COVID-19 Pandemic and Decision-Making

Waiting for Scientific Certainty is a Fool's Game

Signs in many businesses state that "EMPLOYEES MUST WASH HANDS BEFORE RETURNING TO WORK!" Yet this simple and seemingly obvious practice to remove pathogens and prevent the transmission of disease is a relatively recent occurrence. In fact, widespread acceptance regarding the existence of pathogens emerged slowly and became established only late in the 19th century. Prior to that time, miasma—bad air from the environment such as the foul odors associated with death and decay—was thought to cause and spread disease.[1]

Miasmatic theory originated in ancient Greece through the ideas of Hippocrates, became the dominant mode of thought regarding disease transmission in Europe and China, and remained unquestioned until the mid-1800s. For instance, while smallpox vaccination became common in Europe during the early part of the 19th century, miasmatic theory could not explain how that immunity developed. As is common with major changes in science, the transition away from miasmatic theory took many years and involved contributions from numerous scientists.

For example, in 1847, the Hungarian doctor Ignaz Semmelweis noted that when doctors and medical students, after having performed autopsies, then performed vaginal inspections of expectant mothers, the pregnant women suffered significantly higher rates of mortality. Semmelweis dramatically reduced the number of deaths in the hospital by having doctors wash their hands and equipment with soap and chlorine, but the practice met resistance by doctors at the hospital and soon ended.[2]

One year later, the physician John Snow identified a link between contaminated drinking water in London and cholera.[3] This and the handwashing case noted above were difficult, although not impossible, to explain with miasmatic theory's transmission of disease by foul odors. Louis Pasteur subsequently provided a significant advance in understanding disease and its causes. His work in 1856 identified microorganisms as the cause of fermentation and food spoilage, and therefore potentially also the cause of illnesses—an idea that later became known as "germ theory."[3]

Finally, in 1890, Robert Koch provided significant evidence that unique pathogens were responsible for particular diseases, and that physicians using his postulates of disease identification could consistently identify them.[4] Even with these advancements, only with much effort and corroborating studies was germ theory eventually replaced by miasmatic theory.

> **Existing knowledge is not easily abandoned, even in light of emerging contrary evidence. This may appear puzzling and wrong-headed, but fields of research would be in constant turmoil and progress curtailed if experts easily abandoned established ideas in light of initial contrary evidence. Many historical episodes (e.g., see "Accounting for Anomaly: The Discovery of Neptune" at** https://storybehindthescience.org/pdf/neptune.pdf**) illustrate how often well-established knowledge turns out to be correct, even in the face of contradictory evidence. Scientific knowledge can change, but a strength of science is its conservative vetting process that assesses whether change is warranted.**

As widespread acceptance of germ theory occurred in the late 19th century, a mystery unfolded surrounding a plant disease, tobacco mosaic disease. In 1886, the German scientist Adolf Mayer ground up diseased tobacco plants and reported that the resulting liquid was capable of infecting other plants, but he could not culture the disease-causing agent in a manner that would be expected for bacteria.[5] In 1892, a Russian doctoral student named Dimitri Ivanovsky extended the work of Mayer, and in doing so, deepened the mystery surrounding tobacco mosaic disease. Ivanovsky passed liquid from diseased tobacco plants through a Chamberland filter designed to remove bacteria, but to his surprise, he was unable to extract anything.[6]

The results of Ivanovsky's investigation seemed to directly conflict with germ theory. Unwilling to abandon the theory, the Russian instead blamed his methods and equipment as likely reasons for his inability to extract the bacteria. However, six years later, the Dutch microbiologist, Martinus Beijerinck, who was aware of Mayer's work, but not that of Ivanovsky, also reported that the infectious fluid of diseased tobacco plants could pass through standard filters used to remove bacteria. Beijerinck called the substance *contagium vivum fluidum*, although he also used the term “virus” in some of his papers—a word which translates directly from Latin as “venom.”

After extensive investigations, Beijerinck concluded that the *contagium vivum fluidum* was not a bacterium, toxin, or enzyme, and that it behaved like an intracellular parasite that required living cells to reproduce. However, lacking the technology to make viruses visible, and unable to provide practical help to tobacco farmers, Beijerinck and many of his contemporaries who were investigating tobacco mosaic virus (TMV) abandoned their work.[5]

Note how prevailing acceptance of the germ theory for disease influenced Ivanovsky's interpretation of his results. Note also his refusal to claim that germ theory was at fault and in need of replacement. Again, if scientists abandoned prevailing ideas at the first sign of contrary evidence, the progress of science would be significantly curtailed.

In common everyday usage, “theory” usually means “guess.” However, robust scientific theories explain natural phenomena and guide science research. Well-established scientific theories are central to understanding the natural world and conducting research.

Virus research largely languished due to the inability to observe and culture viruses. The submicroscopic size of viruses kept them unseen by humans until technological advances allowed TMV to be viewed in 1935 by Wendell Stanley using X-ray crystallography. In 1939, the first electron micrograph images of TMV emerged, which were consistent with Stanley's rod-shaped crystals.

By the late 1950s, additional refinement of electron microscopy technology and increased knowledge of the structure of DNA had developed. Scientists such as James Watson and Francis Crick used this knowledge to argue that viruses were composed of protein cases surrounding nucleic acids.[7] A vast body of knowledge about viruses has been built since the 1950s supporting the claim that viruses are intracellular parasites, composed of either RNA or DNA encased in a protein shell, and unable to reproduce without a host cell.[8]

Note how technological developments assisted research about viruses. Most advanced technologies would be impossible without scientific knowledge, and progress in science is promoted by technological advancements. Science and technology, while different disciplines, are so intertwined that *technoscience* is sometimes used to describe their interaction. That said, much was learned about the natural world, including the existence of viruses, long before today's advanced technologies.

Of course, viruses also infect humans. Outbreaks of disease, whether they are viral or bacterial, are a constant threat, as evidenced by seasonal flu outbreaks. Diseases that cause widespread illness over an extensive area are called epidemics, but when such outbreaks cross international borders and affect an exceptionally higher proportion of populations, the word pandemic is used. Many pandemics throughout history have been traced to viruses, including the 1918 pandemic that was a H1N1 subtype of influenza, a virus thought to have originated in birds.[9]

Initial reports of the illness appeared in Fort Riley, Kansas, during March 1918, but cases may have existed two months earlier in rural Kansas. The first wave of the virus quickly spread beyond U.S. borders, aided by the transport of troops during World War I. For most of those infected, the illness lasted only a few days and appeared flu-like, with unusual severity. However, a disturbing number of young, healthy, strong individuals who contracted the illness died quickly from pneumonia-like symptoms. In September of that year, a second wave of the virus appeared in France, Sierra Leone, Massachusetts, and New York. The virus spread extremely quickly, and had high death rates. Those afflicted often displayed severe symptoms that included paralysis, lung damage so severe that the tissue looked as if it had been exposed to poison gas, and bleeding from the ears, eyes, stomach, and intestines.[10] The following month, approximately 195,000 Americans died.[11] Surprisingly, those 20-34 years-old had the highest mortality rate of any age group.[11] After the third and final wave of the illness in the spring of 1919, the death toll from the pandemic reached approximately 50 million people worldwide.[12]

On December 31st, 2019, word of a pneumonia-like illness in the city of Wuhan, China, first came to the attention of the World Health Organization.[13] The cause was quickly identified as a novel coronavirus, the same type of virus responsible for Middle East respiratory syndrome (MERS) and previous severe acute respiratory syndrome (SARS) outbreaks.[14] The virus was named severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), and the disease it caused was named COVID-19.[15] People afflicted with COVID-19 experienced a range of symptoms, but the most common included fever, cough, and shortness of breath.[16] Hospitals within the city of Wuhan could not handle all those who became seriously ill. To thwart the spread of the disease, the city went into lockdown on January 23, 2020.

As fears of a global pandemic ensued, scientists around the world were tasked with learning more about the virus, its transmission, its effects on humans, its likely spread, and how it could be stopped or at least slowed. Policymakers required immediate projections and expedited research. The public has often misunderstood the results of that work, ongoing research, and emerging healthcare advice. Many people wrongly expect science to provide absolute certainty, and do so quickly. This and other misconceptions regarding the nature of science can have tragic effects on personal and societal decision-making.

As you continue reading, consider how waiting for scientific certainty before taking action is unwise. The best available science, vetted by the community of scientific experts, must guide personal and public decision-making for the best foreseeable outcome.

Two of the primary goals of science are to accurately explain and predict phenomena in the natural world. Both are key to understanding nature in a way that may then be used to improve the quality of life. However, the natural world is complex, and even when isolated phenomena are well understood, multiple changing variables in nature interact in complex ways that result in probabilistic projections (i.e., what is most likely to occur). This is the reality of nature, not a flaw of science.

For example, meteorologists have for decades worked to create and improve hurricane models for rapid, high-profile projections. One type is called a spaghetti model (Figure 1) because storm tracks predicted by numerous scientific models are combined on one map that look like strands — akin to spaghetti — that convey several likely storm paths. While not providing absolute certainty, the projections have life and death implications for millions of people.

For example, in 2005 forecasters tracking Hurricane Katrina released model projections on August 26th showing a high probability of New Orleans being directly hit.[17] The morning of August 28th, still nearly 24 hours before the hurricane struck the city, the National Weather Service released a dire warning of the catastrophic impacts predicted to result from Katrina.[18] While the warnings and resulting mandatory evacuation of New Orleans saved thousands of lives, those who could not or purposely did not evacuate resulted in harrowing rescues of individuals and approximately 1,500 deaths.

For some natural phenomena like those experienced in school introductory science labs, science ideas make precise predictions. Unfortunately, this creates the misconception that science can and should always provide precise predictions, and this can have devastating consequences for science-based decision-making. In the natural world, many variables interact at both macro and micro-scales, resulting in probabilistic projections.

The tracking and eventual landfall of hurricane Harvey is a more recent example of how valuable hurricane models are despite their probabilistic nature. The variables affecting meteorological events are, however, numerous, complex, and interconnected. In 2015, Hurricane Joaquin's path strayed significantly from some model projections.[19] Even with that marked deviation, meteorologists still accurately identified the formation of a tropical storm located hundreds of miles from shore, warned areas of an impending hurricane despite the storm's erratic movement, and rapidly and consistently updated and improved the storm track projections with incoming data.

Figure 1. Spaghetti Model, from web.uwm.edu*

When viewed through a broader lens, the difficulty projecting Joaquin's path should be seen amidst improving storm-tracking performance. For example, the average difference between a hurricane path projection three days in advance and the actual path has improved from 272 miles in 1999 to 119 miles today.[20] Misses in forecasts made three-days in advance will continue to

* https://web.uwm.edu/hurricane-models/models/archive/2015/al112015/al112015_2015093018_ens.png

occur, but improving scientific models provide the best approach for providing advanced storm warnings that save lives. Those who ignore hurricane projections because of their uncertainty do so at their own peril, and are choosing to return to a time when people received little or no warning about impending storms.

Such was the case in 1900 when the city of Galveston, Texas, was devastated by a Category 4 hurricane that killed 6-12 thousand people; still the deadliest natural disaster in U.S. history.[21] Scientific models are useful in decision-making even though much work remains to further improve them. Science takes time, but waiting until the level of understanding is well established and flawless will result in missing enormous opportunities to benefit society. Meteorological models are constantly being improved as we learn more about the atmosphere, and learn more about problems in the models. Yet, every year, thousands of lives and enormous amounts of money are saved because we rely on the models, imperfect as they are.

Scientific models are not exact replicas of their targeted phenomena, but they assist in projecting outcomes, explaining phenomena, and framing further research.

Scientific models are put forth for many complex natural phenomena. In the case of a pandemic, models serve many purposes, such as projecting the number of future cases and deaths due to a given disease in a certain location, and projecting how the virus will likely spread. Just as with hurricanes, public health experts can draw upon numerous individual scientific models, each with their own strengths and weaknesses, but all based upon historical and contemporary data.[22] Like hurricane projections, epidemiological models are constantly evaluated by comparing their projections to actual data, and changes to the models are made as needed.

Unfortunately, when errant projections play out in high-profile situations, such as with the COVID-19 pandemic or hurricanes, people wrongly focus on the problems with epidemiological models, while ignoring their value when used appropriately for decision-making. For instance, some epidemiological models are purely statistical, making viable short-term projections on current data. Another group of models is mechanistic in nature, taking into account how the SARS-CoV-2 spreads and making transmission projections based on relevant variables. These models put forth projections based on “what-if” scenarios that can be numerous and synergistic (e.g., What if no preventive measures were followed? What if appropriate social-distancing measures were followed? What if mask-wearing was widespread? What if mild COVID-19 cases conferred immunity?). Other models are hybrids of these two general approaches. As with hurricane models, existing knowledge affects their accuracy. With COVID-19 our knowledge about the virus, its transmission, level of immunity of those recovering from COVID-19, and many other factors are improving with ongoing research. Well-established knowledge requires time to develop, and absolute certainty is always elusive. So, what action do we take, knowing that deciding not to act is actually an action? Here also, science provides knowledge important for personal and public decision-making.

1. A strength of science is that even its most well accepted ideas are open to revision in light of new evidence or reinterpretation of prior evidence. (a) Why were initial COVID-19 models important, even though their projections entailed uncertainty? (b) How is the possible revision of scientific knowledge, including models, a strength of science?

The 1918 flu outbreak and several other pandemics that occurred during the 20th century have provided a significant body of scientific knowledge regarding the efficacy of social distancing for reducing disease transmission. During the 1918 pandemic, even with advances in germ theory, the virus causing the disease was not well understood. Social distancing interventions were therefore widely enacted in cities across the United States. For example, St. Louis, Missouri, closed schools, banned public gatherings, and restricted the hours of businesses.[23] Tucson, Arizona, closed all public gathering places, including schools, churches, and theaters.[24] In stark contrast, Philadelphia's public health director, a political appointee, ignored growing warnings of medical experts and permitted a large city parade on September 28th to promote war bonds for the ongoing first world war. Echoing today's misconceptions regarding COVID-19, the director publicly denied that the disease was a threat and referred to it as a typical flu. Three days after the parade, city hospitals filled and within two weeks, approximately 4,500 had died of the flu.

A 2007 study by Hatchett, et. al., reported that cities enacting multiple nonpharmaceutical interventions, such as social distancing, during the early portion of the 1918 pandemic had approximately 50% lower peak death rates, and roughly 20% lower total excess mortality than cities that did not do so.[25] Markel, et. al., in 2007 reported the efficacy of social distancing and other nonpharmaceutical interventions across 43 cities in the United States during the 1918 pandemic, and similarly concluded that such efforts played a critical role in reducing the impact of the disease. They stressed that early and consistent implementation of the policies were key to minimizing the impacts of the outbreak, and cities that relaxed their interventions prematurely often experienced a second spike in deaths, and subsequently had to reenact social distancing and other policies.[23]

Glass, et. al., in 2006 modeled the transmission of a virus with similar properties as that responsible for the 1957-1958 flu outbreak, and reported that social distancing through school closures and keeping young people at home would decrease new cases over the given time period by more than 90%.[26] In 2018, Ahmed, et. al., reviewed fifteen published articles that had utilized epidemiological and/or modeling techniques to investigate the effectiveness of social distancing in relation to influenza transmission. They concluded that social distancing reduces flu transmission by avoiding the respiratory droplets that are prevalent in the air within six feet of an infected individual.[27]

Social distancing during disease outbreaks has likely occurred in some manner throughout human history. For example, Biblical passages describe the isolation of those with leprosy. However, coordinated, state-sanctioned efforts to separate sick people from the rest of the population did not occur until the 14th century, when an inability to combat the plague with medicine led some Italian city-states to restrict the movement of travelers and force infected individuals into isolated camps.[28] In the ensuing centuries, the practice of mandatory isolation spread through many parts of Western Europe, and was given the name "quarantine."

Considerable evidence for social distancing as a nonpharmaceutical intervention during pandemics existed prior to the COVID-19 pandemic. Since the start of the pandemic, many studies have been published evaluating the efficacy of social distancing, including school closures, stay-at-home orders, efforts to maintain six feet of separation between individuals, restrictions on business, and public gathering bans. One example of this research is a study that analyzed data from Google and Apple showing changes in mobility of the companies' users based on GPS information and modes of transportation. Social distancing accounted for nearly half of the variation in disease transmission rates.[29] While research has largely increased confidence in the effectiveness of social distancing interventions, appropriate distancing depends on several variables.

For example, researchers used models to simulate transmission of respiratory droplets under variable wind speeds and relative humidity, and reported that six feet of separation may be insufficient to stop transmission of the SARS-CoV-2 virus in all situations.[30] While previous and ongoing research makes clear that many social distancing practices have significant effectiveness, the large amount of research stemming from the COVID-19 pandemic will continue to refine scientists' understanding of practices having the most positive impact in the context of this outbreak, and why that is the case. The accuracy and efficacy of public health recommendations during future pandemics will undoubtedly be improved as a result.

The wearing of face coverings is another nonpharmaceutical intervention to reduce the spread of disease. The history of wearing face coverings during pandemics dates back to at least the early 17th century.[31] However, such early examples were designed in an era in which the dominant understanding of disease was still miasma theory. As a result, masks during this time were designed to overcome the stench of death with more favorable odors.[32] The rise of germ theory in the late 19th century led to dramatic and rapid changes in the way public health experts viewed disease transmission and prevention efforts. Rather than focusing on miasmas, doctors could attempt to identify bacteria responsible for outbreaks, investigate modes of transmission, and refine interventions to limit transmission more effectively. For example, Dr. Mendes de Leon placed plates on an operating room table and had surgeons say the average number of words that were spoken during a surgery (150-500). The plates were reported to have 75 resultant bacterial colonies from the sputum coming from the surgeon's mouth while speaking, with most of the colonies composed of streptococci bacteria.[33] In 1919, Weaver reported a significant decrease in the occurrence of several types of illnesses among nurses who began using masks, and provided empirical evidence that certain gauze masks could block nearly all bacteria-carrying droplets. Weaver stated that, "In all instances in which infections locate in the respiratory tract and in which the infectious agent is discharged in mouth spray it is reasonable to protect those about the patient by mask."[34]

Since 1918, mask use in operating rooms became nearly universal. However, masks in the context of public use during disease outbreaks introduced a number of variables that resulted in a lack of clarity on the issue. Thus, despite the mounting evidence for the importance of masks in surgical settings, mask use during pandemics was less consistent. Cloth masks were widely used during the 1910 Manchurian Plague because of the advocacy of Wu Lien, but many were skeptical of mask requirements during the 1918 pandemic. Even the Surgeon General of the United States Navy at the time expressed concern that the risks of masks could outweigh their benefits for the public due to improper construction, materials, and use, leading to wet and contaminated fabric in close proximity to the mouth and nose.[35] Because people often crudely construct masks out of ineffective materials, their efficacy can be low. For example, Stockton, California, and Boston, Massachusetts, experienced nearly identical death rates during a period of time in which Stockton was requiring mask use and Boston was not.[35]

Similarly, mandatory mask use in Alberta, Canada failed to stem the increase in influenza cases, which resulted in the public turning against the mandate.[36] However, the culprit was not masks, but poorly crafted masks. Importantly, the types of masks most widely available during a pandemic primarily minimize ill individuals from transmitting a disease, not stop users from contracting a respiratory illness. Since the 1890s, many studies report that masks help reduce disease transmission. However, in the context of widespread use of predominantly homemade masks during a pandemic, a large number of questions remained, and enough conflicting conclusions had been published to cast reasonable doubt on the efficacy of many, but not all, homemade masks.

Early in the COVID-19 pandemic, the Centers for Disease Control (CDC) and other health experts, such as the United States Surgeon General, dissuaded people from purchasing or wearing face masks. Those early recommendations reflected the thinking that disease prevalence was low as well as evidence that more strongly supported social distancing measures than mask wearing. At that time, research regarding the efficacy of mask use for reducing COVID-19 transmission was "contested" and the primary literature on the topic "heterogeneous and somewhat sparse."[37] However, by April 3rd, the CDC reversed course and recommended all people wear face masks in public settings.[38] The change makes sense in light of abundant research that soon indicated SARS-CoV-2 spreads primarily via respiratory droplets.[39]

Simultaneously, several studies provided evidence that masks, compared to when the mouth is uncovered, significantly reduce the distance that respiratory droplet-laden jets of air travel when we exhale, cough, or sneeze.[40] Epidemiological evidence also supports mask use. For example, Lyu and Wehby compared states that required masks during the COVID-19 pandemic and those that did not, and reported that states enacting such requirements experienced greater decreases in growth rates than states that opted not to do so.[41] A systematic review of 172 studies, including a meta-analysis of 44 comparative studies, published June 27, 2020, determined that social distancing of at least one meter and mask wearing both significantly reduce the transmission of coronaviruses. The science behind the efficacy of widespread mask use by the public is still emerging, but sufficient evidence has accumulated in support of its use as an important intervention to help decrease the spread of COVID-19. While research continues, an analysis in a leading medical journal stated:

> *…in the face of a pandemic the search for perfect evidence may be the enemy of good policy. As with parachutes for jumping out of aeroplanes, it is time to act without waiting for randomized controlled trial evidence. A recently posted preprint of a systematic review came to the same conclusion. Masks are simple, cheap, and potentially effective. …worn both in the home (particularly by the person showing symptoms) and also outside the home in situations where meeting others is likely (for example, shopping, public transport), they could have a substantial impact on transmission with a relatively small impact on social and economic life.*[37]

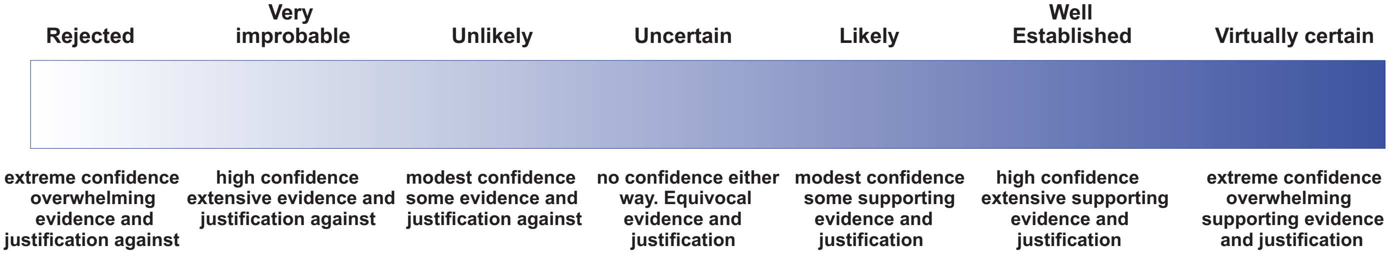
2. Emotions, personal preferences, and ideology affect the decision-making of all humans. What are some potential dangers of giving these greater weight than scientific knowledge in forming decisions about public health issues such COVID-19?

Scientists argue for or against possible public health interventions using evidence from the analysis of historical episodes, the projections of scientific models, and the results of empirical studies. With new evidence and reinterpretation of prior evidence, scientists' views may change, and related public health decisions may also be modified. While such changes can understandably create confusion and distrust among those who do not deeply understand the nature of science, evolving ideas are a normal and powerful part of science. Policymakers and the public must abandon thinking that scientific knowledge must be absolutely certain before it can inform decision-making.

Figure 2 illustrates that rather than absolute certainty, the evidence and justification for and confidence in scientific knowledge as judged by the *authentic community of experts* is what must guide decision-making. A crucial point is that the community of experts in their relevant area

FIGURE 2

How the scientific community regards the certainty and reliability of scientific claims.



of study is far more trustworthy in determining the reliability of ideas regarding nature than is any individual or small group of experts. Science is a social enterprise, and changes are often the result of long-term deliberations based on evidence and arguments presented in scientific research papers and at professional conferences. As evidence accumulates in support of an idea, scientists' confidence in the idea also continues to grow, particularly if the idea coheres with related science ideas. Eventually, an idea can become so well established that it is accepted as “true” and unlikely to experience dramatic changes. Still, even the most well-established ideas are potentially open to challenge.

However, anyone proposing modification or replacement of well-established ideas would face tremendous evidence to the contrary, including years of successful predictions and explanations. Science therefore balances the ability to improve, with the reasonable resistance to change ideas that have extensive evidence and reasoning supporting them. Far from reflecting poorly on science, changes to previously accepted ideas demonstrate the power of science to improve existing ideas and models, collect new data, and increase the understanding, scope, and accuracy of highly complex systems.

The modern era is rife with misinformation and half-truths, which has been highly evident during the COVID-19 pandemic (see the Story Behind the Pseudoscience for more information). Understanding how science functions, accurately determining who are the authentic experts, and accurately identifying legitimate scientific community expert consensus is therefore more important now than ever before. Scientific knowledge is always open to revision and that is a strength.

Despite all scientific knowledge being open to revision, its current ideas are the most reliable understanding of the natural world that humans possess. Perhaps its power is best illustrated by increased human life expectancy that has doubled since the beginning of the 19th-century, dramatically reduced world hunger and poverty, markedly improved storm forecasts, and many other advances that we take for granted.

The increased public skepticism of science would bewilder those in the past who suffered through persistent threats that have largely been eliminated. Even if a person chooses to remain a skeptic despite all that science has accomplished, the fact remains that no viable alternative exists to replace it. Science is by far the most accurate and reliable tool humanity possesses to make predictions about and explain the natural world.

In the past 150 years, science has moved the field of medicine from thinking of illnesses as miasmas to identifying and genetically sequencing many micro-organisms, and subsequently treating and/or preventing the diseases they cause. The COVID-19 pandemic spotlights emerging science, which has resulted in some scientific ideas changing in a very public manner. Additional changes will also undoubtedly occur as additional data about the pandemic become available and are analyzed and discussed by scientists. The pervasiveness and speed of contemporary media often highlights this change, thus exacerbating the public's perceptions that science is an indecisive and fleeting enterprise.

COVID-19 is a serious public health emergency that requires drawing upon genuine experts who are in a position to provide the best currently available knowledge about the natural world. The consensus view among the appropriate community of experts provides the most reliable information to inform personal and public policy decisions. At this time, the consensus is that social distancing, wearing facemasks, and hand-washing are effective at slowing the transmission of the virus causing COVID-19, thus saving lives. Flattening the infection rate curve will avoid overwhelming the health care system, buy time for developing and testing the efficacy and safety of vaccinations, while also permitting appropriate economic activity. Ignoring the best available scientific knowledge about COVID-19 is similar to not heeding warnings about an impending catastrophic hurricane — except that those who fail to social distance, wear masks, and wash their hands place themselves and society at risk. History makes clear that risk cannot be eliminated; it can only be reduced. Those who insist upon absolute certainty before taking appropriate action are truly playing a fool's game.

3. Few citizens or policymakers are well-equipped to understand and judge scientific claims. Even scientists are so specialized that they can only speak authoritatively in their own field of expertise. But citizens and policymakers can and must understand how to judge who are the authentic experts, and then respect that expertise in personal and societal decision-making. Why are recommendations from organizations of experts likely more reliable than that of individuals or small groups of experts?

4. How is expecting scientific certainty and perfection the enemy of sound policymaking?

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