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Published by Princeton University Press
41 William Street, Princeton, New Jersey 08540
6 Oxford Street, Woodstock, Oxfordshire OX20 1TR

press.princeton.edu

LCCN 2020949715
First paperback edition, with a new preface by the author, 2021
Paperback ISBN 9780691212265
Cloth ISBN 9780691179001

British Library Cataloging-in-Publication Data is available

Editorial: Alison Kalett and Kristin Zodrow
Production Editorial: Sara Lerner
Text Design: Leslie Flis
Cover Design: Amanda Weiss
Production: Jacqueline Poirier
Publicity: Sara Henning-Stout and Katie Lewis
Copyeditor: Brittany Micka-Foos

This book has been composed in Arno Pro with Gotham Display

Printed in the United States of America

CONTENTS

Preface to the Paperback ix
Acknowledgments xix

Introduction 1
Stephen Macedo

Chapter 1 Why Trust Science? Perspectives from the History and Philosophy of Science 15

Chapter 2 Science Awry 69

Coda: Values in Science 147

Comments

Chapter 3 The Epistemology of Frozen Peas: Innocence, Violence, and Everyday Trust in Twentieth-Century Science 163
Susan Lindee

Chapter 4 What Would Reasons for Trusting Science Be? 181
Marc Lange

Chapter 5 Pascal's Wager Reframed: Toward Trustworthy Climate Policy Assessments for Risk Societies 191

Ottmar Edenhofer and Martin Kowarsch

Chapter 6 Comments on the Present and Future of Science, Inspired by Naomi Oreskes 202

Jon A. Krosnick

Response

Chapter 7 Reply 215

Afterword 245

Notes 257

References 297

Contributors 335

Index 337

PREFACE TO THE PAPERBACK

COVID-19. Rarely does the world offer proof of an academic argument, and even more rarely in a single word or term. But there it is. COVID-19 has shown us in the starkest terms—life and death—what happens when we don't trust science and defy the advice of experts.

As of this writing, the United States leads the world in both total cases and total deaths from COVID-19, the disease caused by the novel coronavirus that appeared in 2019. One might think that death rates would be highest in China, where the virus first emerged and doctors were presumably caught unprepared, but that is not the case. According to *The Lancet*—the world's premier medical journal—as of early October 2020, China had confirmed 90,604 cases of COVID-19 and 4,739 deaths, while the United States had registered 7,382,194 cases and 209,382 deaths.[1] And China has a population more than four times that of the United States. If the United States had a pandemic pattern similar to China, we would have seen only 22,500 cases and 1128 deaths.

While COVID-19 has killed people across the globe, death rates have been far higher in the United States than in other wealthy countries, such as Germany, Iceland, South Korea, New Zealand, and Taiwan, and even than in some much poorer countries, such as Vietnam.[2] The Johns Hopkins University School of Medicine puts the US death rate per 100,000 people at 65.5.[3] In Germany it is 11.6. In Iceland, 2.83. In South Korea, 0.89. In New Zealand, 0.51. In China, 0.34. And in Taiwan and Vietnam? 0.03 and 0.04. If the American death rate had been similar to New Zealand's, instead of seeing more than 200,000 deaths in the first ten months of the pandemic, we would have seen fewer than 2,000. If we were like Vietnam, we would have seen a little over 100.[4]

Death rate is an imperfect guide to a pandemic, because it is affected by many factors, including population structure, access to health care, and the underlying health of the population. Death rates are also affected by reporting and testing. A country like China, with low transparency, may not be reporting everything accurately. A metropolis like New York City, caught by surprise with inadequate testing capacity in the early stages of the pandemic, probably underestimated the number of cases and therefore overestimated the death rate. (This could help to explain why the death rate in New York appeared to be much higher than elsewhere in the United States.) And since COVID-19 is very deadly to the elderly, a country with an aged population can be expected to see a higher death rate than one with a younger population, but by that measure, Germany should have done more poorly than the United States. In fact, it has done far better.[5] Perhaps the most compelling statistic is this: the United States has 4% of the global population, and it has had 20% of global deaths.

By any measure, the US response has been a disaster. But rather than ask why it has been so bad, it may be more instructive to ask: What is common to the countries that have done well? The answer is straightforward: The countries that have seen low death rates effectively controlled the spread of the virus, and they did so by trusting science.

In December 2019, when COVID-19 first emerged, public health experts raised the alarm that we were seeing a novel virus—of "unknown etiology"—that could pose a pandemic threat.[6] By the end of January 2020, the World Health Organization declared the coronavirus outbreak a PHEIC—a public health emergency of international concern.[7] This was only the sixth time the WHO had invoked this measure since the regulations under which it operates were established in 2005.

Public health experts immediately made recommendations about how to minimize the disease spread. These included frequent, thorough hand washing with soap and hot water; avoiding large public gatherings; and staying home at the first sign of illness. Admittedly, these recommendations were not 100% consistent—this was, after all, a *novel* disease, so there was much about it that was unknown—and the WHO offered contradictory advice on masks. But this was not because the organization did not have reason to think that masks might help. It was because it was afraid that people would hoard them, exacerbating an already serious shortage of masks for health care and other essential workers.[8] (The WHO's confusing mask guidance—which it later altered—was not a failure of scientific knowledge but a failure of scientific communication, grounded in expert distrust of lay people. But this distrust—a better word might be "caution"—was perhaps warranted, given how many people did, in fact, hoard toilet paper, disinfectants, and other essential supplies.) Other scientists felt that in the absence of convincing scientific evidence that masks would work to stop *this particular virus*, they could not recommend the use of them.[9] Overall, however, most of the public health advisories were consistent, based on existing scientific knowledge of how respiratory viruses spread.[10]

In the United States, a great deal of attention has focused on individual action—hand washing, staying home, wearing masks—but public health officials also recommended measures that prior epidemics had proved effective: testing, isolation of sick individuals, contact tracing, and where needed, quarantine. These measures had helped in past pandemics and therefore had at least some likelihood of working in this one. (The word "quarantine," after all, is a very old one, dating from fourteenth-century Italy, where incoming ships were required to stay in port for forty days: *quaranta giorni*.)

More important, a broad program of testing, isolation, and contact tracing was scientific common sense, because viruses do not spread by magic; they spread from sick people to well ones. If you can quickly identify the sick and separate them from the healthy, then you have a good chance of reducing the spread. The countries that can today boast of very low caseloads and death rates all took this scientific experience and expertise to heart.

Vietnam is a case in point.[11] Early in the pandemic the government implemented strict measures to test any symptomatic person, and, where results were positive, to trace, test, and isolate their contacts. The government also promoted the use of mobile apps by which people could record their symptoms and get tested promptly as needed. Passengers arriving from overseas were quarantined, and in a few cases—such as a man returning from a religious festival in Malaysia—the government ordered targeted lockdowns, in this case of a mosque he had visited in Ho Chi Minh City and of his entire home province.[12] The government also restricted travel and public gatherings,

Notes

1. Talha Burki, "China's Successful Control of COVID-19," *The Lancet: Infectious Diseases* 20, no. 11 (October 8, 2020), https://doi.org/10.1016/S1473-3099(20)30800-8.

2. Pablo Gutiérrez and Seán Clarke, "Coronavirus World Map: Which Countries Have the Most COVID Cases and Deaths?," *The Guardian*, October 16, 2020, https://www.theguardian.com/world/2020/oct/16/coronavirus-world-map-which-countries-have-the-most-covid-cases-and-deaths; "COVID in the U.S.: Latest Map and Case Count," *The New York Times*, July 20, 2020, https://www.nytimes.com/interactive/2020/us/coronavirus-us-cases.html; Henrik Pettersson et al., "Tracking Coronavirus' Global Spread," CNN, accessed October 19, 2020, https://www.cnn.com/interactive/2020/health/coronavirus-maps-and-cases.

3. "Mortality Analyses," Johns Hopkins Coronavirus Resource Center, accessed October 19, 2020, https://coronavirus.jhu.edu/data/mortality.

4. Vietnam has a population over 97 million, but it has seen a tiny number of COVID-19 deaths: 38, as of October 19, 2020. Since the US population is 3.33 times as large, $3.33 \times 38 = 127$. "Vietnam COVID 19 Deaths—Google Search," accessed October 19, 2020, https://www.google.com/search?q=vietnam+COVID+19+deaths&oq=vietnam+COVID+19+&aqs=chromVietnam%20has%20a%20population%20of%2095%20million,%20but%20it%20has%20seen%20a%20tiny%20number%20of%20covid. 0C19%20deaths:%2035e.1.0i457j0i20i263j69i57j0i20i263j0j69i60l3.5002j0j9&sourceid=chrome&ie=UTF-8.

5. "The Aging Readiness and Competitiveness Report: Germany," AARP, 2017, http://www.silvereco.org/en/wp-content/uploads/2017/12/ARC-Report-Germany.pdf. Cf. Deidre McPhillips, "Aging in America, in 5 Charts," *US News & World Report*, September 30, 2019, https://www.usnews.com/news/best-states/articles/2019-09-30/aging-in-america-in-5-charts.

6. "Pneumonia of Unknown Cause—China," WHO (World Health Organization), January 5, 2020, http://www.who.int/csr/don/05-january-2020-pneumonia-of-unkown-cause-china/en.

7. "Archived: WHO Timeline—COVID-19," WHO, accessed October 19, 2020, https://www.who.int/news/item/27-04-2020-who-timeline--covid-19.

8. Julia Naftulin, "WHO Says There Is No Need for Healthy People to Wear Face Masks, Days after the CDC Told All Americans to Cover Their Faces," Business Insider, accessed October 18, 2020, https://www.businessinsider.com/who-no-need-for-healthy-people-to-wear-face-masks-2020–4.

9. Ibid.

10. Since then, it has become clear that masks do work and perhaps even more effectively than some of their earlier advocates dared hope. See, for example, Stephanie Innes, "COVID-19 Cases in Arizona Dropped 75% after Mask Mandates Began,

Report Says," *The Arizona Republic*, accessed October 19, 2020, https://www.azcentral.com/story/news/local/arizona-health/2020/10/09/covid-19-cases-az-spiked-151-after-statewide-stay-home-order-and-dropped-75-following-local-mask-man/5911813002. As I have argued elsewhere, it was scientifically logical that masks should help at least somewhat; see Naomi Oreskes, "Scientists Failed to Use Common Sense Early in the Pandemic," *Scientific American*, November 2020, https://www.scientificamerican.com/article/scientists-failed-to-use-common-sense-early-in-the-pandemic.

11. "Vietnam COVID 19 Deaths—Google Search."

12. Todd Pollack et al., "Emerging COVID-19 Success Story: Vietnam's Commitment to Containment," *Our World in Data*, June 30, 2020, https://ourworldindata.org/covid-exemplar-vietnam; Thi Phuong Thao Tran et al., "Rapid Response to the COVID-19 Pandemic: Vietnam Government's Experience and Preliminary Success," *Journal of Global Health* 10, no. 2 (July 30, 2020), https://doi.org/10.7189/jogh.10.020502020502.

13. George Black, "Vietnam May Have the Most Effective Response to COVID-19," *The Nation*, April 24, 2020, https://www.thenation.com/article/world/coronavirus-vietnam-quarantine-mobilization; "How Did Vietnam Become Biggest Nation without Coronavirus Deaths?," Voice of America, June 21, 2020, https://www.voanews.com/covid-19-pandemic/how-did-vietnam-become-biggest-nation-without-coronavirus-deaths.

14. Tran et al., "Rapid Response to the COVID-19 Pandemic."

15. National Oceanic and Atmospheric Administration, "2020 Atlantic Hurricane Season," https://www.nhc.noaa.gov/data/tcr/index.php?season=2020&basin=atl.

16. On anti-experts, see Adapt by Sprout Social, "Combating Anti-Expert Sentiment on Social," May 8, 2018, https://sproutsocial.com/adapt/anti-expert-sentiment.

A particularly damaging pandemic anti-expert is Scott Atlas, a radiologist and senior fellow at the politically oriented, conservative Hoover Institution, who, with no recognizable expertise in immunology, virology, epidemiology, or public health, has been advising Donald Trump on COVID-19 in a manner that conflicts with the views of most public health experts, including Drs. Anthony Fauci and Deborah Birx. See Yasmeen Abutaleb and Josh Dawsey, "New Trump Pandemic Adviser Pushes Controversial 'Herd Immunity' Strategy, Worrying Public Health Officials," *Washington Post*, August 31, 2020, https://www.washingtonpost.com/politics/trump-coronavirus-scott-atlas-herd-immunity/2020/08/30/925e68fe-e93b-11ea-970a-64c73a1c2392_story.html.

A related example of anti-experts muddying the intellectual waters around COVID-19 involves the "Great Barrington Declaration," organized by the American Institute for Economic Research; see "AIER Hosts Top Epidemiologists, Authors of the Great Barrington Declaration," October 5, 2020, https://www.aier.org/article/aier-hosts-top-epidemiologists-authors-of-the-great-barrington-declaration. The American Institute for Economic Research is, as its name suggests, an economic institute with no recognizable claim to biological or medical expertise. Like many such institutes, it promotes a particular political agenda, in this case "free trade, individual freedom, and responsible governance." Those may or may not be good things, but they are not matters of science. AIER also promotes anti-scientific discussion of climate change, much of which promotes the familiar canard that climate change will be minor and manageable. One recent piece, for example, which discounted scientific interpretations of the dangers of climate-induced sea level rise was written not by a scientist but by a "writer, researcher, and editor on all things money, finance and financial history" (Joakim Book, "The Tide-Theory of Climate Change," October 28, 2020, https://www.aier.org/article/the-tide-theory-of-climate-change).

While pandemics do, of course, involve economic matters, the Great Barrington Declaration focused on the *public health response*, urging a herd immunity approach, which most public health experts consider to be a euphemism for allowing people to sicken and die. Indeed, expert estimates suggest that if the United States had undertaken that approach, more than 200 million people would likely have become ill, with the potential for more than 2 million deaths. This, of course, is comparable to the argument that we can just "adapt" to climate change. Of course we can, but at what price?

Moreover, the concept of herd immunity is normally invoked in the context of vaccination: What percentage of a population needs to be vaccinated in order to protect the whole population? In the absence of a vaccine, herd immunity typically means that at least 70% of a population will need to get sick before the population as a whole is protected. See Christie Aschwanden, "The False Promise of Herd Immunity for COVID-19," *Nature* 587, nos. 26–28 (October 21, 2020), https://www.nature.com/articles/d41586-020-02948-4; and Kristina Fiore, "The Cost of Herd Immunity in the U.S.," Medpage Today September 1, 2020, https://www.medpagetoday.com/infectiousdisease/covid19/88401.

The clearest argument against the herd immunity strategy is provided by a comparison of Sweden and Norway. According to a report in *Nature*, drawing on statistics from Johns Hopkins University, "Sweden has seen more than ten times the number of COVID-19 deaths per 100,000 people seen in neighbouring Norway (58.12 per 100,000, compared with 5.23 per 100,000 in Norway). Sweden's case fatality rate, which is based on the number of known infections, is also at least three times those of Norway and nearby Denmark"; see Aschwanden, "The False Promise of Herd Immunity for COVID-19." And the Swedish economy suffered, anyway, because the global economy is, well, global.

ACKNOWLEDGMENTS

This project would never have been completed without the considerable aid of my able and generous graduate student, Aaron van Neste, who helped me in countless ways. I am also deeply grateful to Erik Baker, Karim Bschir, Matthew Hoisch, Stephan Lewandowsky, Elisabeth Lloyd, Matthew Slater, Charlie Tyson, and an anonymous reviewer for comments on early drafts, and to all my students past and present, with whom I have thought through the question raised here. Whether Fleck was right about thought collectives, my own thinking has never been Cartesian.

Many of the ideas expressed here were developed over many years in the Science Studies Program at the University of California, San Diego (UCSD). I am grateful to UCSD colleagues past and present: Bill Bechtel, Craig Callender, Nancy Cartwright, Jerry Doppelt, Cathy Gere, Tal Golan, Philip Kitcher, Martha Lampland, Sandra Mitchell, Chandra Mukerji, Steven Shapin, Eric Watkins, and Robert Westman, with whom over many years I discussed the basis for scientific knowledge, truth, trust, proof, persuasion, and other weighty matters. I am also grateful to my current colleagues in the Department of the History of Science, Harvard University, with whom I have continued the conversation: particularly Allan Brandt, Janet Browne, Alex Cszisar, Peter Galison, and Sarah Richardson and to my

INTRODUCTION

Stephen Macedo

Science confronts a public crisis of trust. From the Oval Office in Washington and on news media around the world, the scientific consensus on climate change, the effectiveness of vaccines, and other important matters are routinely challenged and misrepresented. Doubts about science are sown by tobacco companies, the fossil fuels industry, free market think tanks, and other powerful organizations with economic interests and ideological commitments that run counter to scientific findings.[1]

Yet we know that scientists sometimes make mistakes, and that particular scientific findings now widely believed will turn out to be wrong. So why, when, and to what extent should we trust science?

These questions could hardly be more timely or important. As extreme weather events become more common, sea levels rise, and climate-induced migrations flow across borders, nations around the world confront mounting costs and humanitarian crises. Yet so-called experts do not always agree. A local television meteorologist may report that it is merely "some speculation from scientists" that global warming is contributing to extreme weather events, such as the "polar vortex" that hit the Upper Midwest and Northeast of the United States in late January 2019. On another channel, a scientist at a well-regarded research center insists that "we know why . . . . It's all because of human activities increasing the greenhouse gases in the atmosphere that trap a lot more heat down by the surface."[2]

As vitally important as climate science is to the future of humanity, that is only the tip of the iceberg. Are vaccines effective? Does the birth control pill cause depression? Is flossing good for your teeth? On these questions and so many others, scientists may agree yet doubts circulate. Who should we believe and why?

In *Why Trust Science?* Professor Naomi Oreskes provides clear and compelling answers to the questions of when and why scientific findings are reliable. She explains the basis for trust in science in highly readable prose, and illustrates her argument with vivid examples of science working as it should, and as it should not, on matters central to our lives. Readers will find here a vigorous defense of the trustworthiness of scientific consensus based not on any particular method or on the qualities of scientists, but on science's character as a collective enterprise.

A distinguished scientist and historian of science, Professor Naomi Oreskes has also emerged as one of the world's clearest and most influential voices on the role of science in society and the reality of man-made climate change.

This book grows out of the Princeton University Tanner Lectures on Human Values delivered by Professor Oreskes in late November 2016. On that occasion, four distinguished commentators, representing a variety of fields and perspectives, responded to Professor Oreskes's two lectures. This book contains the lectures, the four commentaries, and an extended reply by Professor Oreskes, all revised and expanded.[3]

Readers will find in the chapters that follow an overview of the leading philosophical debates concerning the nature of scientific understanding, scientific method, and the role of scientific communities. Oreskes defends the role of values in science, discusses the relationship between science and religion, and sets out her own credo as a scientist and defender of science. Our four commentators offer their perspectives on these issues, and

Oreskes closes with comments on the plight and promise of science in our time. A more detailed overview follows.

Why should we trust science? Professor Oreskes's initial answer is crisp and clear: scientific knowledge is "fundamentally consensual" and understanding science properly can help us "address the current crisis of trust."

Chapter 1 develops the problem of trust against the background of an account of philosophical debates about the nature of science and scientific method. In the eighteenth and nineteenth centuries, and before, trust often resided in "great men": science was regarded as trustworthy insofar as the scientists were. Gradually the alternative idea was advanced that careful observation and adherence to scientific methods were the bases of progress. Oreskes also surveys the varieties of empiricism that dominated philosophies of science in the first half of the twentieth century, and the challenge advanced by Karl Popper, who regarded the essence of science not as verification but openness to falsifiability, or "fallibilism."

Most important, on Oreskes's account, was the emergence of the idea of science as a collective enterprise. The "sociological view" of science was first advanced by Ludwik Fleck, in the 1930s, who held that the "truly isolated investigator is impossible . . . . Thinking is a collective activity." Oreskes endorses the idea that scientific progress depends on the collective institutions and practices of science, "such as peer-reviewed journals, and scientific societies through which scientists share data, grapple with criticisms, and adjust their views."

The central importance of scientific communities, their worldviews, and practices is the core of Professor Oreskes's view. When we focus on what scientists do, we find a variety of methods pursued with creativity and flexibility. She explores debates surrounding philosophies of science in the work of

Pierre Duhem, W.V.O. Quine, Thomas Kuhn, and others. She describes the social epistemology developed by feminist philosophers and historians of science, including the contributions of Helen Longino, who helped establish the idea that, as Oreskes puts it, "objectivity is maximized . . . when the community is sufficiently diverse that a broad range of views can be developed, heard and appropriately considered." Or, as she says later, "In Diversity There Is Epistemic Strength."

Professor Oreskes thus defends the "social turn" in our understanding of science while also describing the sense of threat that greeted the idea that scientific realities are socially constructed. Remember the obvious, she advises: scientists are engaged in sustained and careful study of the natural world. The empirical dimension is critical, but scientific expertise is also communally organized: objectivity arises from social practices of criticism and correction, most successfully in scientific communities that are diverse, "non-defensive," and self-critical.

We are warranted in placing "informed trust" in the "critically achieved consensus of the scientific community," argues Professor Oreskes. Individual scientists make mistakes, especially when "they stray outside their domains of expertise," and Oreskes provides some glaring examples. And science has no monopoly on insight into the natural world. Nevertheless, the practices and procedures of scientific communities increase the odds that scientific consensus is reliable.

We should trust the conclusions of the scientific community rather than the petroleum industry when it comes to climate change because the petroleum industry has a conflict of interest. It aims to profit by finding, developing, and selling petroleum resources, and it generally does that well. But those aims conflict with the pursuit of truth regarding climate change. As a general rule, we should be skeptical of the scientific claims of

Values inevitably play a role in shaping science, Oreskes insists. In looking back on eugenics, scientists may say that science was distorted by values, but values were also central to opposing eugenics and also the Limited Energy Theory. Because values play an inevitable role, diverse scientific communities are more likely to be able to detect unexamined assumptions, blind spots, and inherited biases: "A community with diverse values is more likely to identify and challenge prejudicial beliefs embedded in, or masquerading as, scientific theory." She also allows that there can be legitimate non-scientific objections—including ones based on religious or moral values—to policies that are justified partly by science but also by particular value claims.

And humility is important. Diverse scientific communities can correct for the blind spots of arrogant scientists, but the history of science counsels humility: the greatest scientists (and, one might add, philosophers) have sometimes become fetishists about method, drawn false conclusions from evidence, and fallen prey to the prejudices and biases of their times.[4] Even the best of scientists should remember that a complete grasp of the whole truth is yet far beyond us.

So, when should we trust science? In concluding chapter 2, Oreskes summarizes: when an expert consensus emerges in a scientific community that is diverse and characterized by ample opportunities for peer review and openness to criticism. Of course, any particular scientific claim may be false, so she reminds us of Pascal's Wager: consider the stakes of error. It may not be certain that flossing will be good for your teeth, but it is cheap and easy. It may not be certain that human actions and policy changes can reverse the dire effects of climate change, but consider the calamities that await our children and grandchildren if we now ignore scientific predictions that are correct.

In a coda to her two lectures, Professor Oreskes returns to the issue of scientists' values. In theory, scientific findings are one thing and the question of what if anything to do about them is another. So one might suppose that whereas the practical question of "what is to be done" inevitably implicates values, the question of what scientific evidence shows need not. Ideally, science should be able to leave political and moral controversies to others.

Things are not so neat and simple, however. Professor Oreskes observes that people equate science with what they think are its implications. Fundamentalist and evangelical Christians from Williams Jennings Bryan to Rick Santorum have worried that evolutionary accounts of human origins undermine human dignity and morality, by making humans, in Santorum's words, "mistakes of nature." Skepticism about climate science, on the other hand, is fed by the suspicion that environmentalists seek to undermine the "American way of life": big cars, motorboats, and high consumption.

In the face of such suspicions it is profoundly mistaken, argues Oreskes, for scientists to retreat to value neutrality. In the face of the question: why should ordinary people trust science and take it seriously? It cannot be effective to reply that scientists lack values! That is precisely what worries people. Moreover, it is perfectly obvious that scientists do have values—everyone does—and that those values influence their work. To hide your values, Oreskes observes, is to hide your humanity.

So, scientists should be honest about their values. Many people will share those values, and on that basis trust can be built. The Creation revered by Christians is the biodiversity cherished by Scientists, says Oreskes, and the evidence is overwhelming that these are now gravely threatened.

In concluding, Professor Oreskes offers an eloquent summary of her own credo: her guiding values as a scientist and environmentalist. "If we fail to act on our scientific knowledge and it turns out to be right, people will suffer and the world will be diminished."

In the next section of this volume, four distinguished commentators expand upon, elaborate, or criticize central features of Professor Oreskes's lectures.

Professor Susan Lindee is the Janice and Julian Bers Professor of History and Sociology of Science at the University of Pennsylvania, where she also holds a variety of administrative posts. Lindee argues that in responding to scientific skepticism we should draw attention to the science that we encounter and rely upon constantly in our everyday lives. We should "work our way up, from the toaster," to the frozen peas, the smart phones, and the other miracles of modern science and technology that enhance our lives.

Of course, science's contributions are not always so positive. Professor Lindee reminds us of the twentieth century's brutal history of technology-enhanced warfare. She suggests that historians of science have sought to distance pure science from technological applications because of technology's profoundly mixed legacy. Atomic scientists sought to maintain their moral purity by attributing the design of the bomb to mere engineers.

Marc Lange is the Theda Perdue Distinguished Professor and department chair in philosophy at the University of North Carolina, where he specializes in the philosophy of science. Lange notes that the question of why we should trust science seems to lead into a vicious circularity: isn't peer review just experts vouching for other experts?

Professor Lange suggests that asking for an external vindication of science as a whole may be unreasonable: science is self-correcting in that it can subject any particular scientific claim to critical scrutiny, "But science *cannot* reasonably be expected to put *all* its theories in jeopardy *at once*."

Lange also raises the issue of what Thomas Kuhn described as revolutionary challenges to entire worldviews or paradigms, in which methods and theories "interpenetrate." Using the example of Galileo, he suggests that there is typically "sparse common ground" across paradigm shifts, and scientists can use it to build an argument for one of the rival theories against the others. Lange closes by urging philosophers and others to stop overemphasizing "incommensurability and under-determination" and to devote more attention to positive accounts "of the logic underlying scientific reasoning."

Ottmar Edenhofer is deputy director and chief economist at the Potsdam Institute for Climate Impact Research, as well as a professor at the Technical University Berlin. He offered a comment in Princeton, and is joined here by Martin Kowarsch, who is head of the working group on Scientific Assessments, Ethics, and Public Policy at the Mercator Research Institute. They begin by suggesting that the Trump administration accepts much climate science but opposes ambitious climate change mitigation efforts, partly because it heavily discounts the costs of climate change outside the United States. Thus, scientific consensus does not equal policy consensus, and so they ask how Oreskes's account of trust in science may need to be extended or amended for science-based policy assessments. They advise experimentation aimed at incremental learning about alternative policy pathways, and argue that costly mistakes have been made due to insufficient awareness of the complexity of the policy alternatives.

Edenhoffer and Kowarsch agree with Oreskes that value neutrality is impossible. They build on Deweyan pragmatism to propose that all socially important values—"equality, liberty, purity, nationalism, etc."—should be included in policy assessments: this may open the door to new and creative proposals.

Finally, Jon Krosnick offers some thoughts, inspired by Professor Oreskes's lectures, on the current state and future of science. Krosnick is Frederick O. Glover Professor in Humanities and Social Sciences and professor of communication, political science, and psychology at Stanford University, where he also directs the Political Psychology Research Group.

Professor Krosnick describes a number of famous (now infamous) and influential scientific findings—in biomedicine, psychology, and elsewhere—whose results scientists have been unable to replicate. In some cases the data were fabricated, in other cases investigators admitted to repeating an experiment until the desired result was produced.

Flawed research results partly from faulty methods, argues Krosnick, and also the desire for career advancement. Academic departments and professions place a premium on publishing surprising and counterintuitive findings. Is it any wonder that many of these prove unfounded on closer inspection? Journals rarely publish negative results so refutation of bad research is slowed. He insists that scientists must face up to the problems and address the counterproductive motivations that are now rampant.

In her wide-ranging *Reply to Critics*, Professor Oreskes deepens and enriches her argument.

She praises Susan Lindee for her brilliant historical account of scientists' attempts to distance themselves from the technological applications of their work, yet expresses doubt that becoming clearer-eyed about the science embodied in frozen peas and smart phones will have much effect on people's attitudes to climate science. Americans do not reject science in general but of what kinds? The inclusion of women and members of racial, ethnic, religious, and other minority populations has obviously been very good for all of the sciences, and scholarship generally. Are there social sciences (and perhaps other fields of inquiry) in which greater ideological diversity would be helpful?

Readers will come away from this volume armed with a far better understanding of the vitally important enterprise of modern science and the reasons why we should trust scientific consensus. All who care about the future of humanity on this fragile earth should hope that this timely and important book gains a wide audience, before it is too late.

Chapter 1

WHY TRUST SCIENCE?

Perspectives from the History and Philosophy of Science

The Problem[1]

Many people are confused about the risks involved in vaccination, the causes of climate change, what to do to stay healthy, and other matters that fall within the domain of science. Immunologists tell us that vaccines are generally safe for most people, have protected millions of people from deadly and disfiguring diseases, and do not cause autism. Atmospheric physicists tell us that the build-up of greenhouse gases in the atmosphere is warming the planet, driving sea level rise and extreme weather events. Dentists tell us to floss our teeth. But how do they know these things? How do we know they're not wrong? Each of these claims is disputed in the popular press and on the internet, sometimes by people who claim to be scientists. Can we make sense of competing claims?

Consider three recent examples.

One: In a 2016 presidential debate, Donald Trump rejected the position of medical professionals—including that of fellow candidate physician Ben Carson—on the safety of vaccination. Recounting the experience of an employee whose child was vaccinated and later diagnosed as autistic, Mr. Trump stated his view that vaccines should be given at lower doses and be more widely spaced. Few medical professionals share his view.[2] They consider delaying vaccination to increase the risk that infants and children will contract dangerous and otherwise preventable diseases such as measles, mumps, diphtheria, tetanus, and pertussis. Some of the children who contract these diseases will become gravely ill or die. Others will survive but pass on the infections to others. Yet, Mr. Trump is not alone in making this suggestion; prominent celebrities have made similar exhortations. Many parents now reject the advice of their physicians and choose to have their children vaccinated on a delayed schedule—or not at all. As a result, morbidity and mortality from preventable infectious diseases are on the rise.[3]

Two: The vice president of the United States, Mike Pence, is a young Earth creationist, meaning that he believes that God created the Earth and all it contains less than ten thousand years ago. The consensus of scientific opinion is that Earth is 4.5 billion years old, that the genus *Homo* emerged two to three million years ago, and that anatomically modern humans appeared about two hundred thousand years ago. While science cannot answer the question of whether God (or any supernatural being or force) guided the process, most scientists are persuaded that life on Earth evolved largely through the process of natural selection over the course of Earth's history, that humans share a common ancestor with chimpanzees and other primates, and that divine intervention is not required to explain the existence of *Homo sapiens sapiens*.[4]

Do Americans lean toward the scientific view or the Pencian view? The answer depends a bit on how you ask the question, but if you are a religious person in America who attends church regularly, the chances are high that you agree with Mike Pence: 67% of regular churchgoers believe that God created humans in their present form within the last ten thousand years. Some of us may think that these people are all Republicans, but we would be wrong. According to the Gallup polling organization, while 58% of Republicans agreed with the statement that "God created humans in their present form, within the last 10,000 years," so did 39% of independents and 41% of Democrats.[5] Given this popular support for creationism, it is perhaps unsurprising that in 2012, the state of Tennessee enacted what some have called a "twenty-first-century Monkey Law," empowering teachers to teach creationism in science classrooms.[6] Despite repeated rejection of previous laws of this type by US courts, many states continue to attempt to enact comparable laws.[7]

Three: The American Enterprise Institute (AEI) is a long-established and well-funded think tank in Washington, DC, committed to principles of laissez-faire economics, market-based mechanisms to social problems, limited (federal) government, and low rates of taxation. The Institute has long promoted skepticism about the scientific evidence for anthropogenic climate change and disparaged the conclusions of the scientific community, including the Intergovernmental Panel on Climate Change (IPCC).[8] AEI scholars have suggested that climate scientists are suppressing dissent within their community; the Institute at one point offered a cash incentive to anyone willing to search for errors in IPCC reports. Jeffrey Sachs, head of the Earth Institute at Columbia University from 2002–16 and special advisor to UN secretary-general António Guterres on the Millennium Development Goals, has said of one well-known AEI scholar that he "distorts, misrepresents, or simply ignores" relevant scientific conclusions.[9] In 2016, this particular scholar referred to scientists as an "interest group," demanding to know why "scientific analysis conducted or funded by an agency headed by political appointees buffeted by political pressures . . . [should] be viewed ex ante as any more authoritative than that originating from, say, the petroleum industry?"[10]

I am no fan of the American Enterprise Institute. With my colleague Erik M. Conway I have shown how they (along with other think tanks promoting laissez-faire approaches to social and economic issues) have persistently mispresented or mischaracterized scientific findings on climate change, as well as a variety of public health and environmental questions. (They are no fans of mine, either. Their scholars have attacked my work on scientific consensus.)[11] But the question raised is a legitimate one. Should a scientific analysis be viewed as ex ante authoritative? Is it reasonable to take the default position that the scientific community can in general be trusted on scientific matters, but the petroleum industry (to use his example) cannot?

Science in North American universities and research institutes is generally well funded and respected—typically much more so than the arts and humanities—but outside those hallowed halls something very different is transpiring. The idea that science should be our dominant source of authority about empirical matters—about matters of fact—is one that has prevailed in Western countries since the Enlightenment, but it can no longer be sustained without an argument.[12] *Should* we trust science? If so, on what grounds and to what extent? What is the appropriate basis for trust in science, if any?

This is an academic problem but one with serious social consequences. If we cannot answer the question of why we should trust science—or even if we should trust it at all—then we stand little chance of convincing our fellow citizens, much less our political leaders, that they should get their children vaccinated, floss their teeth, and act to prevent climate change.

Scholars' views on the answer to this question have changed dramatically and more than once in the past century. Moreover, some of the answers that scientists offer are manifestly contradicted by historical evidence. It is routine, for example, for serving as a necessary transition.[17] In the "positive stage" of human development, theology and metaphysics are replaced by scientific reasoning. And scientific reasoning is rooted in observation.

It has been argued that Comte was seeking to replace conventional religion with a new religion of science, and there is some justice to this claim. Teleology is a common feature of many religions. He accepted that people had a need for moral principles but thought those principles could be found in the humanistic ideals of truth, beauty, goodness, and commitment to others. He also believed that people had a need for ritual and proposed to replace the veneration of Christian saints with a set of positivist heroes. In his own life, he set aside time for meditation and affirmation of his central values.[18] But whether his views were quasi-religious or not, the key point for our discussion is that for Comte—and generations of those who followed him, knowingly or not—science was reliable because of its commitment to method. This leads one to ask: what is that method?

Comte was sensitive to the variety of scientific disciplines that were developing at that time. He did not assert that their practices were uniform, but he did believe that they shared a fundamental characteristic of the "positive" state of human existence. He wrote:

> In the positive state, the human mind, recognizing the impossibility of obtaining absolute truth, gives up the search after the origin and hidden causes of the universe and a knowledge of final causes of phenomena. It endeavours now only to discover, by a well-combined use of reasoning and observation, the actual laws of phenomena—that is to say their invariable relations of succession and likeness. The explanation of facts, thus reduced to its real terms, consists henceforth only in the connection established

> between different particular phenomena and some general facts, the number of which the progress of science tends more and more to diminish.[19]

In stressing the importance of empirical regularities, Comte was making an argument similar to the British empiricists, particularly David Hume.[20] He acknowledged his debt to British empiricism, particularly the work of Francis Bacon, writing, "All competent thinkers agree with Bacon that there can be no real knowledge except that which rests upon observed facts."[21] But he was not the "naïve positivist" that some later commentators made him out to be. He was a sophisticated thinker who recognized that our theories structure our observations as much as our observations structure our theories:

> If we consider the origin of our knowledge, it is no less certain that . . . [as] every positive theory must necessarily be founded upon observations, it is, on the other hand, no less true that, in order to observe, our mind has need of some theory or others. If in contemplating phenomena we did not immediately connect them with some principles, not only would it be impossible for us to combine these isolated observations and, therefore, to derive any profit from them, but we should even be entirely incapable of remembering the facts, which would for the most part remain unnoted by us.[22]

We can understand, therefore, why primitive humans had need of religion, superstition, and metaphysics: these early concepts were a step toward apprehending the world around us. We need not disdain or disparage these early stages in human development, we simply need to recognize and accept that to move forward—to identify the true laws that govern nature—our thinking needs to be grounded upon observation. In his words: "we must proceed sometimes from facts to principles [and] at other times from principles to facts," but ultimately we will establish "as a logical thesis that all our knowledge must be founded upon observation."[23]

Comte was also a fallibilist: he recognized that our views would grow and change and that his own vision would in time be modified. (Indeed, if his basic concept was correct, then the progress of knowledge would necessarily modify our views, and we might note that the persistence of religion has falsified a key element of his teleology.) But, to his credit, Comte was consistent insofar as he insisted that future change in our thinking would be the outcome of our observations.

Comte was also reflexive, recognizing that the practices of observation must themselves be subject to observation. An improved knowledge of positive method must come, therefore, not by *theorizing* it but by studying it; we must observe science in order to understand it. Comte thus anticipated Bruno Latour and his anthropological studies of laboratory science by more than a century when he held: "When we want not only to know what the positive method consists in, but also to have such a clear and deep knowledge of it to be able to use it effectively, we must consider it *in action*."[24]

Comte's key move was to insist that science is reliable not by virtue of the character of its practitioner, but by virtue of the nature of its practices.[25] We need to attend to these practices by studying them empirically. The key questions, then, for those who took up the Comtean program were: What exactly are those practices? Is there a scientific method?

Varieties of Empiricism

For twentieth-century empiricists, which we have come to call logical positivists or logical empiricists, the answer to the question of the method of science was the principle of verification.[26] The concept was developed most extensively by a group of German-speaking philosophers and scientists, known as the "Vienna Circle." The most famous English language articulation of the verificationist program came from the Oxford philosopher A. J. Ayer (1910–89). In his 1936 book, *Language, Truth and Logic,* which is still in print, Ayer summarized the principle by framing it in terms of the problem of meaning: A statement can be considered meaningful if and only if it can be verified by reference to observation. Put another way, "some possible observation must be relevant to the determination of [the statement's] truth or falsehood."[27] Science is the practice of formulating meaningful statements, and using observations to judge whether a meaningful statement is correct.

Verification gives us the basis for evaluating what is or is not justified true belief. If a claim can be verified through observation, and if it has in fact been so verified, then we are justified in believing it, which is to say, justified in accepting it as true. If a claim cannot be so verified, then it is meaningless and need not detain us further. Thus, in one fell swoop did Ayer dispense with religion, superstition, and various forms of political ideology and theory that were unverifiable. The principle of verification provided a means of demarcating scientific knowledge from non-scientific knowledge: scientific claims were verifiable thorough observation; claims that were not verifiable were not scientific.

Like Comte, Ayer was ambitious but not naïve. He understood that in practice any observation necessarily entails background assumptions. But, like his Vienna Circle colleagues Rudolf Carnap and Otto Neurath, he insisted that verification through observation was the key component to meaning, hence the moniker *verificationism*. In order to test a statement, one had to be able to deduce an observable consequence from it and express that deduction as a *statement*, and that deduction had to be specific to the statement under investigation for the verification to be dispositive. Ayer wrote: "A statement is verifiable, and consequently meaningful, if some observation statement can be deduced from it in conjunction with certain other premises, without being deducible from those other premises alone."[28]

Ayer and his colleagues recognized that any program that foregrounded observation necessarily faced the problem of induction: namely, how many observations are needed to conclude that a statement is true? Following Hume, his answer was that inductive knowledge was necessarily probabilistic, and he suggested that one needed to allow for weak and strong forms of verification, based on the quantity and quality of available relevant observations. These sorts of concerns underpinned research on the character of scientific observation, which quickly led to various complications regarding the formulation of observation statements, the meaning of terms, and the identification of what, precisely, was being verified by any particular observation or set of observations.

These issues detained many logical empiricists for the rest of their lives. Carl Hempel, in particular, paid attention to the role of hypothesis in generating testable observation statements; Carnap focused on the observation statements and the language in which they were rendered, and famously argued with Willard Van Orman Quine over whether observations could really confirm or refute beliefs. (Quine concluded they could not, a point we will take up.) This work did not resolve the issues empowers resistance to authoritarianism of both the right and the left. Therefore he labeled his approach *critical rationalism*. His project was both epistemological and political: he sought an epistemology that would enable not just scientific rationality but also political rationality in democratic forms of governance. Among other things, Popper sought to refute Marxism by showing that "scientific socialism" was an oxymoron, because problems in Marxist theory were never taken as refutations but only as elements to be explained or accounted for in some way.[31]

Popper's critical rationality ironically opened the door for a form of radical skepticism that he abhorred. Popper pushed fallibility further than his predecessors, insofar as he insisted that refutation is not merely an inevitable feature of science, but the goal of it; it is through refutation that science advances. But if our scientific views are not only soon to be refuted, but *should* be refuted, then why should we believe any of it?[32] Popper's answer was to develop the notion of corroboration: that we can have good reason to believe theories that have passed severe tests, such as the deflection of starlight as a test of the general theory of relativity. Successful empirical tests corroborate theories, even if they do not prove them. In making this move, Popper helped to explain why theory testing plays such a major role in scientific practice, but he also radically weakened the otherwise strict tenor of his work: we are now left with having to make subjective judgments as to what constitutes a "severe" test and how many such tests we need.

Ludwik Fleck and Thought Collectives

The various forms of positivism that developed from the mid-nineteenth to the mid-twentieth century were all concerned with method, paying less attention to the people who were pursuing that method or the institutional structures within which they operated. Popper paid some heed to the character of the individual scientist, insofar as he stressed the importance of a critical investigative attitude. But Popper's epistemology (like his political theory) was individualistic; he vested the advance of science in the actions of the bold individual who doubted an existing claim and found a means to refute it. Popper paid less attention to the institutions of science, and was actively hostile to suggestions of collectivism, redolent as they were of the Marxist philosophy and Communist politics that he loathed.[33]

The recognition of science as a collective activity thus laid the grounds for a radical challenge to received views of science that would flourish in the second half of the twentieth century. Whether one had read Comte or Ayer or Popper, one could have come away with the impression that scientists, like Descartes in his room staring at melting wax, lived, worked, and thought alone. Yet anyone who studied science in action—as Comte instructed us to do—or who participated in scientific research knew that wasn't so. Yet somehow this had escaped sustained scholarly attention.

Ludwik Fleck (1896–1961) changed that. A microbiologist who made the social interactions of scientific life a centerpiece of analysis, in hindsight he is credited with developing the first modern sociological account of scientific method. In his 1935 work, *The Genesis and Development of a Scientific Fact: An Introduction to the Theory of Thought Style and Thought Collective*, Fleck shifted attention from the individual scientist to the activities of communities of scientists, and proposed that scientific facts are the collective accomplishment of communities. In doing so, he pioneered the analysis of the social interactions that yield scientific facts.

Fleck was aware of the logical positivists' work; he sent his work to the Viennese positivist Moritz Schlick seeking help to get it published.[34] He was also in contact with historians and philosophers of medicine and mathematics in Poland at that time. But scholars have mostly concluded that his work was primarily influenced by his experience as a researcher and his attention to developments in science, particularly the rise of quantum mechanics in physics, which (he believed) had led to the emergence of new styles of thinking.

Fleck's key point was that scientists worked in communities in which styles of thought became shared resources for future work, including the interpretation of observations. He labeled these communities "thought collectives." Groups of scientists within any particular discipline—biology, physics, geology—constituted thought collectives whose common ways of thinking made it possible for them to work together, share information, and interpret that information in meaningful ways. Without a thought collective, science could not exist. He wrote:

> A truly isolated investigator is impossible . . . Thinking is a collective activity. . . . Its product is a certain picture, which is visible only to anybody who takes part in this social activity, or a thought which is also clear to the members of the collective only. What we do think and how we do see depends on the thought-collective to which we belong.[35]

The term "thought collective" may invoke the specter of thought police, and Fleck recognized that collectives could be conservative or even reactionary—as he believed religious thought collectives were. But a thought collective could also be democratic and progressive, and this was the key to understanding science. Science (unlike most European religion) has a democratic character: all researchers can participate in an equitable way, and through their interactions with each other, refine and change the views of the whole.

Fleck had a radical view of how far such change could go, stressing that over time changes could be so great that the meanings of terms changed, that problems that were previously seen as central could now be dismissed as irrelevant or even illusory, and new issues would emerge that previously went unrecognized. While the increments of change were small—the pathways of change more evolutionary than revolutionary—eventually the thought style may have changed so much that the old view is essentially unrecognizable, even indecipherable.

> Thoughts pass from one individual to another, each time a little transformed, for each individual can attach to them somewhat different associations. Strictly speaking, the receiver never understands the thought exactly in the way that the transmitter intended it to be understood. After a series of such encounters, practically nothing is left of the original content.[36]

Scientific ideas, like evolution itself, may change dramatically over time, but they do so by the accumulation of small transformations and differing interpretations.

"Whose thought is it that continues to circulate?" Fleck asks. His answer: "It is one that obviously belongs not to any single individual but to the collective."[37] As Helen Longino would later put it in a slightly different context, "Of course, Galileo and Newton and Darwin and Einstein were individuals of extraordinary intellect, but what made their brilliant ideas *knowledge* were the processes of critical reception." Fleck would say: of reception and transformation.[38] Newtonian mechanics is not equivalent to the contents of the *Principia,* nor is evolutionary biology coincident with the contents of the *Origin of Species*. The ultimate outcome is the result of Newton and Darwin's work and the diverse ways in which over time it has been interpreted, adjusted, and altered.

Scientific progress in this view is inextricably connected with the institutions of science such as conferences and workshops, books and peer-reviewed journals, and scientific societies through which scientists share data, assess evidence, grapple with criticisms, and adjust their views. Scientific research is organized, it is cooperative and interactive, it creates shared worldviews, and observations are interpreted in accordance with these worldviews. Progress, Fleck holds, consists of the revision and adjustment of worldviews as the community deems appropriate, and over time these adjustments may be so great as to constitute a new worldview, a new style of thought, even a new reality.[39] What the thought collective previously recognized as physical reality may no longer be viewed as reality. Fleck is unambiguously anti-realist on this point: what members of a collective call truth is merely what the thought collective has settled upon at that point. He is also unambiguously anti-individualist and anti-methodological: the agency of scientific progress is located not in the individual but in the group, and the core of science lies not in a particular method but in the diverse interactions of that group.

Under-determination: Pierre Duhem

Fleck's work received some attention when first published, but became much more famous in later years when it came to be viewed as anticipating and influencing the work of Thomas Kuhn. Something similar may be said about Pierre Duhem (1861–1916), whose work was recognized by the Vienna Circle but is now seen as influential primarily because of its uptake by the American philosopher W.V.O. Quine (1908–2000).

disagreed. Even if Foucault's experiment contradicted Newton's corpuscular theory, other forms of corpuscular theory might yet be consistent with the result.[47]

Yet Duhem did not adopt the radical holism with which his name later became associated. (Holism is the idea that theories stand or fall in their entirety and that a challenge to any one component is potentially a challenge to the entire intellectual fabric.) In places, it may appear that he is on the verge of radical holism, as when he writes of the "radical impossibility [of separating] physical theories from the experimental procedures appropriate for testing these theories," or that an "experiment in physics can never condemn an isolated hypothesis but only a whole theoretical group."[48] But elsewhere he makes clear that he believes some elements of our belief structure are so well established that we are unlikely to doubt them, and rightly so. Some elements of our work are well confirmed through other sources, or strongly linked to principles that we have little doubt are correct. Basic instruments such as thermometers and manometers, for example, are unlikely to be distrusted, as are the concepts that accompany them, such as temperature and pressure. Indeed, he insists that in testing the accuracy of a proposition, a physicist must make use of a whole group of theories that are accepted by him as "beyond dispute." Otherwise he would be paralyzed; it would be impossible for him to proceed. (One may suppose that basic principles of thermodynamics, such as conservation of mass and of energy, are in his mind.) Likewise if an experimental test fails, it does not tell us where the failure lies. It tells us only that somewhere in the system "there is at least one error."[49]

> In sum, the physicist can never subject an isolated hypothesis to experimental test, but only a whole group of hypotheses; when the experiment is in disagreement with his predictions, what he

> learns is that at least one of the hypotheses constituting this group is unacceptable and ought to be modified; but the experiment does not designate which one should be changed.[50]

Duhem did not conclude that for this reason we should be radically skeptical. Rather he argued that we should adopt an attitude of reasonable humility toward intellectual commitments. Following Claude Bernard, he reminds us to be antidogmatic, to maintain an openness to the prospect that our theories may need revision, and to preserve an essential "freedom of mind."[51] Hypothesis, theories, and ideas in general are essential for stimulating our work, but we should not have "excessive faith" in them.[52] We should not be too pleased with our own accomplishments. As Americans at that time might have put it, we should not become "auto-intoxicated."[53]

In the face of an apparent refutation, how does a scientist decide which element(s) of the relevant nexus of theory, instruments, experimental setup, and auxiliary hypotheses should be revised? On this point, Duhem is not entirely satisfactory, invoking Pascal that there are "reasons which reason does not know." In the end, he concludes that these decisions ultimately are matters of judgment and "good sense."[54] Duhem uses history to underscore this point:

> We must really guard ourselves against believing forever warranted those hypotheses which have become universally adopted conventions, and whose certainty seems to break through experimental contradictions by throwing the latter back on more doubtful assumptions. The history of physics shows us that very often the human mind has been led to overthrow such principles completely, though they have been regarded by common consent for centuries as inviolable axioms, and to rebuild its physical theories on new hypotheses.[55]

Yet at the same time, he makes equally clear his conviction that history gives us grounds for confidence in the processes of scientific investigation, so long as we do not become dogmatic. He concludes with the following passage:

> The history of science alone can keep the [scientist] from the mad ambitions of dogmatism as well as the despair of . . . skepticism. By retracing for him the long series of errors and hesitations preceding the discovery of each principle, it puts him on guard against false evidence; by recalling to him the vicissitudes of the cosmological schools and by exhuming doctrines once triumphant from the oblivion in which they lie, it reminds him that the most attractive systems are only provisional representations, and not definitive explanations. And, on the other hand, by unrolling before him the continuous tradition through which the science of each epoch is nourished by the systems of past centuries . . . it creates and fortifies in him that conviction that physical theory is not merely an artificial system, suitable today and useless tomorrow, but that it is an increasingly more natural classification and an increasingly clearer reflection of realities which experimental method cannot contemplate directly.[56]

W.V.O. Quine and the Duhem-Quine Thesis

Duhem's views became known to American audiences primarily through the Harvard philosopher Willard Van Orman Quine, and in the process came to be viewed as more radical than they arguably were. Quine took the problem of refutation and reformulated it under the rubric of what has come to be known as "under-determination." If theories are tested not in isolation but in whole theoretical groups, then how do we know which piece of the group is in need of revision when something goes awry? Duhem's answer was: We rely on judgment. Quine's answer is: We *don't* know. Knowledge, he insists, is a web of belief. When we encounter a refutation, there is a universe of potential adjustments we can make, a universe of threads that can be tightened or loosened to sustain the fabric or reweave it. In Quine's words: "our statements about the external world face the tribunal of sense experience not individually but only as a corporate body."[57]

Duhem would have agreed with that, but he also believed that evidence could lead us to reexamine and adjust parts of that corporate body appropriately. This is one of his two key purposes of experimentation—to strengthen or weaken the support for particular elements in physical theory. If saving the phenomena required us to abandon something that is very strongly held—such as conservation of energy—we would be unlikely to do it. We would conclude that the experiment revealed a problem somewhere else or that there was a problem with our instrumentation. For Duhem, the various parts of the whole theoretical group are not created equal and not equally up for grabs. But Quine thinks that they are, concluding, famously: "any statement can be held true, come what may, if we make drastic enough adjustments elsewhere in the system."[58]

Quine's radical holism came to be known as the Duhem-Quine thesis and is taken by many scholars to weaken the grip of evidence on theory, because if theories are under-determined by experiment—and we have a world of choices in how to respond to experimental failure—then what is the basis for our belief?[59] It appears that some additional component is necessary to explain how scientists come to the conclusions that they do. This became the foundation of a great deal of what followed: