. While this sentiment is directed at politicians, it can be used to explain why any individual might act the way they do; more specifically, it explains the pressures that scientists and communicators of science face. Scientists may be guided by their own personal political beliefs, their sponsors, or other individuals in a research group. Those who communicate scientific results and studies play a key role in the flow of false information. Often, these individuals are certain journalists or politicians who spread inaccurate scientific information to acquire political capital or financial profits. Those who are centered around sources of communication, such as newscasters or politicians, have the power to mislead and deceive some people that the information propagated, is not false but rather true, even though in fact it is false. This power comes from public-centered platforms that actively seek to control the general public rather than provide accurate information about scientific studies. In these large groups, false information can spread rapidly to the point where combating the four kinds of false information with true information becomes increasingly difficult. However, those who propagate these falsehoods have fallen victim to the political, economic, social, and psychological influences undermining scientific principles of integrity and truth because the individual's personal and professional goals have assumed greater importance for the individual, and displaced any prior commitment the individual may have had to telling the truth and defending truth in science.

Table 3: Percent of misinformation originating from countries and number of COVID-19 related deaths per 100,000 persons [22]

Countries	Misinfo percent	Death rate
India	15.94	34.44
USA	9.75	240.13
Brazil	8.57	291.67
Spain	8.03	187.27

Real World Impact

COVID-19

In December 2019, there was an local outbreak of pneumonia which quickly became known as Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-COV-2) or simply COVID-19. In March 2020, the World Health Organization went on to declare COVID-19 a pandemic. Since then, the virus has claimed the lives of over five million people around the world [23]. But since December 2019, there has not only been a spread of COVID-19, but also of false information. False information during the COVID-19 pandemic has occurred in fraudulent reporting of research and conspiracy theories regarding the virus [24].

When the COVID-19 virus emerged, instead of notifying the World Health Organization about the potential threat the virus posed, the Chinese Communist Party censored information and silenced doctors. While the true motivations behind this action remain unclear, one thing is certain: The Chinese government's minimizing the threat of the virus allowed it to spread quickly turning the epidemic into a pandemic. But this downplaying of truth was not isolated to the Chinese government. In the current era of COVID-19, Americans, more so than the majority of the world, have witnessed the blatant disregard for science result in the deaths of more than 850,000 people. At the time in February of 2020 when serving as President of the United States, Donald Trump acknowledged the threat of COVID-19, stating that it was "more deadly than even [the] strenuous flus". However, in public, Donald Trump not only downplayed the lethality of the viral pandemic, but knowingly spread conspiracy theories and inaccurate information, thereby further undermining truth in science. At one point, Donald Trump even

bizarrely encouraged the nation's top health officials to study whether the injection of disinfectants into the human body could be a means of fighting the virus. Table 3 shows data from a study conducted by Al-Zaman [22] analyzing 9,657 pieces of identified misinformation that originated in 138 countries and fact-checked by 94 organizations. The table shows the percentage of this misinformation that originated from India, the United States, Brazil and Spain, which appear to be the countries most affected by COVID-19 misinformation.

The representation of science in the media is often distorted by politics, an issue extremely evident during the COVID-19 pandemic. Eichengreen *et al.* conducted a review of the impact past global pandemics have had on people's trust of the scientific community. According to the paper, a reason for uncertainty in following standard health protocols was, depending on the individual's background, because of the miscommunication and conflicting opinions of scientists. The more opinions thrown into the mix, the more it was viewed as "signs of bias or dishonesty" and reduced trust in scientists despite the fact that science is intended to *always* represent the proven truth without outside influence [25]. The representation of science in the media is often distorted by politics, an issue extremely evident during the COVID-19 pandemic. But it was not just governments spreading misinformation. In the United States, there was a situation that seemed to be the epitome of misinformation during the COVID-19 pandemic: the Surgisphere Scandal.

On May 22, The Lancet published a paper stating that the antimalarial drug hydroxychloroquine had been associated with an increased risk of death in patients hospitalized from COVID-19. However, the paper was not scientifically sound. The study the paper derived its results from was not a randomized controlled trial; rather, it was taken from a registry of observational data that Surgisphere claimed to have collected from a large population. After the paper was published, the implications of the study, along with those who promoted it, were intensely analyzed and scrutinized. The World Health Organization and the UK Medicines and Healthcare Products Regulatory Agency instructed organizations to suspend use of the drug while the French government deemed the drug could no longer be prescribed to patients, delaying important clinical trials. However, upon closer inspection, the Lancet paper was deemed to have significant discrepancies in the data [26]. The Surgisphere scandal demonstrates how one research paper containing misinformation can have a negative impact on public health policy and clinical trials worldwide.

Biogen's Aduhelm

Alzheimer's Disease (AD) is estimated to affect over 6 million Americans, many of which are age 65 and older [27]. For years, AD research has been dominated by what has been known as the amyloid hypothesis: the theory that the protein amyloid-β was a main cause of AD [28]. To address this theory, different medicines were made with the desired intent of reducing the abnormal deposition and accumulation of this amyloid-β protein in the brain. After a 2007 deal with Swiss startup Neurimmune, the American biotech and pharmaceutical company Biogen began to develop the drug aducanumab, which would later be marketed and sold as Aduhelm. This drug was designed to slow the progression of Alzheimer's disease by reducing the amount of amyloid-β plaque in the brain via the stimulation of the immune system to induce improved clearance of this protein [29], [30].

In 2015, Phase 1 of the trials completed successfully showing that Aducanumab reduced amyloid-β i n patients with early or prodromal AD [31] leading to green lights for further clinical trials. Yet in 2019, Biogen abandoned their Phase 3 clinical trials due to failure to demonstrate improvement in AD patient's cognition and condition [32], only to subsequently begin planning to restart again with Phase 4 in May of 2022 [33]. Meanwhile, one third of patients undergoing treatment with Aduhelm in these clinical trials have experienced severe cerebral edema and inflammation, in some cases leading to death [34], [35]. Testing and research continued, despite concern from numerous scientists [30], [34], [36] within the academic medical community, including the lack of publication in a reputable peer-reviewed journal [37] and the criticism that the inferred conclusion of drug benefits may have been improperly derived from a misreading and misunderstanding of PET brain imaging [38]. Physician scientists from the FDA and investors had concerns as well [39], with debate exchanged by other authors invested in continued research related to the amyloid hypothesis [40], [41] claiming that other anti-amyloid-β monoclonal antibody based treatments are proving successful. With contrasting decisions, the US Food and Drug Administration approved the drug in June 2021 while the European Medicines Agency rejected the drug [42].

Aduhelm did not only come with debated medical concerns. The drug also came at the exorbitantly high cost of $56,000 per year per patient. Initially, it was rejected by the FDA because it did not appear to have any benefit to patients [43]. A pair of journalists, Feuerstein and Garde from the STAT Biotech journal, looked into the story finding that lead scientists from Biogen changed the approval request for the study outcome from an endpoint of slowed AD progression to an endpoint of amyloid-β clearance, even though the clearance of amyloid-β had shaky evidence that it benefited patients. Since the approval, backlash against Biogen has prompted the pharmaceutical company to halve the price from $56,000 USD to $28,000 USD [44]. Regardless of price drops, the original message of a revolutionary new Alzheimer's drug has given false hope to many whose loved ones or themselves are afflicted by the disease, as the medication has not been shown to help patients. This reframing of experimental data and eventual approval of Aduhelm has enabled Biogen to profit from the suffering caused by AD, when it has not yet been demonstrated with compelling evidence that the benefits outweigh the risks of the drug treatment Aduhelm for the dementing illness AD. Perhaps, hopeful scientists genuinely misunderstood data, therefore constituting misinformation, or a drive for financial gain and success influenced the deliberate reframing of data to enable profit. Either way, the deficits of medical-scientific truth and transparency in this case have harmed public trust in medical science.

Fact, Fiction, or Opinion?

In the current mal-information wars, often the biggest hurdle to overcome when advocating for the honest reporting of scientific truth has been the simple question: 'Is a piece of information fact, fiction, or opinion?' With the advent of the internet and worldwide web, it is not difficult to determine the origins of a certain piece of information, but the real issue lies with an individual's perception of it. Even in the face of overwhelming factual evidence, mistrust and false claims of invalidity result in dissemination of false information. In the past year of the COVID-19 pandemic, the world has seen and heard claims of the COVID-19 vaccine containing magnetic tracker chips which connect to 5G [45], government-induced snow to cause the February blizzard in

the US mid-south [46], and a belief that wind turbine noise somehow caused cancer [47]. Acceptance with a belief in such fake information has been rampant, causing one group of authors to conduct a set of studies finding that a high conspiracy theory belief can be associated with low critical thinking skills [48].

From a historical perspective, the rise in conspiracy theories and false information has been a consequence of the information flood in the 21st century. Information sources in the 1970s rapidly switched from newspapers and radio to broadcast news networks (ABC, NBC) that brought information directly to the public. In the 1990s, information sources expanded to the internet, which became an ocean of news and information. The internet brought ease of communication, consolidation of news in news sites and social media, all of which expanded the virtual universe of information flowing to the public. The greater amount of opportunities there were, the greater amount of opinions that flooded these sites, particularly highly politicized forums, broadcast networks, and mainstream outlets. Along with the internet came trolls and bots to wreak havoc among users by intentionally spreading falsified information [49]. In the midst of recent politics, the spread of false information, and an overall decrease in public confidence in science, scientific communication has fallen over the past few decades with a decline in respect for both science and medicine. As demonstrated during the COVID-19 pandemic, this decline in trust and confidence in science and medicine has presented itself in the politicization of scientific results with misrepresentations and misinterpretations of those results. Miscommunications have occurred when government reports, journalism, or talk shows have discussed the present state of COVID-19 research based on incomplete reports of studies or studies that have not been adequately peer-reviewed [50].

Scientific Communication

How can we improve scientific communication with the public? Kappel and Holmen [51] discuss two paradigms of existing scientific communication: the dissemination paradigm, and the public participation paradigm. In the dissemination paradigm, scientific communication has been considered to be the process of transmitting information from scientific experts to the public, either through education programs, television documentaries, science magazines and blogs, or broadcast communication through news sites. This dissemination paradigm has been based on a unidirectional or one-way communication channel from professional scientists to lay persons, ideally with a free flow of information that adheres to the truly fair open access principles of the Fair Open Access Alliance [52]. In contrast, the public participation paradigm has been conceptualized as a bidirectional or two-way communication channel between the public and scientific experts, which also enables dialogue between multiple different stakeholders including government regulators and corporate providers of products and services. This bidirectional communication paradigm also includes the model of *citizen science* with encouragement and support for citizens to participate in open clinical trials [53] and open science research [54], an endeavor which enlists the public in helping to collect large quantities of data especially when organized in a specific region for a particular identified problem. Such data collection can be processed by a team of experts who then analyze results that are shared with the public, following the older dissemination model of communicating scientific progress from experts to lay persons. Therefore, it is imperative that we seek to improve the public's opinions and beliefs about science, and to promote and build public acceptance and involvement in scientific research with transparent and truthful disclosures in scientific reporting. During infectious disease pandemics, scientific communication with the public should be explained with respect to both known and unknown risks and benefits anticipated from research innovation during the spread of disease, especially up-to-date information on the development of vaccines and therapeutics as well as the efficacy of behavioral and social interventions to protect public health and safety.

Scientific research requires conformance with standards for methodology, quality, accountability, effective communication, and truthful attribution and reporting. Without them, scientific reproducibility falls into uncertainty. The validity of scientific information and reporting also depends on the entire community of researchers who strive to contribute their work to recorded scientific history, supported by the experimental evidence from current research based on the foundation of past research. This work should adhere to the tenets of creative authenticity and fair citation of past relevant work in order to avoid scientific misconduct [4]. Science and the scientific method remain powerful means of inquiry and investigation, and with them, we can discover vast amounts of information about anything. As Steven Pinker states, the best tool we have at our disposal is one at the heart of the human condition: rationality [55]. We consider and evaluate, think and analyze, contrast and compare, and then make judgements and decisions, all in an effort to contribute to progress. Rational tools can be used in every aspect of science, and also taught to assure a better understanding of science by the public, as we continue to seek answers to questions about the world around us. Reproducible experiments with validation of accurate and reliable results conducted with research integrity and truthful reporting constitute the core requisites of the scientific method in which we re-evaluate current research in the context of past research to build continuously on the foundations of science, technology, engineering, and medicine. After all, what is science without truth?

Acknowledgments

The authors express their appreciation to Prof. Arthur Caplan of New York University School of Medicine and Prof. Daniel Sewell of University of California San Diego School of Medicine for their valuable contributions to the preparation and content of this document.

Citation

Brainiacs 2021 Volume 2 Issue 1 Edoc M85EC99EE, Pages 1 – 10
Title: "Truth in Science"
Authors: S. K. Taswell, A. Athreya, M. Akella, and C. Taswell
Dates: received 2020-Dec-28, published 2021-Dec-31, revised 2022-Jan-19, endorsed 2022-Jan-19, typeset 2022-Feb-06

Contact: CTaswell at Brain Health Alliance
URL: www.BrainiacsJournal.org/arc/pub/Taswell2021Truth
PDP: /Nexus/Brainiacs/Taswell2021Truth
DOI: /10.48085/M85EC99EE

References

[1] Merriam-Webster Dictionary, *Truth*. Online: https://www.merriam-webster.com/dictionary/truth (visited on 10/10/2021).

[2] Dictionary.com, *Truth*. Online: https://www.dictionary.com/browse/truth (visited on 10/10/2021).

[3] Francis Bacon, *Novum Organum (New Instrument)*. 1620, Originally published 1620, reprinted 2019 by Wentworth Press, ISBN: 978-0526322435.

[4] S. K. Taswell, C. Triggle, J. Vayo, *et al.*, "The hitchhiker's guide to scholarly research integrity," in *2020 ASIS&T 83rd Annual Meeting*, (Oct. 22, 2020), vol. 57, Wiley, 2020, e223. DOI: 10.1002/pra2.223. Online: asistdl.onlinelibrary.wiley.com/doi/abs/10.1002/pra2.223.

[5] S. Kean, *The Soviet era's deadliest scientist is regaining popularity in Russia*, Dec. 2017. Online: https://www.theatlantic.com/science/archive/2017/12/trofim-lysenko-soviet-union-russia/548786/.

[6] R. Van Voren, "Abuse of psychiatry for political purposes in the USSR: A case-study and personal account of the efforts to bring them to an end," in *Ethics in Psychiatry*, Springer, 2010, pp. 489–507.

[7] H. Schneider and D. Fassin, "Denial and defiance: A socio-political analysis of AIDS in South Africa," *Aids*, vol. 16, S45–S51, 2002.

[8] S. Boseley, *Mbeki aids denial 'caused 300,000 deaths'*, Nov. 2008. Online: https://www.theguardian.com/world/2008/nov/26/aids-south-africa.

[9] C. Wardle and H. Derakhshan, "Thinking about 'information disorder': Formats of misinformation, disinformation, and mal-information," in *Journalism, Fake News & Disinformation: Handbook for Journalism Education and Training*, C. Ireton and J. Posetti, Eds. Paris: UNESCO, 2018, ch. 2, pp. 44–55, Includes bibliographical references. Online: http://digitallibrary.un.org/record/1641987.

[10] Online Etymology Dictionary, *Etymology of word prefix caco-*. Online: https://www.etymonline.com/word/caco- (visited on 12/29/2021).

[11] B. K. Redman, H. N. Yarandi, and J. F. Merz, "Empirical developments in retraction," *Journal of Medical Ethics*, vol. 34, no. 11, pp. 807–809, Nov. 2008. DOI: 10.1136/jme.2007.023069.

[12] N. S. L. Yeo-Teh and B. L. Tang, "An alarming retraction rate for scientific publications on coronavirus disease 2019 (COVID-19)," *Accountability in Research*, vol. 28, no. 1, pp. 47–53, Jun. 2020. DOI: 10.1080/08989621.2020.1782203.

[13] Wikipedia, *Galen (aka Aelius Galenus, Claudius Galenus, or Galen of Pergamon)*. Online: https://en.wikipedia.org/wiki/Galen (visited on 01/16/2022).

[14] Twitter Inc., *Permanent suspension of @realDonaldTrump*, Jan. 8, 2021. Online: https://blog.twitter.com/en_us/topics/company/2020/suspension.

[15] Twitter Inc., *The Twitter rules*. Online: https://help.twitter.com/en/rules-and-policies/twitter-rules (visited on 10/10/2021).

[16] L. Nott and B. Peters, "Free expression on social media," *Freedom Forum Institute*, 2021. Online: https://www.freedomforuminstitute.org/first-amendment-center/primers/free-expression-on-social-media/.

[17] M. E. Oswald and S. Grosjean, "Confirmation bias," *Cognitive illusions: A handbook on fallacies and biases in thinking, judgement and memory*, vol. 79, 2004.

[18] P. Guiney, W. Goodfellow, and T. J. Canfield, *An overview of confirmation bias in science: Examples and opportunities for improvement*, Nov. 15, 2020. Online: https://cfpub.epa.gov/si/si_public_record_Report.cfm?dirEntryId=350904&Lab=CESER.

[19] D. Fanelli, "Do pressures to publish increase scientists' bias? An empirical support from US states data," vol. 5, no. 4, E. Scalas, Ed., e10271, Apr. 2010. DOI: 10.1371/journal.pone.0010271.

[20] National Academies of Sciences Engineering Medicine, *Fostering Integrity in Research*. National Academies Press, 2017, ISBN: 9780309391252.

[21] John F. Kennedy, *Profiles in Courage*. New York: HarperPerennial Modern Classics, 2006, originally written in 1955, first published in 1956, Deluxe Modern Classic edition reprinted in 2013, ISBN: 9780062278791.

[22] S. Al-Zaman, "Prevalence and source analysis of COVID-19 misinformation of 138 countries," *medRxiv*, 2021. DOI: 10.1101/2021.05.08.21256879. eprint: https://www.medrxiv.org/content/early/2021/05/12/2021.05.08.21256879.full.pdf. Online: https://www.medrxiv.org/content/early/2021/05/12/2021.05.08.21256879.

[23] E. Dong, H. Du, and L. Gardner, "An interactive web-based dashboard to track COVID-19 in real time," *The Lancet Infectious Diseases*, vol. 20, no. 5, pp. 533–534, May 2020. DOI: 10.1016/s1473-3099(20)30120-1.

[24] J. Roozenbeek, C. R. Schneider, S. Dryhurst, *et al.*, "Susceptibility to misinformation about COVID-19 around the world," *Royal Society Open Science*, vol. 7, no. 10, p. 201199, Oct. 2020. DOI: 10.1098/rsos.201199.

[25] B. Eichengreen, C. G. Aksoy, and O. Saka, "Revenge of the experts: Will COVID-19 renew or diminish public trust in science?" *Journal of Public Economics*, vol. 193, p. 104343, 2021, ISSN: 0047-2727. DOI: 10.1016/j.jpubeco.2020.104343. Online: http://www.sciencedirect.com/science/article/pii/S0047272720302073.

[26] C. Offord, *The Surgisphere scandal: What went wrong?* Oct. 2020. Online: https://www.the-scientist.com/features/the-surgisphere-scandal-what-went-wrong--67955.

[27] J. Cubanski and T. Neuman, *FDA's approval of Biogen's new Alzheimer's drug has huge cost implications for Medicare and beneficiaries*, online, Jun. 2021. Online: https://www.kff.org/medicare/issue-brief/fdas-approval-of-biogens-new-alzheimers-drug-has-huge-cost-implications-for-medicare-and-beneficiaries/.

[28] F. Kametani and M. Hasegawa, "Reconsideration of amyloid hypothesis and tau hypothesis in Alzheimer's disease," *Frontiers in Neuroscience*, vol. 12, Jan. 2018. DOI: 10.3389/fnins.2018.00025.

[29] J. Ferrero, L. Williams, H. Stella, *et al.*, "First-in-human, double-blind, placebo-controlled, single-dose escalation study of aducanumab (BIIB037) in mild-to-moderate Alzheimer's disease," vol. 2, no. 3, pp. 169–176, Jun. 2016. DOI: 10.1016/j.trci.2016.06.002.

[30] L. Schneider, "A resurrection of aducanumab for Alzheimer's disease," vol. 19, no. 2, pp. 111–112, Feb. 2020. DOI: 10.1016/s1474-4422(19)30480-6.

[31] J. Sevigny, P. Chiao, L. Williams, *et al.*, "Aducanumab (BIIB037), an anti-amyloid beta monoclonal antibody, in patients with prodromal or mild Alzheimer's disease: Interim results of a randomized, double-blind, placebo-controlled, phase 1b study," vol. 11, no. 7S_Part_6, Jul. 2015. DOI: 10.1016/j.jalz.2015.07.367.

[32] Biogen, "Biogen and Eisai to discontinue phase 3 ENGAGE and EMERGE trials of aducanumab in Alzheimer's disease," *Biogen Investor Relations*, 2019. Online: Howhttps://investors.biogen.com/news-releases/news-release-details/biogen-and-eisai-discontinue-phase-3-engage-and-emerge-trials.

[33] Biogen, "Update on the phase 4 confirmatory study of Aduhelm," *Biogen Investor Relations*, 2021. Online: https://investors.biogen.com/news-releases/news-release-details/update-phase-4-confirmatory-study-aduhelmr.

[34] J. Karlawish and J. D. Grill, "The approval of Aduhelm risks eroding public trust in Alzheimer research and the FDA," *Nature Reviews Neurology*, vol. 17, no. 9, pp. 523–524, Jul. 2021. DOI: 10.1038/s41582-021-00540-6.

[35] M. Terry, "Study: Biogen's Aduhelm caused brain swelling in over one-third of study participants," *BioSpace*, 2021. Online: https://www.biospace.com/article/study-biogen-s-aduhelm-caused-brain-swelling-in-over-one-third-of-patients/.

[36] B. Kallmyer, M. Daven, L. Thornhill, *et al.*, "Impact of Aduhelm approval on care and policy," *The Journal of Prevention of Alzheimer's Disease*, pp. 1–2, 2021. DOI: 10.14283/jpad.2021.42.

[37] S. Gandy, D. S. Knopman, and M. Sano, "Talking points for physicians, patients and caregivers considering Aduhelm infusion and the accelerated pathway for its approval by the FDA," *Molecular Neurodegeneration*, vol. 16, no. 1, Nov. 2021. DOI: 10.1186/s13024-021-00490-z.

[38] P. F. Høilund-Carlsen and A. Alavi, "Aducanumab (marketed as Aduhelm) approval is likely based on misinterpretation of PET imaging data," *Journal of Alzheimer's Disease*, pp. 1–4, 2021, ISSN: 13872877, 18758908. DOI: 10.3233/JAD-215275.

[39] G. C. Alexander, S. Emerson, and A. S. Kesselheim, "Evaluation of aducanumab for Alzheimer disease," *JAMA*, vol. 325, no. 17, p. 1717, May 2021. DOI: 10.1001/jama.2021.3854.

[40] M. N. Sabbagh and J. Cummings, "Open peer commentary to 'Failure to demonstrate efficacy of aducanumab: An analysis of the EMERGE and ENGAGE trials as reported by Biogen December 2019'," *Alzheimer's & Dementia*, vol. 17, no. 4, pp. 702–703, Nov. 2020. DOI: 10.1002/alz.12235.

[41] J. Cummings, P. Aisen, C. Lemere, *et al.*, "Aducanumab produced a clinically meaningful benefit in association with amyloid lowering," *Alzheimer's Research & Therapy*, vol. 13, no. 1, May 2021. DOI: 10.1186/s13195-021-00838-z.

[42] M. Brooks, "Aducanumab for Alzheimer's gets thumbs down in Europe," *Medscape Medical News*, 2021. Online: https://www.medscape.com/viewarticle/965062.

[43] A. Feuerstein and D. Garde, "Biogen's reckoning: How the Aduhelm debacle pushed a troubled company and its fractured leadership to the brink," *STAT*, 2021. Online: https://www.statnews.com/2021/12/08/biogen-aduhelm-al-sandrock-michel-vounatsos-company-reckoning/.

[44] J. Walker, "Biogen cuts price for Alzheimer's drug Aduhelm by half," *Wall Street Journal*, 2021. Online: https://www.wsj.com/articles/biogen-cuts-price-for-alzheimers-drug-aduhelm-by-half-11640001661.

[45] K. Schoolov, "Why it's not possible for the COVID vaccines to contain a magnetic tracking chip that connects to 5G," *CNBC Tech*, 2021. Online: https://www.cnbc.com/2021/10/01/why-the-covid-vaccines-dont-contain-a-magnetic-5g-tracking-chip.html.

[46] I. Cockrell, "The year in conspiracy theories, a 2021 round-up," *Coda Story*, 2021. Online: https://www.codastory.com/waronscience/2021-conspiracy-theories/.

[47] E. Browne, "5 new conspiracy theories that science proved wrong," *Newsweek*, 2021. Online: https://www.newsweek.com/new-conspiracy-theories-science-proved-wrong-magnetic-vaccine-5g-covid-chip-debunked-mars-pentagon-1663020.

[48] A. Lantian, V. Bagneux, S. Delouvee, *et al.*, "Maybe a free thinker but not a critical one: High conspiracy belief is associated with low critical thinking ability," *Applied Cognitive Psychology*, vol. 35, no. 3, pp. 674–684, Jan. 2021. DOI: 10.1002/acp.3790.

[49] S. Iyengar and D. S. Massey, "Scientific communication in a post-truth society," *Proceedings of the National Academy of Sciences*, vol. 116, no. 16, pp. 7656–7661, 2019. DOI: 10.1073/pnas.1805868115.

[50] L. Strazewski, *How science communication is failing during COVID-19*, Jul. 2020. Online: https://www.ama-assn.org/delivering-care/public-health/how-science-communication-failing-during-covid-19.

[51] K. Kappel and S. J. Holmen, "Why science communication, and does it work? A taxonomy of science communication aims and a survey of the empirical evidence," *Frontiers in Communication*, vol. 4, p. 55, 2019, ISSN: 2297-900X. DOI: 10.3389/fcomm.2019.00055.

[52] Fair Open Access Alliance, *The fair open access principles*. Online: https://www.fairopenaccess.org/the-fair-open-access-principles/ (visited on 01/16/2022).

[53] H. Thornton, "Patient and public involvement in clinical trials," *BMJ*, vol. 336, no. 7650, pp. 903–904, Apr. 2008. DOI: 10.1136/bmj.39547.586100.80.

[54] Foster Plus Project Partners, *What is open science? introduction*. Online: https://www.fosteropenscience.eu/content/what-open-science-introduction (visited on 01/16/2022).

[55] S. Pinker, *Rationality: What it is, Why it Seems Scarce, Why it Matters*. Penguin Books, 2021, ISBN: 9780525561996.

