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The Importance of Communicating Empirically Based Science for Society

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Introduction

Societies around the world have received immeasurable gains from scientific innovations and humanity's ability to communicate the changes in agriculture and food science over the past centuries. In 1651, Thomas Hobbes published *Leviathan*, describing life at the time as "poor, nasty, brutish and short". It was a long time before things improved. At the beginning of the 20th century, global life expectancy ranged from the mid 30s to the high 40s (Kinsella 1992). Presently, the global average for life expectancy is in the low 70s, rising to almost 80 in some industrial countries (Roser, Ortiz-Ospina, and Ritchieet 2019).

While multiple factors come into play for the increase in life expectancy, one of the key drivers of this trend is the role that science-based technological innovation has played in food security; not only in mechanistic advances in agriculture, but also in higher yielding crops and synthetic

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chemicals. Public and social health have been improved with the development of vaccines, antibiotics, and risk reduction in processing for foodborne illnesses. Together, these all contribute to not only improving the length of life, but also improving the quality of life.

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Over the past 500 years of Reformation, Enlightenment, and Industrial Revolution, science that possessed rigor and reliability, (i.e., developed a codified method, with repeatable results) underpinned the technology advancements enjoyed by societies. During this time, many potential technologies were promised, but failed to ever reliably materialize or be developed—broadly referred to as alchemy. Innovation has been based on the continuous advancement of scientific evidence and knowledge. However, a recent change is the reappearance of alchemy. It is now common for unproven, disreputable research to be referred to as scientific fact or evidence, when in reality it is nothing more than modern alchemy. As has always been the case, alchemy has an impact on social response and government policy, with individuals currently preferring to reject safe, proven technologies, such as vaccines, in favor of magical elixirs and potions.

Quality of life improvements have led to social complacency. Many in modern society are generationally removed and urbanely isolated from farming and labor-intensive food production. Because of the success of increased food production and provision, health care and medicine, and access to clean water and sanitation, we are a society that has forgotten the history of plagues, cholera, and diseases (such as polio). Current estimates are that 55% of the global population live in urban areas, rising to 68% over the next 30 years (United Nations Department of Economic and Social Affairs 2018). Conversely, the percentage of the population with direct connections to farms is in the low single digits, for example, 3% in Canada (Farm and Food Care Saskatchewan 2017) While we can, in some sense, see this as a collective benefit of scientific innovation, social complacency has led some in society to now question the role and contribution of science. The dramatic improvements in human health and food security have given rise to the luxury affluence of activist organizations whose key messages challenge the safety and necessity of a range of new technologies, from nuclear energy to vaccines to genetically modified foods.

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On the specific issue of genetically modified (GM) crops and food, seventy countries have conducted risk assessments on human and environmental safety, with all concluding they are safe (ISAAA 2019). The World Health Organization reports tremendous vaccine adoption, with 191 countries introducing vaccines against meningitis and pneumonia, 189 countries having vaccination programs for infants against hepatitis B, and 171 implementing measles vaccination programs (WHO 2019). Yet the overwhelming science consensus is under challenge in our age of instant and mass communication, where objectivity and accuracy has been sacrificed for the sake of “clickbait” headlines in a largely attention-driven world. This current age of media anarchy has weakened confidence in the integrity of science and scientists. Instant, online communications and social media platforms have fundamentally changed how we interact and have become, essential fixtures in the social aspects of our societies. Misinformation, mobilized through social media and online, ripples through society and has significant impacts on public perceptions of science, technology and—pertinent to this paper—food production and agriculture.

While the benefits accruing from the adoption of a new technology or product are capable of being quantified through economic impact benefit models, the cost of not embracing an innovation is more difficult to discern. One study that examined the cost of not adopting new agricultural technologies compared the adoption of GM canola in Canada and Australia. Canada approved GM canola in 1995, where it entered a two-year multiplication system and was commercially available in 1997. Australia approved GM canola in 2003, which was followed by a moratorium on the commercial cultivation of GM canola in the main canola growing states. The moratoriums existed until 2008 in Victoria, 2010 in Western Australia, and South Australia is in the process of lifting the moratorium and has approved GM crop production for 2020. Biden, Smyth, and Hudson (2018) estimated the cost of the delayed adoption of GM canola in Australia by comparing this adoption pattern to adoption in Canada, finding significant economic and environmental costs. The moratoria cost Australian farmers A$485 million in lost production, while the production of non-GM canola resulted in more herbicide and fuel use, a higher environmental impact, and the release of an extra 24 million kilograms of greenhouse gases.

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The economic and environmental costs of not adopting or delayed innovation adoption are substantial, but pale in comparison to the human costs of delayed adoption. The biofortification of crops has been an area of active research for an extended period of time. The most well known biofortified crop is Golden Rice, designed to increase the provision of vitamin A. Opposition to the commercialization of Golden Rice has been a focal point of many environmental groups. Their opposition has become so entrenched that even Nobel Laureates have banded together to issue a public call for environmental organizations to end their opposition for humanitarian reasons (Roberts 2018), all to no avail. The cost of environmental organization opposition has been estimated at a loss of 1.4 million lives in India alone between 2004 and 2014 (Wesseler and Zilberman 2013). In addition to the staggering cost of human lives lost, Wesseler and Zilberman estimate an accompanying social welfare fiscal cost over the period of nearly US$2 billion.

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While misinformation has negative effects on adopter profitability, the environment, and human health, there are also long-term costs from the destruction of plant research field trials by activists opposed to GM crops. The costs of this are staggering as the destruction of field trials wipes out an entire season in the expensive and timely process of developing new crop varieties. Delays in breeding programs result in farmers having less innovative varieties and ultimately, in higher food costs for society.

This paper discusses the crucial factors of what we define as empirically based science (rigorous, proven methodologies, and peer-reviewed results), emphasizing that whether science is conducted by a private company, a university, or a government department or agency, it is all the same, requiring that sound methodologies be followed. Scientific research protocols and methodologies have been developed, reviewed and refined, through the application of each scientific method and the peer-review of experimental protocols and results, creating global standards on research methods. Empirical science is empirical science, it is not an ice cream flavor, one cannot pick and choose which aspect of the scientific method to support and which to reject. The application of empirical science is consistent, whether applied to climate change, vaccines or GM crops and foods.

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A challenge for modern day science is how to apply a precise definition. With science being a process, not a product, it defies the nature required for a tight, narrow, well-defined description. Science is a process of discovery and exploration, which can only be well-defined once something is known. Research is based on the testing of a well-reasoned hypothesis. Some hypotheses are confirmed, contributing to the stock of knowledge that allows a technology to move forward. Other hypotheses are rejected, which also contributes to the stock of knowledge. Empirically based science is grounded in three basic tenants: first, the process is transparent; second, results and methods are publicly shared, allowing for repeated production and validation; and third, data collection methods are well-defined and rigorous, with the conclusions being supported by the data (Aschwanden 2017). These topics are discussed further in the next section.

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There are organizations that benefit from sharing misinformation and disinformation and work deliberatively to advance business models to problematize food production and agriculture. Unfortunately, these business models and underlying motivations are largely invisible to the public. Raising awareness is both a business and moral imperative, if we are to ensure the social license of those in industry, academia, and science to continue to develop technologies and for decision makers to develop science-based policy.

Empirically Based Science: What Is It and What Does It Look Like?

Knowledge is a compendium of past experiences, both successes and failures. History is full of examples of how engineers, for example, have increased their knowledge over time regarding the building of bridges. This knowledge is based on examples of when innovations were applied to the design and construction of a new bridge, but it is also based on the lessons learned from when bridges fail. Similarly, humans over time developed knowledge on which plants were safe to consume and which were not. Insights were gained as to which plants grew best in which locations and when the appropriate time was to plant and harvest. Environmental impacts continually provided challenges to this knowledge through droughts, floods, and insect plagues, resulting in devastating production declines, food shortages, starvation, and death.

The current stock of knowledge has its roots in the 1660s work of Robert Boyle. Through the use of repeated experiments and written summary of the process, method, and results, Shapin and Schaffer (1985) argue that Boyle was the first to separate science from alchemy. Boyle advocated that the essay (what became peer-reviewed journal articles), should be written such that it defined the scientific process, both successes and failures. Critical discussions should be based on theories, methodologies and results and not personal attacks targeted at the scientist. In this sense, science is governed by its peers, whereby experiments are conducted, knowledge generated and reported, which in turn generates further research, reporting and discussions.

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The Structure of Empirically Based Science

Good science is based on sound research. The work of a research scientist starts with making an observation or seeking a solution to a problem or need (Creswell and Creswell 2018). The scientist formulates the observation or problem into a testable question, also referred to as a hypothesis. The hypothesis must be focused and specific in order to be testable. To test the hypothesis, an experimental design is developed which includes protocols for collecting or generating data. These protocols must include sufficient controls and standards to ensure the experimental results are accurate and to enable distinguishing between normal variability in data and a true effect. Because the range of science is broad, each scientific discipline has experimental designs and protocols that are considered robust to test hypotheses that have been codified over the course of decades of previous research. These may range from observing and recording the responses of children to different types of television commercials, to measuring changes in body composition of rats fed a specific type of diet, to quantifying the growth of cells in a dish when treated with a therapeutic drug.

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The way data are collected is especially important for sound research. A scientist must make every attempt to prevent bias in the data collection and to ensure that the methods are consistently applied. For example, researchers might need to be blinded to which commercials children are watching to protect them from assuming responses are occurring based on their own personal biases. When not blinded, researchers could over-estimate consumption of sugary foods by the children after being shown a commercial for such products because they assume the children will be influenced by the commercial. In addition, the experiments must include comparison groups, typically referred to as controls or standards. Showing children commercials for healthy foods and measuring their responses, for example, would determine if there is something specifically enticing about commercials for sugary foods or if all commercials affect food intake in children. Statistical tools are applied to determine if meaningful differences among the data occurred, for example the treatment compared to the control. In the use of statistics, variance is a critical measurement, as its use allows for the distinction between a treatment effect and normal variability in data (i.e. signal to noise). If bias is present in data collection, appropriate controls have not been used, or if improper statistical tests are applied, the experiment will be flawed. When the data have been collected and analyzed, the scientist must then interpret the results and determine if their hypothesis was supported or not. Most commonly, the scientist compiles their hypothesis, experimental design, data, and interpretation into a manuscript that is submitted to a peer-reviewed journal. Equally important, is when the experiment does not go as planned. In many instances, the experiment fails to produce the anticipated result. This is not a failure of science, but it forces the scientist to revisit the

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experiments hypothesis, revising it based on what was learned in the failed experiment, or to reject the hypothesis and move on to different experiments. The process of peer-review provides an opportunity for peers to deconstruct and critique the research to determine if the tenets of empirically based science were met.

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The Peer Review Process of Scientific Consensus

The primary avenue for sharing scientific findings is through publication of the work in peer-reviewed journals. Originally, scientific societies published the work of their members to encourage dialog and sharing of ideas. As science progressed, the process became more formalized and taken over by publishing companies, although many are still very closely associated with scientific societies. Today the process of publishing scientific research involves selection by the scientist of a suitable journal for their work. The number and types of scientific journals has increased significantly in recent years and can include some that are not peer-reviewed. Once the scientist has selected a journal to submit their work to, they must follow strict submission guidelines that include content and text formatting that complies with the journal's standards. The submitted work is then routed to an editor who reviews the article's appropriateness for the journal. If the manuscript is found suitable, the editor recruits one to three reviewers to evaluate the submission. These reviewers, or peer evaluators, are scientists who are experts in the area of the research and have published similar types of studies to the submitted work. To retain independence of the peer evaluators, they are not paid and their identity is not shared with the authors, although some journals now provide reviewers with the opportunity to be identified in the published article. It is considered a responsibility of scientists to contribute time for evaluating the science of others. The peer evaluators assess the quality of the work, including the methodology used, if the data are accurately presented, and if the interpretation of the research by the author is logical, supported by the data, and consistent with current understanding. The editor compiles the peer evaluations and responds to the author with one of three outcomes: rejected, edit and resubmit, or accepted. The peer evaluators' comments are shared anonymously with the authors. The vast majority of research submitted to peer-reviewed journals is unacceptable for publication and the work is rejected. The rejection rate for many top journals can be as high as 90%. Those submissions that are not rejected will almost always require editing, and are sent back to the authors for revision based on the peer-reviewers' comments. The author addresses the comments, resubmits the work and the editor sends it out to the same peer evaluators to reassess the work. This process may be repeated another cycle. Once the work has met the reviewers' and editors' approval it will be accepted for publication. For most journals, the authors will pay page charges to have the work printed, or an open access fee that allows any individual to freely access the article. These charges may be as much as US$5,000 per article.

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These reviewers, or peer evaluators, are scientists who are experts in the area of the research and have published similar types of studies to the submitted work.

Scientific research is often referred to as the scientific process. That is because it is an ongoing and evolving process, with no starting or ending point. Each experiment is of course finite, and data collection is time-bound, although no one experiment can fully answer a scientific question or prove/disprove a hypothesis. Each research study adds a piece to the puzzle but to see the final picture requires many puzzle pieces and hence, many experiments confirming the findings.

A good example of how this works is to examine the process through which cigarette smoking was conclusively linked to lung cancer (Proctor 2012). Until the 1940s, lung cancer was essentially unheard of in the medical profession. Cigarettes were not considered hazardous to health and in fact were promoted as ways to reduce stress and even lose weight. As the incidence of the disease began to increase in the middle of the 20th century, researchers began to develop hypotheses to uncover the cause and smoking was just one of these hypotheses. Several lines of evidence were required to provide sufficient weight to the connection between cigarette smoking and lung cancer. These included population studies showing higher rates of lung cancer in smokers than in non-smokers, animal studies that found tobacco smoke and tars could induce cancer, cellular changes in the lungs of smokers that were not found in non-smokers and identification of specific carcinogenic compounds in cigarette smoke. Each of these findings, as they were released, were insufficient to convince the medical and scientific community, government, and public of the risks of smoking and in fact were often reputed as being inaccurate and not empirically based science. It took the preponderance of evidence of all the puzzle pieces to finally convince the scientific community, and importantly the U.S. Surgeon General, to conclude in 1964 that smoking cigarettes causes lung cancer. Yet, even with this strong scientific evidence and warnings about risk, many people still continue to smoke cigarettes (Rocha 2019).

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The scientific process involves many false starts and leads, and incorrect conclusions may be made along the way until more evidence is collected and a pattern begins to emerge. In some cases, this may be because of the inability to fully understand or test a mechanism due to lack of tools or technology. For example, in 1922, it was found that insulin was required to maintain blood glucose levels (Ward and Lawrence 2011). But it was not until 1985 that the actual mechanism by which insulin binds to a cellular receptor and opens channels for glucose to move across the cell was understood. This deeper understanding of the cellular mechanism for insulin action was facilitated by molecular biology tools, which were not even imagined in the 1920s. The advancement of scientific tools has been remarkable in the past 100 years, allowing scientists to reassess previously conducted research and in some cases change their thinking. In addition to constantly evolving technology, scientific thinking changes over time. Scientists are continually challenging ideas or concepts that were once supported by the current evidence when newer evidence or pieces of the puzzle are uncovered. This may make it seem like the scientific process is fickle, and that no right answers are possible. However, in fact, this evolving process of reassessment and refocus is essential for empirically based science. As new information or evidence is found, scientists review how that fits the puzzle picture. In some cases, the picture stays the same but in other cases the picture will be different.

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A good example of how scientists change their positions is the dietary recommendations around cholesterol. By the 1930s, a connection was made between heart disease risk and the accumulation of cholesterol-rich plaque in the arteries (Steinberg and Gotto 1999). This led scientists to conduct studies that further confirmed that cholesterol and plaque were related to cardiovascular disease risk. Cholesterol is a naturally occurring substance and is synthesized by humans and animals, in addition to being consumed from food. Because of the connection between cholesterol in plaque and the fact that animal foods such as butter, eggs, red meat, and whole milk contain cholesterol, nutritionists recommended reduced consumption of these foods as a way to reduce the risk of heart disease (USDA 1980). Many thousands of studies were published showing links between cholesterol intake and heart disease. But as the science of cholesterol metabolism by humans became better understood, evidence arose that suggested dietary cholesterol was not the primary culprit of cardiovascular disease (Fernandez 2012). Many factors contribute to the accumulation of plaque and only in some people does dietary cholesterol impact risk. As a result of these new puzzle pieces, nutritionists have changed their recommendations relative to cardiovascular disease to be less focused on limiting the intake of cholesterol-rich foods for the general population (USDA 2015).

Empirically based scientific research is essential to understanding our world and how it affects our lives. Scientists have an important responsibility to design and execute experiments that are unbiased, and that directly answer a specific question. It requires many experiments to gather sufficient puzzle pieces to see the full picture. Science is an iterative process that will always be changing and evolving as new evidence, new tools and new thinking arises.

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Research Funding

Scientists working in the public sector—at universities, colleges and government-sponsored facilities—must find ways to secure sufficient funding to conduct their work. A majority of research that is conducted by these scientists is funded by grants provided by the federal government. While public investment has decreased over the last few decades (from over 70% in the 1960s), the AAAS (2020) reports that federal share of university R&D remains at around 60%. The National Institutes of Health, Department of Energy and National Science Foundation have the largest pools of research grant funding in the United States, but other agencies such as the Department of Agriculture, Centers for Disease Prevention and Control, National Aeronautics and Space Administration and Department of Transportation, also fund research. Typically, these agencies post requests for proposals that are open to all researchers. To secure grant funding, scientists must submit their plans that explain their hypotheses, experimental designs, and research protocols. Similar to peer-review for journals, a group of peers evaluate the value of the hypothesis being tested, the robustness of the experimental design, methods and analysis, and the capacity of the researcher to complete the work. Grant funding is highly competitive, with only a small percentage of submitted protocols receiving funding. Researchers that receive federal grant support are required to follow strict guidelines for their work, including having protocols that are approved by a research ethics board for projects that work with humans or animals, oversight and management for the use of funds, meeting reporting deadlines, and providing open access to their results.

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Beyond federal grants, there are other sources of research funding available to scientists, including private foundations, commercial industry, and commodity boards. Some of these operate similarly to government agencies, with open calls for proposals and peer-review of applications, but others may provide targeted funding that would not be openly available or peer-reviewed. In some cases, the research that has been funded from these non-governmental agencies has been criticized as being potentially biased due to the perception that a private, commercial, or commodity board would only fund work that would be favorable to their mission (Sismondo 2008). For this reason, it is inherent upon the scientist to ensure that they are following robust scientific methodology and that their work is assessed by their peers through the publication process to avoid any conflict of interest. In their study of 224 journals on environmental, occupational, or public health research, Resnik and colleagues (2017), found 96% of journal publication policies required conflict of interest (COI) disclosure, 92% required funding disclosure, 76% defined COIs, 70% provided examples of COIs, 69% addressed nonfinancial COIs, 34% applied to editors and reviewers, 32% required discussion of the role of the funding source, and 2% included enforcement mechanisms.

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Conducting sound science, broadly sharing research findings, and critically assessing results are core elements of the scientific process. These elements are cumbersome and labor-intensive, and subject to human error. Drawing definitive conclusions to complex problems requires multiple research approaches, diverse contributors, and careful interpretation. To ensure integrity of the system, it is essential for open access to scientific work, and unbiased financial support for scientific research.

Peer Review, Publication, and Their Changing Roles

The nature of reviewing scientific literature has undergone a polar revolution in the past 20 years. Gone are the days of hunting through dusty library stacks, searching for the volume and issue for a specific journal article of interest or reading all of the articles in a single journal issue when it arrived in the mail. Access is now instantaneous, for a cost, with the click of a mouse.

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While access has become easier for some, it is not translating into greater exchanges of information or enhanced understanding. In fact, the sheer volume of specific information has narrowed our field of studies, because we no longer have enough time to review scientific literature outside of our field of study. As with conducting the research, there is a cost to scientific publishing. Demands and changes in access are changing how publishing is funded feeding back to change access and availability of science in publications. As scientific publication proliferates exponentially, the sheer cost and volume impact the ability to communicate the best science.

The Publication Proliferation

Scientific output as reported in scientific journals, books, and across the web, doubles every nine years (Bommann and Mutz 2015). The rapid increase in output began following World War II and has recently been accentuated by an increase of new methods of publication. In reality, there is no current measure that tells us if the proliferation in scientific papers or new scientific publication venues equates to a growth in knowledge or an increase in quality research, but we do know that authors now expect more options and/or variations in where they publish, availability of the publications, how data are displayed, method of communication, the method of review, and how publication is funded. Enhanced availability of scientific publications to scientists had an interesting side effect: the publications suddenly became available to the public. As authors ask for more and more options, the public is exposed to an explosion of easily available data without publicly understood indices of quality (Funk et al. 2019). The historical paradigm is

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that to be credible it should be peer-reviewed and indexed, but inside the scientific community we understand that peer-review is changing and that not all peer-review is created equal (Crossley 2018) and that indexing statistics can be skewed by publications model (Kiermer 2016). Not only can poor quality science become ‘fact’ to some, but high quality science may be lost in the meteoric increase in available data; publications that are never cited are essentially useless. Gone are the days where it is displayed in a scientific journal; therefore, it must be accurate and high quality peer-reviewed science.

Electronic publishing has been the single greatest driver of enhanced quantity, speed and availability of publications to both scientists and the public.

Electronic publishing has been the single greatest driver of enhanced quantity, speed, and availability of publications to both scientists and the public (Wulster-Radcliffe et al. 2015). Online publishing simply drove increased public dissemination. In the early days of online publishing, scientists and publishers alike were shocked that online publishing did not decrease costs and in fact, in many cases, as journals had to develop new dynamic technologies, it increased the costs. This was hard on the scientific community; finally more people could see our work, but that increased visibility came with a price that we were not sure how we were going to pay. In order to balance cost and demand for access, the scientific publishing community has had to create a variety of new publications models.

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The most common business model to grow from online publishing and public demand to see science that previously they might not even know existed is open access. In 2018, there were approximately 11,811 fully open access journals listed in the Directory of Open Access Journals, with 15% to 20% of articles published in open access, and another 10% to 15% published via delayed access. There are four main approaches to open access publishing:

1. Gold open access: Journals provide free, immediate access to articles via the publisher website. Article publishing is often paid by author fees (article processing charges).
2. Green open access: Authors publish in a journal, with a short-term embargo on free access to the article (six months to one year). Article publishing is often paid by a combination of author fees and subscription income.
3. Hybrid models: Most often green open access journals that have an additional per article optional fee paid by the author to allow the article to be immediately OA.
4. Traditional closed models: Journals are only available through subscription, where these fees offset the majority of publication costs and authors therefore, do not need to pay for publication.

The Rise of Predatory Journals

The push for Open Access—through a demand of public transparency—meant scientific publishers had to find a way to make journals available to the public for free; suddenly if articles are free to the public why would libraries pay for scientists’ access?

Traditional publishing is funded by a combination of dollars, including library subscriptions and page charges. Libraries, most typically university libraries, are charged an annual fee, allowing faculty and students free access to all articles published by a specific journal, while scientists and academics that have had an article accepted would pay a per page fee to have their article published in a journal. Why do we care? Because before the demands of open access scientific publishing was supported by a subscription model that allowed the costs of publishing to be covered. The push for open access—through a demand of public transparency—meant scientific publishers had to find a way to make journals available to the public for free; suddenly if articles are free to the public why would libraries pay for scientists' access?

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With the rise of open access publishing, publishers have scrambled to develop new business models to sustain high-quality journals, while they are losing subscription revenues. Often, this has led to a model in which authors pay an open access premium to offset costs associated with preparing articles for publication, such as proofreading, formatting, and typesetting. This allows for high quality, high value content to be produced resulting in the protection and availability of content in perpetuity, plus helping to compensate for the loss of subscription revenue. Why can scientists not forgo publishers and publish online for free? Simply put, working through publishers ensures that science is reviewed and quality checked and the peer-review and evaluation of scientific work is part of the bedrock of quality scientific communication.

The single most prevalent method of controlling article processing charges in the absence of subscription income is to increase the volume published.

Publications, like many other businesses, can cut costs by increasing volume; consequently, the single most prevalent method of controlling article processing charges in the absence of subscription income is to increase the volume published. In general, top journals are already getting the top submissions, increases to volume published does not come from increased submissions, but rather from increased acceptances and publication. In other words, there is a decrease in the quality standards for publication to publish more and collect adequate article processing charges (APCs) to cover publication costs. In the first few years of open access, reputable and society-based publishers rebelled against this change, clinging to subscription-based models. But the increased demand for instant electronic access, created an opening for two new breeds of journals: (1) mega-journal—characterized by three features: full open access with a relatively low publication charge; rapid 'non-selective' peer-review based on 'soundness not significance' (i.e., selecting papers on the basis that science is soundly conducted rather than more subjective criteria of impact, significance or relevance to a particularly community); and a very broad subject scope and (2) predatory journals—publish for profit, in the absence of quality review. In 2013, there were approximately 4,000 journals deemed predatory, today there are more than 15,000.

Because predator journals often look real and mega-journals are real but have changed the criteria for publishing, reputable established journals have been forced to change policies to compete. In addition, credible looking predator journals and open access mega-journals have helped perpetuate the public sentiment that open access journals are more transparent for the general public and as such more credible, forcing more and more reputable publishers to 'flip the switch' to fully open access (Funk et al. 2019). It can be noted that as established journals turn to 100% open access, they are forced into the mega-journal business model and invariably increase the number of pages published. The increase in pages published is not due to an increase in quality submissions, but rather to a decrease in rejection rates, as we increase pages published in an attempt to decrease the price burden on individual articles. Therefore, the reality is to stay in business, unsound science ends up being publishing.

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Measuring Impact

With new options driven by open access, how do we know where the good science resides? Which new publications will contribute long-term to our field and which ones are designed purely to profit from the electronic age of easy publication? As established journals switch to open access and increase publication rates and decrease rejection rates, how do we train the public and scientists to look at each article individually and judge quality? How do we get this message out to publishers, authors and the public without inadvertently hurting potentially ethical and important new journals and new journal models: white lists versus black lists, or lists of criteria? And, if the scientific publishing industry started creating lists of good and bad, who becomes the judge?

Interestingly, the influence of social media and open access are also changing how we look at citations and metrics. Previously we relied almost exclusively on Impact Factor, which is actually not an article measure, but a measure of the impact of an entire journal. As a single article that is open access published can also now be pushed out across social media platforms, we have begun to use several article level measures of individual article 'impact' or dissemination. One example is Altmetrics. Altmetrics and similar platforms are being used by credible publishers to monitor amplification of articles in mainstream and social media. However, some poorly executed (non-peer-reviewed) studies/articles get amplified on social media because of (compelling) content or agenda (or they may be shaped that way in the media). Does adding methods of evaluating amplification across social media platforms in the publication process re-incentivize scholars in new ways and/or give the public a way to judge quality of information in social media? However, Altmetrics are based on an article level and therefore more indicative of the impact of a single authors work than Impact Factor. Scholars are only just realizing that the science does not end at publication in academic journals and what goes to social media matters.

Altmetrics and similar platforms are being used by credible publishers to monitor amplification of articles in mainstream and social media.

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As academics, we tend to downplay or completely dismiss the harm that 'predatory' journals or decreases in rejection rates can cause to the scientific community. After all, we know we can identify good science! But what about people who are not experts in scientific disciplines and have little or no knowledge of how scientific publishing works? They will have an exceedingly difficult time distinguishing credible journals and articles. Even credible scientists have been duped into sitting on the 'editorial board' of predatory journals, thereby lending their name and credibility to predatory journals.

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The Tradeoffs Between Transparency and Visibility

In addition to the economic drivers there has been both a political and a public push for enhanced visibility within publishing. Really, who can argue against transparency and visibility? This has led to the terminology open science versus open access. Open science can be defined as transparency about funding sources and access to datasets to verify the accuracy of results. Open access is when authors pay a set fee to ensure that any individual is able to have free access to the published journal article. Social networks and other social media are just beginning to have an impact on scholarly communication. Researchers remain cautious about using means of scholarly communication not subject to peer-review, but in an era of Open Science and Altmetrics, social networks have a new place in the wide dissemination of data (Enago Academy 2018).

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Cost, availability of new models, speed to publishing, and open access have not only changed the quality of reviews, but also how submitted papers are reviewed (Horbach and Halffman 2018). In the past, papers were pushed through review by the journal following article submission. Frustrated with long review times and a greater demand for quick release of scholarly work, many researchers are opting to use new open access review systems—preprints. Preprints are likely to be an even larger change to scholarly infrastructure than open access, because they change the bedrock concept that scholarly information is not available until after it has been formally reviewed and accepted by others in the field. A preprint is a full draft research paper that is shared publicly before it has been peer-reviewed with the intent of using viewers of the unreviewed work for review and to strengthen the article.

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Recognizing the large number of external pressures on publishing revenue, publishers both large, and small society publishers of scientific journals, are scrambling to find new ways to fund scientific scholarly publishing. The newest coming directly from the push for open access, read and publish agreements, with the initial move called transformative agreements (Janicke Hinchliffe 2019). Read and publish is exactly as titled, institutions enter into subscriptions that allow their institution to read work held in a scholarly archive and obtain a new type of prepay subscription publishing for their authors.

As has been witnessed at this point, these agreements have come full circle using the same dollars to pay for essentially the same end products, with the only addition that articles are now open access to the public. However, in this shell game, there is a downside that is being overlooked**—**freedom of scientists to choose the best possible place to share their work. Authors will be pushed to publish where their institutions have a read and publish deal/ subscription versus publishing based on the next possible journal for the data, fundamentally decreasing the right of a scientist to pick where work should be published**.**

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Advocacy-Driven Pessimism About Technological Innovation in Agriculture in the Media

We live in a precautionary era in which technological breakthroughs poised to dominate the coming decades—from artificial intelligence and nanotechnology to the biotechnology revolution in medicine and agriculture—are often cast in a dark shadow. Journalists are mirrors, reflecting the broader, societal anxiety that we will not be able to rein in the seemingly runaway forces of technology. It is a cultural and economic war between pessimism and progress. Social media only amplifies the cacophony.

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It is part of a historical pattern. The idealization of the past in the face of paradigm-shifting technology is not a new phenomenon. New technology is disruptive, which means that while the direction of change may be positive for society as a whole, there will be innocent losers as well as many winners. The Luddites of early 19th century Britain have emerged as the historical symbol of technological rejectionism. This oath-based organization of rural fabric and button makers were horrified about the mechanization of their crafts, as textile mills began replacing their small-town shops. They fashioned themselves as the liberals of that era, chosen by God to protect the pastoral English life they were so used to, and protest the disruptions of industrialization sparked by the machine technology and coal mining revolutions (the 'disruptive' technologies of that time) (Sale 1996).

The idealization of the past in the face of paradigm-shifting technology is not a new phenomenon.

History abounds with examples of epic misjudgments rooted in pessimism about the promise of emerging disruptive technologies. Consider a Western Union internal memo, dated 1876: “This ‘telephone’ has too many shortcomings to be seriously considered as a means of communication [and] is inherently of no value to us” (Wadwha 2014). Or a comment by a British Member of Parliament in 1903: “I do not believe the introduction of motor-cars will ever affect the riding of horses” (van Wulfen 2016). Additionally, the infamously flip quip by an executive editor at Prentice-Hall in 1957: “I have talked with the best people and I can assure you that data processing is a fad that won’t last out the year” (Sherman 2012).

Resurrecting these anti-innovation sentiments are insightful because we are in the early stages of a once-in-a-generation, and maybe once-in-a-century, innovation earthquake that is making food safer, more nutritious and more abundant, and helping us fight the scourge of climate change. New techniques of biotechnology—from genetic modification to CRISPR (clustered regularly interspaced short palindromic repeats) gene editing—are propelling dramatic change in food and farming. But many in the media mainstream, spurred in part by self-described “progressive environmentalists,” will have little of it, and their views have sowed doubt amongst the public at large.

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Reporting on food is not like covering City Hall—its products—food—are visceral, deeply personal, and cultural. When it comes to applying technology to farming, everyone has an opinion, informed or not. President Dwight Eisenhower, who was raised in Kansas farm country, became skeptical of reporters and Washington bureaucrats who misunderstood the Green Revolution and the role of synthetic pesticides and fertilizers that revolutionized global farming beginning in the 1940s and 1950s. “Farming looks mighty easy when your plow is a pencil and you're a thousand miles from the corn field,” he quipped in a speech at Bradley University in 1956. He called critics of modern agriculture ‘synthetic farmers’ (Smith 2009).

GMO Rejectionism

The targeted manipulation of genes that began in the 1980s and 1990s that became known as genetically modified organism (GMO) technology has long been received with a similar mixture of alarmism and misreporting. Although there are many examples of nuanced critiques of biotech-inspired farming practices, much of the media coverage has been shaped by environmentalists and advocacy groups who define themselves as “liberal” but have adopted a Luddite-like precautionary view of GMOs and transgenic plants and, more recently, of the advances ushered in by gene editing and other new breeding techniques.

No surprise that the 2000s are marked by dozens of scientifically challenged, best-selling books (e.g. *Seeds of Deception* by Jeffrey Smith, 2003; *Omnivore’s Delight* by Michael Pollan, 2006; *The Unhealthy Truth* by Robyn O’Brien, 2009) and documentaries (e.g. *The World According Monsanto*, Marie-Monique Robin, 2018; *GMO OMG*, Jeffrey Seifert, 2013; *Sustainable*, Matt Wechsler and Annie Speicher, 2016) that lack supporting evidence, thereby promote a pessimistic view of agricultural technology.

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An unflattering meme has emerged about conventional farming and the agro-businesses that support it. Books, movies, and thousands of newspaper articles and online stories generated by advocacy groups and journalists conclude, with little variation in subtlety, that the world food system is dominated by rapacious transnational corporations and that biotechnology is making farmers more vulnerable, endangering our collective health, and, in its most apocalyptic expression, threatens the sustainability of our planet.

Its titular leaders, such as Vandana Shiva, an Indian philosopher, who has been described by supporters as the "rock star" of progressive environmentalism, goes so far as to reject the Green Revolution as a vestige of corrupt global capitalism. She dismisses it as a symbol of the failure of 20th century science technology and of the 'rational' Enlightenment agenda itself. Shiva rejects the use of synthetic fertilizers and pesticides altogether, criticizes agricultural biotechnology as an "assault on nature," and promotes a return to small-scale farming, early 20th century farming even if it means a radical reduction in yields and lower incomes for farmers (Genetic Literacy Project 2019).

By-and-large the arguments these biotechnology critics advance bewilder many scientists, farmers, and independent journalists because they do not address scientific risk or compare costs and benefits and they deify a prosperous "pastoral" farming past that never existed. Subtlety and nuance are not the currency of modern science journalism and advocacy lobbying.

An unwillingness to recognize, let alone embrace, what might be called 'innovation with reasonable risk' is not a new phenomenon, as proponents of the telephone, automobile, and computers can attest to.

An unwillingness to recognize, let alone embrace, what might be called "innovation with reasonable risk" is not a new phenomenon, as proponents of the telephone, automobile, and computers can attest to. Past critics share the common mistake of exaggerating the disruptions that accompany all innovation and under-appreciating the prosperity often ushered in by disruptive, paradigm-shifting innovation (Juma 2016). This brings us, chronologically, to circa today.

It is desultory enough to see simplistic criticisms associated with an influential environmental organization; what makes this kind of statement so telling is that its perspective is mainstream among many 'progressive' groups throughout Europe, North America, and elsewhere. This technological pessimism is reflected in the tone and substance of mainstream media reporting of modern agriculture.

Sustainability Factor

Biotechnology is shaping up as the fundamental building block of innovation in the 2020s. CRISPR and other biotechnology tools are poised to make a tremendous impact on medicine, with gene editing and gene therapy promoting the development of new treatments and cures. As with any new technology, scientists need to apply the technology to confirm its safe use, with regulatory scientists conducting risk assessments that confirm the resulting products are no riskier than existing products. But the most immediate impact of the gene editing revolution is on food and farming and it is already ushering in an era of more sustainable agriculture.

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Challenging the popular narrative in journalism, which has helped shape consumer beliefs, organic, agro-ecological, and regenerative farming techniques may not be the most sustainable approach to feeding a population-expanding planet with the smallest ecological footprint while addressing climate-related agricultural challenges.

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"Contrary to widespread consumer belief," writes plant pathologist Dr. Steve Savage, "organic farming is not the best way to farm from an environmental point of view. There are now several cutting-edge agricultural practices which are good for the environment, but difficult or impossible for organic farmers to implement within the constraints of their pre-scientific rules” (Savage 2013).

Among new breeding biotechnologies with environmentally beneficial innovations:

- GMO crops designed to be grown without tilling, which dramatically limits the release of carbon from the soil (Entine and Randall 2017).
- Genetically engineered insect and disease resistant crops, from cotton and soybeans to eggplant and papaya, repel pests using natural bacterium, which has resulted in as much as a 90% reduction in chemical usage compared to standard practice when weighted by environmental impact (Perry et al. 2016).
- GMO and gene edited plant-based foods, such as the Impossible Burger (also Impossible Pork, Fish, etc.) use up to 87% less water, 96% less land, resulting in 89% fewer greenhouse gas emissions, and emit 92% less dead zone-creating nutrient pollution than ground beef from cows (Impossible Burger Impact Report 2019).
- CRISPR engineered plants engineered with climate-adaptive traits, such as heat tolerance (Yu et al. 2019), drought tolerance (Shi et al. 2017), and salt tolerance (Farhat et al. 2019).
- Gene editing hardier produce staples (Cremer 2019) that last longer on shelves, with fewer pathogens developing (Chandrasekaran et al. 2016) so that more food makes it from farm to plate, limiting wastage.
- CRISPR engineered staple crops produce less methane, cattle feed that is easier to digest and can help crops fix more carbon directly (Miller and Jameel 2020).
- Gene edited plants that enhance nutrition, such as Calyxt soybeans that are engineered to produce a “high oleic” oil with no trans fats and less saturated fat (Calyxt 2020).

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CRISPR engineered plants engineered with climate-adaptive traits, such as heat tolerance, drought tolerance, and salt tolerance.

This is a non-exhaustive list of the myriad of sustainability benefits ushered in by biotechnological innovation. But these ecologically advanced agricultural products are sparsely reported on by the most influential media sources and face ideological attacks from many nominally mainstream environmental organizations, including Greenpeace, Friends of the Earth, ETC Group, Third World Network, Center for Food Safety, Organic Consumers Association, and the Environmental Working Group—all of which reject the scientific consensus that gene editing, as well as transgenic breeding, is both efficacious and safe. Rather, these and similar non-governmental organizations (NGOs) often focus their analysis on the theoretically abstract, however unlikely, unintended consequences these new technologies may (or may not) encourage while ignoring the sustainability benefits that are already being delivered. This is more commonly known as speculative science, where there is no agreed upon theory and no corroborating data.

Sensational Reporting Leads to Poor Legislation

There are significant consequences for persistent, out-of-context of misreporting. The media influence public opinion and therefore political and regulatory decision making. Legislation significantly influences whether new technologies will get a fair chance in the marketplace. Consider what has

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happened in Europe, where advocacy group criticism of agricultural biotechnology was designed to ensure public opinions developed that were against GMOs and spurred politicians to pass restrictive legislation that has severely limited the benefits of the GMO revolution. In the late 1990s, with many of the largest agro-businesses headquartered in Europe, the European Union (EU) was on the cusp of establishing itself as a global biotechnology epicenter. But a spate of public food crises such as Mad Cow Disease (bovine spongiform encephalopathy, or BSE) damaged public trust in the ability of government to protect them from unintended consequences of modern farming practices. Anti-biotechnology NGOs used this “food crisis” to lobby politicians, ignoring the European Union’s science community. With the food industry on the defensive, the EU acquiesced to precautionary principle-inspired lobbying by the Greens and more liberal parties, passing restriction after restriction that effectively has gutted agro-biotechnology innovation in that region.

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In the decades since, the EU has slowly entered into agricultural biotechnology gridlock—no longer able to approve GM crops for production—it has begun transferring its technologies to North America and other regions with more hospitable regulatory climates. Europe only has but one genetically modified crop authorized for cultivation (corn) and a very cumbersome process for importing GM crops, used mostly for animal feed. As a result, Europe is not sharing in the biotech-inspired agricultural boom sweeping through the industrialized West and extending to such developing countries as Bangladesh, Sudan, and India (Library of Congress 2015).

The CRISPR gene editing revolution offers Europe a chance to reset its priorities, but so far it is recapitulating its rejectionist biotechnology policies. In July 2018, the Court of Justice of the European Union rejected the recommendation of its science advisor to take a more flexible view toward emerging CRISPR technology, and instead decided to regulate based on anti-GMO legislation passed in 2001, before gene editing was even invented. The Court of Justice of the European Union ruled that plants developed using gene editing and new breeding techniques should be regulated the same way as GMOs, effectively rendering them illegal to be grown (Daley 2018). Upwards of 117 prominent EU research facilities are campaigning to reverse EU policy but have made little headway so far (Max-Planck-Gesellschaft 2019). The region’s once strong edge in sustainable food production faces the prospect of continued erosion.

In July 2018, the Court of Justice of the European Union rejected the recommendation of its science advisor to take a more flexible view toward emerging CRISPR technology, and instead decided to regulate based on anti-GMO legislation passed in 2001, before gene editing was even invented.

Despite aggressive opposition, there is much room for hope as the biotechnology revolution in agriculture continues to unfold globally. Most ‘environmental’ groups and mainstream journalists are even more detached from the ‘reality on the ground’; farmers are rolling out genetically modified crops across Asia and Latin America. The Philippines defied years of aggressive opposition by environmental organizations to humanitarian applications of nutrition-enhanced Golden Rice, and appears poised to authorize distribution of Golden Rice in 2020 (Dubock 2020). Africa is the new frontier, with Nigeria and Kenya introducing insect-resistant crops in 2020.

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Advocacy groups, and some journalists in the mainstream media who deeply influence legislators and regulators are largely ignorant of the day-to-day challenges faced by farmers; they are as Eisenhower wrote, “thousands of miles from the corn field.” Their criticisms of modern agriculture while simultaneously popularizing small-scale farming practices, such as organic and regenerative food growing systems, ends up promoting the very opposite of what they claim to desire: they are making farming less productive and denying the benefits of sustainable innovation to the most vulnerable populations of the world. That in turn contributes to the climate crisis, the most fearsome environmental challenge of our time. The challenge for journalists and the web-based information media is whether they can separate themselves from the anti-biotechnology influence of old-guard environmental groups and embrace science-based innovation.

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Misinformation

In 2016, Del Vicario and colleagues reported that online digital misinformation is so pervasive that the World Economic Forum listed it as one of the main threats to modern society. The terms misinformation and disinformation are often interchanged. It is important to distinguish between the two terms as they are associated with different behaviors and are incentivized differently (Ryan et al. 2019). In the literature, misinformation is referred to as inaccurate or incomplete information (Fallis 2009; Fallis 2014; Karlova and Fisher 2013; Karlova and Lee 2011; Losee 1997; Zhou and Zhang 2007). Misinformation "can mislead people whether it results from an honest mistake, negligence, unconscious bias, or intentional deception" (Fallis 2014). Disinformation, however, is viewed exclusively as "a product of a carefully planned and technically sophisticated deceit process" (Fallis 2009) by grabbing attention and monetizing it to meet rent-seeking ends. For the purposes of this report, the term misinformation has been adopted and applied to the discussion.

In the literature, misinformation is referred to as inaccurate or incomplete information. Disinformation, however, is viewed exclusively as "a product of a carefully planned and technically sophisticated deceit process" by grabbing attention and monetizing it to meet rent-seeking ends.

Misinformation is nothing new. One only needs to think about the War of the Worlds that aired in 1938 (Grech 2017) or the variety of reality-based television programming that we have access to through mass media (Creeber 2015). What is new today in terms of misinformation is the scale by which society is exposed to it.

Impacts of Social Media

Social media has fundamentally changed how we connect as humans and, of course, in how we exchange information. The "scale of the [social media] platforms have raised the speed limit in our information society." Users reportedly spend an average of 142 minutes per day on social media (Smith 2019). Complicating all of this is that vendors (people, organizations, other actors) have learned to game the system. They leverage the gap between the accuracy (or inaccuracy) of the information shared and the behavioral habits and biases of users and consumers of that information (Ryan et al. 2020). This has add-on implications for decision- and policy-making. Lewandowsky et al. (2012) state that, "misinformation may form the basis for political and societal decisions that run counter to a society's best interest".

Misinformation has evolved into a form of currency for many and as Baccarella and colleagues (2018) state, 'attracts millions of readers' that are drawn to the magnetic appeal of rumors, urban legends, and conspiracy theories. Social and mainstream media misinformation spread into online spaces where media, citizens, and communities share and re-share it in perpetuity. Content producers, in both media and blogs, frequently cater to sensationalism when looking to increase site traffic and maximize social media engagement, which are then monetized through ad sales, site performance metrics and sales of supplements, alternative therapies and 'natural' foods.

Social and mainstream media misinformation spread into online spaces where media, citizens, and communities share and re-share it in perpetuity.

Impacts on Food Production

The gains from sharing misinformation are significant when it comes to food and farming because the topics have gained wide public and media attention over the past several years. The problematization of agriculture more broadly has been a primary strategy in anti-agriculture activism according to Stevens and colleagues (2018). Anti-GMO protests, in particular, "were among the most successful protest movements in modern history" (Clancy 2016). Vendors use the Internet and social media to shape broader public opinion about GMOs, grabbing attention across several platforms often through compelling visuals. Emotive images are powerful, even more so than emotive words (Winkielman and Gogolushko 2018). The pervasive 'syringe in a tomato' is a good example of this, conflating technology, food, and nutrition in a very visual way. It is a highly shared visual meme. Memes like these are often used in efforts to intentionally propagate negative positions concerning GM crops in the United States by perpetuating inaccuracies or myths in how genetic modification works (Dorius and Lawrence-Dill 2018).

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Another by-product of misinformation on GMOs is the establishment of new markets and marketing approaches. The Non-GMO Project mission is "dedicated to building and protecting a non-GMO food supply through consumer education and outreach programs; marketing support provided to Non-GMO Project verified brands; and training resources and merchandising materials provided to retailers" (Non-GMO Project 2019). The first product with the Non-GMO Project butterfly label was introduced in 2010 and, by the end of that year, annual sales of verified products reached US$348.8 million. As of today, more than 3,000 verified brands, representing over 50,000 products are 'Non-GMO Project' verified and net more than US$26 billion in annual sales (Gelski 2016; Non-GMO Project 2019). The Non-GMO Project provides its logo to whoever pays its fees, regardless of whether there are GM varieties or not. Examples of deliberately mislead consumers through the application of the Non-GMO Project logo include tomatoes, grapes, and pasta, as there are no GM varieties of tomatoes, grapes, or wheat.

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GM crops and agriculture and food production have evolved into a deeply politicized set of topics; ones that continue to invoke strong emotional responses from the public (Aerni 2018). As a result, public opinion has deviated greatly from scientific consensus on GMOs (Funk, Rainie and Page 2015; McFadden 2016) despite growing rates of adoptions (ISAAA 2019), the economic benefits at the farm level (Brookes and Barfoot 2018), the stringency of regulatory approvals and safety testing worldwide (McHughen and Smyth 2008; Smyth and McHughen 2012) and the more than 3,000 scientific studies that attest to the safety of GM crops (Norero 2017).

GMO has been actively employed as a "dubious meme often used as a target for determined opposition by many activist groups" (Tagliabue 2018), conflating seemingly unrelated issues. For example, misinformation vendors continue to amplify and legitimize a flawed connection between GMOs and autism and other developmental issues (Keenan and Dillenburger 2018). According to the analysis of almost 100,000 articles from 2009 to 2019 conducted by Ryan and colleagues (2020), the most visible or impactful coverage of GM crops for the lay-public originate from alternative health blogs and websites which typically frame their coverage in the most attention-grabbing fashion and not necessarily an accurate reflection of facts. Often, the content from these venues focuses on the importance of natural and that processing is harmful, especially in regards to food production. These sites often perpetuate anti-vaccination propaganda and this type of misleading information can shift public perceptions, affect behavior, and influence policy making at the cost of public health (Rosselli et al. 2016).

The socio-economic costs of misinformation campaigns can be significant, wasting money, time, and animals.

The anti-GMO movement resulted in subsequent studies and reviews which cost the EU tax payers in excess of €15 million which only re-confirmed previous findings that there are no harmful health effects related to consumption of GMOs.

The ongoing distortion of science inappropriately raises the perceived risk profile of good science and technologies.

The socioeconomic costs of misinformation campaigns can be significant, wasting money, time, and animals (Arjó, et al. 2013; Barale-Thomas 2013; Wager et al. 2013). The anti-GMO movement, for example, resulted in subsequent studies and reviews which cost the EU tax payers in excess of €15 million which only re-confirmed previous findings that there are no harmful health effects related to consumption of GMOs (Coumoul et al. 2018; Steinberg et al. 2019). Additionally, less perceptible costs of misinformation have longer-term effects including diminished confidence in science. As Ryan and colleagues (2020) state, the ongoing distortion of science—through the promulgation of misinformation—inappropriately raises the perceived risk profile of good science and technologies. These technologies are important for agriculture, food production, economies, and societies. Impacts include delays in getting socially vital products to societies that need them (e.g., virus-resistant cassava), to shelved or unrealized innovations, such as New Leaf potato or Calgene tomato (Ryan and McHughen 2014), and even the loss of important research through vandalization of Golden Rice field trials (Lynas 2013). These losses have economic, nutritional, food security and public health implications for societies all over the world.

There are implications of misinformation for societies and the agricultural industry alike. The strategies driving the mobilization of misinformation, however, are often not visible and neither is the economy that underlies those transactions. With the number of worldwide users of social media expected to rise to almost 3.1 billion by 2021 (Clement 2020), the channels for misinformation will grow. More research needs to be conducted to explore underlying motivations, the transactions, as well as the cognitive behaviors that drive the promulgation of misinformation. Understanding this interconnected, information-driven world is a challenge faced by policy and decision-makers, and societies alike.

The Road Ahead

The first draft of this document was finalized in late February, just as the world was beginning to become aware of COVID-19 and the emerging health concerns that accompanied its spread. As the pandemic triggered economic shutdowns, quarantine periods, self-isolation and personal distancing, much of what we discussed above, has unfortunately been evident. Misinformation abounds, witness the recommendations that bathing in cow urine would prevent COVID-19, as would drinking bleach. While there is a certain sense of humor that accompanies those examples, the ultimate tragedy is the loss of life that accompanied these fake cures. In a response to the pseudoscience that exists regarding COVID-19, health law expert Tim Caulfield at the University of Alberta states that, “[t]he fight against pseudoscience is weakened if trusted medical institutions condemn an evidence-free practice in one context and legitimize it in another. We need good science all the time, but particularly during disasters” (Caulfield 2020).

The challenge for institutions, but more importantly individuals, whether they are scientists in academia, government, or industry is how to respond to the ‘infodemic’.

The challenge for institutions, but more importantly individuals, whether they are scientists in academia, government, or industry is how to respond to the “infodemic”, as the World Health Organization has coined the problem. Some communication experts advocate the solution lies in flooding society with digestible bites of correct information, that are readily shareable through social media platforms. However, the concept of simply increasing the publics' level of scientific literacy is not the solution that many hoped it might be, it is now evident that trust needs to be fostered between science communicators and those seeking information (Bauer, Allum and Miller 2007; Covello and Sandman 2001).

Instead of undertaking a rational assessment of a specific piece of information, people trust the information if it comes from someone they trust.

Consumers are bombarded by information on a daily basis. In an article for *Forbes Magazine*, Jon Simpson indicates that digital marketing experts have estimated that the number of ads that we as consumers are exposed to daily, ranges from 4,000 to 10,000 (Simpson 2017). While the gist of this article is on how to build product brand value, the key take-away message is that consumers apply filters to the information they are exposed to. If consumers filter ads, it is logically expected they will filter information about vaccines and GM crops in a similar manner. Instead of undertaking a rational assessment of a specific piece of information, people trust the information if it comes from someone they trust. For example, if an individual sees an anti-vax message that is shared on Facebook by someone they trust, the likelihood this anti-vax message is viewed as credible information increases. Alternatively, individuals will seek out those they believe have knowledge or expertise about a subject and seek their insights, such as talking to an automobile mechanic prior to purchasing a new vehicle.

Scientists, whether they work for academia, government or industry need to be better trained in how to communicate technical aspects of science, in a manner that aligns with how consumers want to receive information.

This brings us to the heart of the challenge, how can scientists begin to build trust with those seeking information from credible sources? The solution to the challenge is education. Scientists, whether they work for academia, government or industry need to be better trained in how to communicate technical aspects of science, in a manner that aligns with how consumers want to receive information. Individuals seeking information require value statements about technologies and innovations, while much of science speaks in statistics or probabilities. Universities, governments, and firms need to fund this training and provide ongoing support for their scientists. Without this fundamental enabling first step, the cycles of activist misinformation, expert frustration and public uncertainty, will continue in perpetuity.

The fundamentals of basic scientific research need to be brought into the 21st century.

Large-scale scientific research projects require more than natural scientists working in laboratories, they also require social scientists that are able to identify a broader set of scientific issues that are important for society, not just for science.

In addition to helping scientists become better communicators, the fundamentals of basic scientific research need to be brought into the 21st century. Large-scale scientific research projects require more than natural scientists working in laboratories, they also require social scientists that are able to identify a broader set of scientific issues that are important for society, not just for science. The vast majority of modern societies embrace innovation, yet they fear change. People highly value their cellular phone, however the idea of a COVID-19 tracing app, raises privacy concerns for many. As consumers, people are logically inconsistent in the relationship between innovation and adoption. Scientific research needs to evolve to become a systems approach. In any given research project, there will be technical issues that will need to be researched by biologists, geneticists, chemists, etc. There will also be societal and regulatory issues that will need be addressed by psychologists, sociologists, economists, political scientists and legal experts. The design and structure of large-scale, multi-institution research projects needs to be greatly broadened to reflect the information needs and demands of a 21st century society.

Social uncertainty about innovation has paralleled innovation for centuries. Historically, much of the social reservations about a specific innovative product was grounded in myths and rumors, whereas currently,

One facet of scientific research that funders, both public and private, need to recognize is that misinformation campaigns have evolved to become a business model for activist organizations, raising hundreds of millions in donations annually.

deliberate campaigns of misinformation are disseminated by activist organizations. One facet of scientific research that funders, both public and private, need to recognize is that misinformation campaigns have evolved to become a business model for activist organizations, raising hundreds of millions in donations annually (Ryan et al. 2020; GLP 2020). Until science communicators establish higher trust levels with the public, donations to activist organizations will continue, in turn, financing their misinformation campaigns. In time, the public's trust in science communicators will results in fewer donations and serve to mitigate misinformation campaigns. Many misinformation campaigns are now being deliberately targeted to resonate with specific consumer or societal segments, requiring science communicators to proactively develop information that is specifically designed to reach a target segment of society.

One result from the communication regarding COVID-19 that is evident is there has been increased interaction between anti-vax and anti-GM activist organizations. Some activists have even gone so far as to attempt to blame GM crops as being responsible for creating the corona virus. With the anti-vax and anti-GM activists groups working more collaboratively, science needs to rapidly develop strategies that contribute to refuting the resulting misinformation. One crucial strategy that would enable this would be to develop science communication programs at post-secondary institutions. As an industry, scientific research and development (R&D) is worth billions annually. Investments are now urgently required to protect this investment of public and private R&D funds.

With misinformation dissemination having become a business model with full time employees, the scientific community needs to step up and respond by investing more resources.

The communication of scientific information requires a 21st century transformation of its own. With misinformation dissemination having become a business model with full time employees, the scientific community needs to step up and respond by investing more resources. Many companies have initiated communication teams that are engaged daily in these activities and these firms need to be congratulated for their leadership. More firms need to do the same, as do commodity organizations, who are able to be the cumulated voice of the farmer. Post-secondary institutions need to respond and begin to develop and offer course in science communication. Granting agencies need to recognize the importance of ensuring the scientific R&D being funded is communicated to the tax paying public, by ensuring funds are allocated for science communication within research grants. The broad scientific research community needs to collaboratively organize a response strategy, fund it and allow it to succeed. The methodology required to communicate science efficiently and effective, is no different than that required to investigate a laboratory hypothesis.

References

AAAS. 2020. R&D at Colleges and Universities. *American Association for the Advancement of Science.* Available online at: https://www.aaas.org/programs/r-d-budget-and-policy/rd-colleges-and-universities. Accessed on April 28, 2020.

Aerni, P. 2018. The use and abuse of the term 'GMO' in the 'Common Weal Rhetoric' against the application of modern biotechnology in agriculture. Pp 39–52. In H. S. James Jr. (ed.) *Ethical Tensions from New Technology: The Case of Agricultural Biotechnology*. CABI Publishing, Wallingford, United Kingdom pp. 39–52.

Arjó, G., M. Portero, C. Piñol, J. Viñas, X. Matias-Guiu, T. Capell, A. Bartholomaeus, W. Parrott, and P. Christou. 2013. Plurality of opinion, scientific discourse and pseudoscience: an in depth analysis of the Séralini et al. study claiming that Roundup™ Ready corn or the herbicide Roundup™ cause cancer in rats. *Transgenic Res* 22 (2): 255–267.

Aschwanden, C. 2017. There's No Such Thing As 'Sound Science'. https://fivethirtyeight.com/features/the-easiest-way-to-dismiss-good-science-demand-sound-science/.

Baccarella, C. V., T. F. Wagner, J. H. Kietzmann and I. P. McCarthy. 2018. Social media? It's serious! Understanding the dark side of social media. *Eur Manag J* 36 (4): 431–438.

Barale-Thomas, E. 2013. The SFPT feels compelled to point out weaknesses in the paper by Séralini et al. (2012). *Food Chem Toxicol* 53:473–474.

Bauer, M. W., N. Allum, and S. Miller. 2007. What can we learn from 25 years of PUS survey research? Liberating and expanding the agenda. *Public Understanding of Science* 16 (1): 79–95.

Biden, S., S. J. Smyth, and D. Hudson. 2018. The economic and environmental cost of delayed GM crop adoption: The case of Australia's GM canola moratorium. *GM Crops Food* 9 (1): 13–20.

Bommann, L., and R. Mutz. 2015. Growth rates of modern science: A bibliometric analysis based on the number of publications and cited references. *J Assoc for Inf Sci Tech* 66 (11): 2215–2222.

Brainard, J. 2019. Open access megajournals lose momentum as the publishing model matures. Science, doi:10.1126/science.aaz4585.

Brookes, G., and P. Barfoot. 2018. Farm income and production impacts of using GM crop technology 1996–2016. *GM Crop Food* 9 (2): 59–89.

Calyxt. 2020. One oil for all of your formulation needs, https://calyxt.com/products/high-oleic-soybean-oil/.

Caulfield, T. 2020. Pseudoscience and COVID-19—we've had enough already. *Nature* doi: 10.1038/d41586-020-01266-z.

Chandrasekaran, J., M. Brumin, D. Wolf, D. Leibman, C. Klap, M. Pearlsman, A. Sherman, T. Arazi, and A. Gal-On. 2016. Development of broad virus resistance in non-transgenic cucumber using CRISPR/Cas9 technology. *Mol Plant Pathol* 17:1140–1153.

Clancy, K. A. 2016. *The Politics of Genetically Modified Organisms in the United States and Europe.* Palgrave Macmillan, New York.

Clement, J. 2020. Number of social network users worldwide from 2010 to 2023. Statistica, https://www.statista.com/statistics/278414/number-of-worldwide-social-network-users/.

Coumoul, X., R. Servien, L. Juricek, Y. Kaddouch-Amar, Y. Lippi, L. Berthelot, C. Naylies, M.-L. Morvan, J-P. Antignac, C. Desdoits-Lethimonier, B. Jegou, M. Tremblay-Franco, C. Canlet, L. Debrauwer, C. Le Gall, J. Laurent, P.-A. Gouraud, J.-P. Cravedi, E. Jeunesse, N. Savy, K. Dandere-Abdoulkarim, N. Arnich, F. Fourès, J. Cotton, S. Broudin, B. Corman, A. Moing, B. Laporte, F. Richard-Forget, R. Barouki, P. Rogowsky, and B. Salles. 2018. The GMO90+ project: absence of evidence for biologically meaningful effects of genetically modified maize based-diets on Wistar rats after 6-months feeding comparative trial. *Toxicol Sci* 68 (2): 315–338

Covello, V. and P. M. Sandman. 2001. Risk communication: Evolution and revolution, In A. Wolbarst (ed.), *Solutions to an Environment in Peril*. Baltimore: John Hopkins University Press, 164–178.

Creeber, G. 2015. *The Television Genre Book*. Bloomsbury Publishing, New York.

Cremer, J. 2019. Can these apples change the GMO conversation? 15 April 2019 https://allianceforscience.cornell.edu/blog/2019/04/can-apples-change-gmo-conversation/. (Accessed 13 April 2020)

Creswell, J.W. and J. D. Creswell. 2018. *Research Design Qualitative, Quantitative, and Mixed Methods Approaches*. 5th ed. Sage Publications, Inc., Thousand Oaks, California.

Crossley, M. 2018. Not all peer reviewed science is the same. Here's how to tell what to trust. 14 July 2018, https://www.sciencealert.com/guide-how-to-trust-peer-review-journal-science (Accessed 13 April 2020).

Daley, J. 2018. Europe applies strict regulations to CRISPR crops. *Smithsonian Magazine* https://www.smithsonianmag.com/smart-news/europe-applies-strict-regulations-gene-edited-crops-180969774/.

Del Vicario, M., A. Bessi, F. Zollo, F. Petroni, A. Scala, G. Caldarelli, H. E. Stanley and W. Quattrociocchi. 2016. The spreading of misinformation online. *Proceedings of the National Academy of Sciences*, 113 (3): 554559.

Dorius, S. F. and C. J. Lawrence-Dill. 2018. Sowing the seeds of skepticism: Russian state news and anti-GMO sentiment. *GM Crops Food* 9 (2): 53–58.

Dubock, A. 2020. "On the wrong side of humanity and science", Greenpeace Philippines launches last gasp effort to derail GMO Golden Rice approval. Genetic Literacy Project, https://geneticliteracyproject.org/2020/01/29/viewpoint-on-the-wrong-side-of-humanity-and-science-greenpeace-philippines-launches-last-gasp-effort-to-derail-gmo-golden-rice-approval/.

Enago Academy. 2018. Will open access & open science disrupt the future of academic publishing?, https://www.enago.com/academy/will-open-access-and-open-science-disrupt-the-future-of-academic-publishing/.

Entine, J. and R. Randall. 2017. GMO sustainability advantage? Glyphosate spurs no-till farming, preserving soil carbon, https://geneticliteracyproject.org/2017/05/05/gmo-sustainability-advantage-glyphosate-sparks-no-till-farming-preserving-soil-carbon/.

Fallis, D. 2009. A conceptual analysis of disinformation. Paper presented at the 2009 iConference, 8–11 February.

Fallis, D. 2014. A functional analysis of disinformation. Paper presented at the 2014 iConference, 4–7 March.

Farhat S., N. Jain, N. Singh, R. Sreevathsa, P. K. Dash, R. Rai, S. Yadav, P. Kumar, A. K. Sarkar, A. Jain, N. K. Singh, and V. Rai. 2019. CRISPR-cas 9 directed genome engineering for enhancing salt stress tolerance in rice. *Semin Cell and Dev Bio* 96: 91–99.

Farm & Food Care Saskatchewan. 2017. Farm to Fork Tour brings national and international food writers, dieticians, and chefs to experience Saskatchewan. https://farmfoodcaresk.org/2017/08/farm-to-fork-tour-brings-national-and-international-food-writers-dietitians-and-chefs-to-experience-saskatchewan/.

Fernandez, M. L. 2012. Rethinking dietary cholesterol. *Curr Opin Clin Nutr Metab Care* 15 (2): 117–121.

Funk, C., L. Rainie, and D. Page. 2015. Public and scientists' views on science and society. Pew Research Center, 29 January 2015, https://www.pewresearch.org/internet/wp-content/uploads/sites/9/2015/01/PI_ScienceandSociety_Report_012915.pdf

Funk, C., M. Hefferon, B. Kennedy, and C. Johnson. 2019. Trust and mistrust in Americans' view of scientific experts. Pew Research Center Science and Society, https://www.pewresearch.org/science/2019/08/02/trust-and-mistrust-in-americans-views-of-scientific-experts/.

Gelski, J. 2016. Cargill ingredients now Non-GMO Project verified https://www.foodbusinessnews.net/articles/6982-cargill-ingredients-now-non-gmo-project-verified

Genetic Literacy Project. 2020. Anti-GMO Advocacy Funding Tracker: Vast network of donors and NGOs seed doubt about crop biotechnology, https://geneticliteracyproject.org/2020/05/05/anti-gmo-advocacy-funding-tracker-vast-network-of-donors-and-ngos-seed-doubt-about-crop-biotechnology/.

Genetic Literacy Project. 2019. Vandana Shiva: ‘Rock Star’ of GMO protest movement has anti-science history, https://geneticliteracyproject.org/glp-facts/vandana-shiva/.

Grech, V. 2017. Fake news and post-truth pronouncements in general and in early human development. *Early Hum Devel* 115:118–120.

Horbach, S. P. J. M. and W. Halffman. 2018. The changing forms and expectations of peer review. *Research Integrity and Peer Review* 3 (8), https://researchintegrityjournal.biomedcentral.com/articles/10.1186/s41073-018-0051-5.

Impossible Foods. 2019. Impact Report 2019. https://impossiblefoods.com/mission/2019impact/.

International Service for the Acquisition of Agri-biotech Applications (ISAAA). 2019. Biotech Crops Continue to Help Meet the Challenges of Increased Population and Climate Change. ISAAA Brief 54, http://www.isaaa.org/resources/publications/briefs/54/executivesummary/default.asp.

Janicke Hinchliffe, L. 2019. Transformative agreements: A primer. The Scholarly Kitchen. Online, https://scholarlykitchen.sspnet.org/2019/04/23/transformative-agreements/.

Juma, C. 2016. *Innovation and Its Enemies: Why People Resist New Technologies*. Oxford University Press, Oxford.

Karlova, N.A. , K. E. Fisher 2013. Plz RT: A social diffusion model of misinformation and disinformation for understanding human information behavior *Information Research* 18 (1): 117

Karlova, N. A., J. H. Lee. 2011. Notes from the underground city of disinformation: A conceptual investigation *Proc Am Soc Info Sci Tech* 48:1–9.

Keenan, M. and K. Dillenburger. 2018. How ‘Fake News’ affects autism policy. *Societies* 8 (2): 29.

Kiemer, V. 2016. Measuring Up: Impact Factors Do Not Reflect Article Citation Rates. *PLOS Blogs* https://blogs.plos.org/plos/2016/07/impact-factors-do-not-reflect-citation-rates/.

Kinsella, K. 1992. Changes in life expectancy 1900–1990. *Am J Clin Nutr* 55:1196–1202.

Law Library of Congress. 2015. Restrictions on Genetically Modified Organisms: European Union, https://www.loc.gov/law/help/restrictions-on-gmos/eu.php.

Lewandowsky, S., U. K. Ecker, C. M. Seifert, N. Schwarz and J. Cook. 2012. Misinformation and its correction: Continued influence and successful debiasing. *Psychol Sci Public Interest* 13 (3): 106–131.

Lewis, G. S. and M. C. Wulster-Radcliffe. 2014. Predators and impersonators: A new breed of journals. *Animal Frontiers* 4 (1): 46–47.

Losee, R. M. 1997. A discipline independent definition of information. Journal of the American Society for Information Science, 48 (3): 254–269

Lynas, M. 2013. The true story about who destroyed a genetically modified rice crop, 26 August 2012. *Slate* https://slate.com/technology/2013/08/golden-rice-attack-in-philippines-anti-gmo-activists-lie-about-protest-and-safety.html

Max-Planck-Gesellschaft. 2019. Scientists call for modernizing of EU gene-editing legislation, 29 July 2019, https://www.mpg.de/13761643/scientists-call-for-modernization-of-the-european-genetic-engineering-law.

McFadden, B. R., and J. L. Lusk. 2016. What consumers don't know about genetically modified food, and how that affects beliefs. *The FASEB Journal* 30 (9): 3091–3096.

McGuire, M. K., M. A. McGuire, W. J. Price, B. Shafii, J. M. Carrothers, K. A. Lackey, D. A. Goldstein, P. K. Jensen and J. L. Vicini. 2016. Glyphosate and aminomethylphosphonic acid are not detectable in human milk. *American Journal of Clinical Nutrition* 103 (5): 1285–1290.

McHughen, A. and S. J. Smyth. 2008. US regulatory system for genetically modified [genetically modified organism (GMO), rDNA or transgenic] crop cultivars. *Plant Biotechnol J* 6 (1): 2–12.

Miller, L. and A. L. Jameel. 2020. Making real a biotechnology dream: nitrogen-fixing cereal crops. *MIT News* http://news.mit.edu/2020/making-real-biotechnology-dream-nitrogen-fixing-cereal-crops-0110.

Norero, D. 2017. More than 280 organizations and scientific institutions support the safety of GM crops, http://www.siquierotransgenicos.cl/2015/06/13/more-than-240-organizations-and-scientific-institutions-support-the-safety-of-gm-crops/

O'Brien, R. 2009. *The Unhealthy Truth.* Penguin Radom House, New York.

Parsons, J. 2016. Who pays for open access? *Library Journal*. http://lj.libraryjournal.com/2016/03/oa/welcome-to-science-2-0-open-access-in-action/.

Perception in Reality. 2013. Philippine farmers uproot, destroy GMO rice test field. https://www.youtube.com/watch?v=xoBicEnevjs.

Perry, E. D., F. Ciliberto, D. A. Hennessy, and G. C. Moschin. 2016. Genetically engineered crops and pesticide use in U.S. maize and soybeans. *Science Advances* 2 (8): e1600850, doi:10.1126/sciadv.1600850.

Pollan, M. 2006. *The Omnivore's Dilemma: A Natural History of Four Meals*. Penguin Press, London

Proctor, R. N. 2012. The history of the discovery of the cigarette-lung cancer link: Evidentiary traditions, corporate denial, global toll. *Tob Control* 22 (1): 87–91.

Regis, E. 2019. Golden Rice could save children. Until now, governments have barred it. *Washington Post* 11 November 2019, https://www.washingtonpost.com/opinions/2019/11/11/golden-rice-long-an-anti-gmo-target-may-finally-get-chance-help-children/.

Resnik, D. B., B. Konecny and G. E. Kissling. 2017. Conflict of interest and funding disclosure policies of environmental, occupational, and public health journals. *Journal of Occupational and Environmental Medicine* 59 (1): 28.

Roberts, R. 2018. The Nobel Laureates' campaign supporting GMOs. *Journal of Innovation & Knowledge* 3 (2): 61–65.

Rocha. S. A. V., A. T. De Carvalho Hoepers, T. S. Fröde, L. J. M. Steidle, E. Pizzichini and M. M. M. Pizzichini. 2019. Prevalence of smoking and reasons for continuing to smoke: A population-based study. *Jornal Brasileiro de Pneumologia* 45 (4): 1–7.

Roser, M., E. Ortiz-Ospina, and H. Ritchie. 2019. Life expectancy, https://ourworldindata.org/life-expectancy.

Rosselli, R., M. Martini and N. L. Bragazzi. 2016. The old and the new: Caccine hesitancy in the era of the Web 2.0. Challenges and opportunities. *J Prev Med Hyg* 57 (1): E47.

Ryan, C. and A. McHughen. 2014. Tomatoes, potatoes and flax: Exploring the cost of lost innovations. Pp. 841–852. In S. J. Smyth, P. Phillips, and D. Castle (eds.), *Handbook on Agriculture, Biotechnology and Development* Edward Elgar, Cheltenham, UK

Ryan, C. D., A. J. Schaul, R. Butner, and J. T. Swarthout. 2020. Monetizing disinformation in the attention economy: The case of genetically modified organisms (GMOs). *Euro Manag J* 38 (1): 7–18.

Sale, K. 1996. *Rebels Against the Future: The Luddites and Their War on the Industrial Revolution: Lessons for the Computer Age.* Perseus Publishing, Cambridge, Massachusetts.

Savage, S. 2013. Six reasons organic is NOT the most environmentally friendly way to farm, https://appliedmythology.blogspot.com/2013/04/six-reasons-organic-is-not-most.html.

Shapin, S., and S. Schaffer. 1985. Leviathan and the Air-Pump: Hobbes, Boyle, and the Experimental Life. Princeton University Press, Princeton, New Jersey.

Sherman, R. J. 2012. *Supply Chain Transformation: Practical Roadmap to Best Practice Results* John Wiley & Sons, Hoboken, New Jersey

Shi, J., H. Gao, H. Wang, H. R. Lafitte, R. L. Archibald, M. Yang, S. M. Hakimi, H. Mo and J. E. Habben. 2017. ARGOS8 variants generated by CRISPR-Cas9 improve maize grain yield under field drought stress conditions. *Plant Biotechnol J* 15 (2): 207–216.

Simpson, J. 2017. Finding brand success in the digital world. *Forbes Magazine*, https://www.forbes.com/sites/forbesagencycouncil/2017/08/25/finding-brand-success-in-the-digital-world/#1ef65a40626e.

Sismondo, S. 2008. Pharmaceutical company funding and its consequences: A qualitative systematic review. *Contem Clin Trials* 29 (2): 109–113.

Smith J. 2003. *Seeds of Deception: Exposing Industry and Government Lies About the Safety of the Genetically Engineered Foods You're Eating*. Yes! Books, Portland, Maine

Smith, C. 2009. Fifty-Three-Year-Old quote still rings true today. *Corn South*, https://cornsouth.com/2009/october-2009/fifty-three-year-old-quote-still-rings-true-today/.

Smith, K. 2019. 126 amazing social media statistics and facts. Brandwatch, https://www.brandwatch.com/blog/amazing-social-media-statistics-and-facts/.

Smyth, S., J. and A. McHughen. 2012. Regulation of genetically modified crops in USA and Canada: Canadian overview. In C. Wozniak and A. McHughen (eds.) *Regulation of Agricultural Biotechnology: The United States and Canada* Springer Netherlands, Dordrecht, Netherlands.

Steinberg, D. and A. M. Gotto, Jr. 1999. Preventing coronary artery disease by lowering cholesterol levels. *JAMA* 282 (21): 2043–2050.Steinberg, P., H. van der Voet, P. W. Goedhart, et al. 2019. Lack of adverse effects in subchronic and chronic toxicity/carcinogenicity studies on the glyphosate-resistant genetically modified maize NK603 in Wistar Han RCC rats. *Arch Toxicol*, doi:10.1007/s00204-019-02400-1.

The Non-GMO Project. History. 2019. From https://www.nongmoproject.org/about/history/, Accessed 1st Oct 2019.

United Nations Department of Economic and Social Affairs. 2018. 68% of the world population projected to live in urban areas by 2050, says UN. https://www.un.org/development/desa/en/news/population/2018-revision-of-world-urbanization-prospects.html.

United States Department of Agriculture (USDA). 1980. Nutrition and Your Health Dietary Guidelines for Americans. https://www.dietaryguidelines.gov/sites/default/files/2019-05/1980%20DGA.pdf.

United States Department of Agriculture (USDA). 2015. Dietary Guidelines For Americans 2015-2020 US Dietary Guidelines for Americans, 2015–2020. https://health.gov/our-work/food-nutrition/2015-2020-dietary-guidelines/guidelines/.

van Wulfen, G. 2016. 10 great ideas that were originally rejected. *Innovation Excellence* https://www.innovationexcellence.com/blog/2016/12/19/10-great-ideas-that-were-originally-rejected/.

Wadwha, V. 2014. Why we should believe the dreamers and not the experts. Washington Post, 31 July 2014, www.washingtonpost.com/news/innovations/wp/2014/07/31/why-we-should-believe-the-dreamers-and-not-the-experts/.

Ward, C. W. and M. C. Lawrence. 2011. Landmarks in insulin research. *Front Endocrinol* 2: 1–11.

Ward. R. 2020. Mushrooms, oregano oil and masks targeted in crackdown on misleading COVID-19 ads, https://www.cbc.ca/news/canada/calgary/health-canada-compliance-list-1.5525563.

Wesseler, J. and D. Zilberman. 2013. The economic power of the Golden Rice opposition. *Environment and Development Economics* 19 (6): 724–742.

World Health Organization. 2019. Immunization coverage. https://www.who.int/news-room/fact-sheets/detail/immunization-coverage.

Wulster-Radcliffe, M. C., D. L. Hamernik, L. Reynolds, G. S. Lewis and S. Zinn. 2015. Scientific publications: From the stone tablet to the electronic tablet. *Animal Frontiers* 5 (3): 45–50.

Yu, W., L. Wang L, R. Zhao, J. Sheng, S. Zhang, R. Li, and L. Shen. 2019. Knockout of SlMAPK3 enhances tolerance to heat stress involving ROS homeostasis in tomato plants. *BMC Plant Biology* 19 (354), doi:10.1186/s12870-019-1939-z.

Zhou, L., and D. Zhang. 2007. An ontology-supported misinformation model: Toward a digital misinformation library *IEEE Transactions on Systems, Man, and Cybernetics - Part A: Systems and Humans* 37 (5): 804–813

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