WHY THE LATTER-DAY SAINT COMMUNITY CAN TRUST SCIENCE (IN THE SAME WAY SCIENTISTS DO)

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On June 30, 1860, Samuel Wilberforce, a fiery Anglican bishop, addressed the British Science Association at the Oxford University Museum of Natural History on the subject of Darwin's recent publication, *On the Origin of Species by Means of Natural Selection, or the Preservation of Favored Races in the Struggle for Life*. This was the famous encounter between Bishop Wilberforce and Thomas Huxley, Darwin's "Bulldog," in which the bishop inquired of Huxley whether it was from his mother's or his father's side that he was descended from a monkey? And Huxley quipped back something like, "Better a monkey than a bishop who used his talents to obscure the truth." There might be some surprise to learn that Wilberforce had not been arguing from a religious perspective that the book was dangerous (although there may have been an element of that). He was arguing it was bad science and that the facts did not warrant the conclusions.

Something else happened at the meeting worth noting. During the gathering, an old man stood and held over his head a large, weathered copy of the Bible. He begged the audience to "believe God rather than man," telling the assembled spectators that *The Origin* had given him "acutest pain."[1] The audience shouted for him to be silent and sit down.[2]

1. Derek Barlow, "The Devil Within: Evolution of a Tragedy," *Weather* 52, no. 11 (1997): 338. *Weather* is a publication of the Royal Meteorological Society.

2. Diane B. Paul, John Stenhouse, and Hamish G. Spencer, "The Two Faces of Robert FitzRoy, Captain of HMS *Beagle* and Governor of New Zealand," *Quarterly Review of Biology* 88, no. 3 (2013): 219–25, https://doi.org/10.1086/671485.

The man was Robert FitzRoy, a former member of parliament, a one-time governor of New Zealand, and, in his most celebrated role, the captain of the history-changing expedition of the HMS *Beagle*, aboard which Darwin had his first intimations of the evolutionary theory that would change the world. Since his famous voyage, FitzRoy had become a biblical literalist. Still a man of science and member of the Royal Society at the time of this incident, he felt a growing discomfort at the implications of his former companion's book that threatened his view of God and the inerrancy of the Genesis accounts of the Creation and the Great Flood.

He would not be alone. Darwin's book became one of the principal targets in the rise of biblical fundamentalism in the late nineteenth and early twentieth centuries. Darwin's *Origin* seemed to intrude on the territory mapped out as the provenance of God's creation. As a result, the relationship between science and religion has been and continues to be complex and often fraught. Recently, however, some scientists who embrace both science and religion have begun to argue that this conflict model is unnecessary.[3]

3. For more information, see M. Elizabeth Barnes, James Elser, and Sara E. Brownell, "Impact of a Short Evolution Module on Students' Perceived Conflict Between Religion and Evolution," *American Biology Teacher* 79, no. 2 (2017): 104–11; William S. Bradshaw, Andrea J. Phillips, Seth M. Bybee, Richard A. Gill, Steven L. Peck, and Jamie L. Jensen, "A Longitudinal Study of Attitudes Toward Evolution Among Undergraduates Who Are Members of The Church of Jesus Christ of Latter-day Saints," *PLOS One* 13, no. 11 (2018): e0205798, https://doi.org/10.1371/journal.pone.0205798; Jamie L. Jensen, Katie F. Manwaring, Richard A. Gill, Richard S. Sudweeks, Randall S. Davies, et al., "Religious Affiliation and Religiosity and Their Impact on Scientific Beliefs in the United States," *BioScience* 69, no. 4 (2019): 292–304, https://doi.org/10.1093/biosci/biz014; Katie F. Manwaring, Jamie L. Jensen, Richard A. Gill, Richard R. Sudweeks, Randall S. Davies, and Seth M. Bybee, "Scientific Reasoning Ability Does Not Predict Scientific Views on Evolution Among Religious Individuals," *Evolution: Education and Outreach* 11, no. 2 (2018): 1–9, https://doi.org/10.1186/s12052-018-0076-8; Steven L. Peck, *Science the Key to Theology* (BCC Press, 2017); Johan De Smedt and Helen De Cruz, *The Challenge of Evolution to*

To consider this conflict more thoroughly, a more complete understanding of science as practiced in the twenty-first century is useful. Often, science gets reduced to this simple four-step method: (1) find a falsifiable hypothesis; (2) test that hypothesis through experimental methods designed to detect or expose whether the hypothesis is false; (3) if the experiment fails to confirm, reject the hypothesis and start again at (1); or (4) try another experiment and see if one can reject the hypothesis this time. As it turns out, however, this is a far cry from the way science is practiced.

Scientific practice is more nuanced than this simple model would suggest. Science, although it has ancient origins, is an invention that appeared from investigative developments beginning in the sixteenth century and extending into the mid-eighteenth century. It framed a set of practices and attitudes that would generate knowledge about the physical universe.[4] It is a complex human activity that demands the very best humans have to offer in terms of trying to understand the world in all its complexity and generate knowledge about the physical world. Here's a short list of what science is: a human social activity based upon programs of study; the collective agreement on what counts as evidence;[5] research paradigms that define the theories and gather and present evidence obtained through various natural and apparatus-assisted observations or experimental manipulation of the same; the willingness to be open to criticism and critique by others who are

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Religion, Elements in the Philosophy of Biology (Cambridge University Press, 2020), https://doi.org/10.1017/9781108685436; and Ethan E. R. Tolman, D. G. Ferguson, M. Mann, A. M. Cordero, and J. L. Jensen, "Reconciling Evolution: Evidence from a Biology and Theology Course," *Evolution: Education and Outreach* 13, no. 19 (2020): 1–8.

4. David Wootton, *The Invention of Science: A New History of the Scientific Revolution* (Penguin, 2015).

5. Michael Strevens, *The Knowledge Machine: How Irrationality Created Modern Science* (Liveright, 2020), 119.

qualified to examine what a researcher and those working with her have done;[6] a commitment to uncertainty;[7] the skeptical examination of the work that has proceeded and motivated what's been done before; years of education, training, and apprenticeships; and then presenting that work in papers that are scrutinized by peers and publicly published, with all comers able to examine the merits of all aspects of the science engaged to create the paper.[8] As a human enterprise, science is committed to certain values and subject to all the strengths and weaknesses that define what it means to be human—for example, bias, conceptual blindness, fear of being wrong, holding to certain opinions long after they should have been abandoned, and all the other limitations and missteps found in being human. I've done a bit of hand-waving, so let me give some details to help structure what I've just claimed for an abstract of what science entails, at least in part. In what follows, for ease or readability, "science" is used as a personified shorthand for what the practice of science entails. For example, "Science says" should be read as general practices and activities of trained scientists, not as a free-floating entity dictating scientific practices.

Science as a Way of Knowing?

It is helpful to pause in order to examine what science is not. It is not a formal monolithic activity with clear boundaries, procedures, and methods. Science is not a method, although it embraces certain methods. It is not a set of procedures that if one unfailingly follows, then one is doing science. It is not just a precise way of doing experiments, testing hypotheses, or framing questions, although all these things play a role.

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6. Jonathan P. Tennant, "The State of the Art in Peer Review," *FEMS Microbiology Letters* 365, no. 19 (2018): fny204, https://doi.org/10.1093/femsle/fny204.

7. Kostas Kampourakis and Kevin McCain, *Uncertainty: How It Makes Science Advance* (Oxford University Press, 2020).

8. Naomi Oreskes, *Why Trust Science?* (Princeton University Press, 2019), 56.

Science is a social activity performed by humans for humans that carries with it certain cognitive, perspectival, and other limitations from which we cannot escape.[9] We are limited creatures in so many ways. To ignore this would be profound hubris. In addition, science is also a set of ethical practices that are committed to a careful examination of the world and its processes. It is this set of ethical practices that garner trust in its findings.[10]

In these ways, being a scientist is, in part, taking a particular ethical stance toward the world, with specific assumptions and values that condition your activities. These provide an agreed-upon certification of your findings. Science has been wildly productive, with major advancements in everything to which it has turned its attention, from establishing a basic understanding of how the large-scale universe works to discovering important insights into the microworld of quarks and electrons. Scientific practices have helped create everything from cell phones to frozen peas.[11] Not that this productivity has been a linear and constantly forward march in the advancement of knowledge. It has not been. Setbacks are common, reversals abundant, missteps and dead ends almost the order of the day. But despite these, science continues to advance, sometimes painstakingly slow of pace, but on it goes. Why is that? Why does it work so well?

To understand science, we must first understand its values, tools, assumptions, and guiding ethics. Practicing scientists generally hold

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9. Thomas S. Kuhn, *The Structure of Scientific Revolutions*, 4th ed. (University of Chicago Press, 2012); Ludwik Fleck, *Genesis and Development of a Scientific Fact*, trans. Thaddeus J. Trenn and Robert K. Merton (University of Chicago Press, 1979); Helen E. Longino, *The Fate of Knowledge* (Princeton University Press, 2002).

10. Robert T. Pennock, *An Instinct for Truth: Curiosity and the Moral Character of Science* (MIT Press, 2019).

11. Susan Lindee, "The Epistemology of Frozen Peas: Innocence, Violence, and Everyday Trust in Twentieth-Century Science," in Oreskes, *Why Trust Science?*, 163–80.

that the universe is real and that the behavior of its constituting objects and processes can be rationally described with representations that aim at shedding light on that reality. In some fields, like physics and chemistry, there are law-like descriptions of nature. In others, like biology, the focus is on regularities and patterns that we find repeated in the natural world. These systems might be deterministic, bathed in chaos, or statistical distributions of genuinely random variables, but there are assumed to be rules we can discern and discover.

Values of Science

Truth

Science embraces several values that speak to our ability to confirm that we have an adequate grasp (always incomplete) on the things we study. Its primary value is truth. Uncovering the reality that underlies the objects and processes inhabiting the world, and getting the story right insofar as is possible given the limits of our perceptual abilities, is the target of the scientific enterprise. Science seeks knowledge that creates a match between our understanding of the world and whatever reality underlies our capacities for discovery. This is reflected nicely in Doctrine and Covenants 93:24: "And truth is knowledge of things as they are, and as they were, and as they are to come." In science, this is defined as a representation that reflects an aspect of the world that we are interested in understanding more fully. Science is committed to lining up our beliefs about the world with ontological realities or, as just stated, "things as they are."

Explanation, Prediction, and Objectivity

Objectivity embraces the idea that different observers can be led to the same conclusions about facts that scientific studies are trying to elucidate. If one scientist discovers how far a tsetse fly can move in certain types of savanna river forests in Burkina Faso, another independent investigator will come to the same conclusion about flight distances under the same conditions. Conversely, subjective truths broker more flexible and personal perspectives. For example, we might disagree on the beauty of a sunset, the worth of a painting hanging in the Musée d'Orsay, or how we have come to a testimony of the Book of Mormon. Objectivity is described nicely by John Nolt: "Objectivity is a collection of virtues that aim to transcend self-centeredness toward a wider and truer understanding. To be objective is, among other things, to: seek to understand and compensate for one's own prejudices; accept the findings of adequately conducted scientific research; strive for consistency; suspend judgment on factual issues when the evidence is inconclusive; cultivate awareness of your own fallibility; and seriously consider the well-informed opinions of others."[12]

Objectivity is related to two other values of science: causal explanation and prediction. If the rules we propose are operating in the universe, we should be able to confirm them by making predictions about the phenomena we study. If we have causal explanations for the way things behave, then those explanations should allow repeatable and useful manipulations by others based on the causal structure we propose.[13]

Simplicity

Another value of science is simplicity of explanation. Simple explanations tend to be more useful and make it easier to find principal regularities and patterns. For example, if I want to explain the relationship between a volume of gas, its temperature, and the pressure that it exerts, I might try to simulate the momentum of every atom present and calculate the impacts of those moving particles on the container, which creates pressure. This might explain the entire process, but it is easier to

12. John Nolt, *Environmental Ethics for the Long Term: An Introduction* (Routledge, 2015), 31.

13. Peter Godfrey-Smith, *Theory and Reality: An Introduction to the Philosophy of Science* (University of Chicago Press, 2003), 190–201.

use the equation $P = \rho RT$, which gives the pressure P as a relationship between ρ the density, a universal constant R, and the temperature T. The equation is more parsimonious than a massive accounting of each and every atom in the container and therefore favored in most cases. If there are two explanations for the same phenomenon, the simpler is preferred if both capture all of the relevant facts, as in this equation capturing pressure exerted by a gas.

Repeatability

Repeatability captures a value based on the assumption that the rules that structure the universe hold anywhere in the universe where similar conditions obtain. Repeatability should be achievable at both different times (if my experiment works today, all things being equal, it should work tomorrow) and diverse locations (other researchers should get the same result when they try it under the same conditions—even if they live on different planets located on opposite sides of the galaxy).

Fallibility

Science values the ability to falsify predictions and explanations. When a scientist is exploring some aspect of the world, it is best practice to make some prediction in the form of a hypothesis about what they expect. If a hypothesis is falsifiable, when it is not rejected through some appropriate test, it lends some credence that the hypothesis might be on the right track. A rejection is evidence that the hypothesis is false.

Keep in mind, however, when it is not rejected, scientists often speak of the hypothesis not as being true but of having not been disconfirmed yet. It is also not usually just a matter of rejecting it out of hand. If a well-confirmed hypothesis fails a particular test, usually the matter is not put to rest on that instance alone. Other things could have gone wrong. The apparatus the experimenter was using might not have been set up properly; a student might have been singing loudly in the lab, causing vibrations unaccounted for; or a loose rat might have crept in and made some mischief. There are usually several ancillary hypotheses and assumptions that go into any experimental setup. One must be careful that it was not one of these other possibilities that is responsible for the experiment's failure to confirm a hypothesis.

Diversity

Another value is diversity.[14] It has been found repeatedly that diversity of race, gender, or age, along with other aspects of human diversity, add to the success, originality, and advancement of science.[15] Science relies on creativity. Finding questions often turns out to be more important to the enterprise of science than the answers that it ultimately provides. Diversity probes problems with morevaried eyes, leading to better questions and ways of thinking.

Tools of Science

To realize the values above, science uses a standard set of tools. These have been embraced largely for pragmatic reasons: they work. Let's look at some of the most common tools used by a number of disciplines in science. This is not an exhaustive list.

Experimentation

Roger Bacon is credited with one of the first articulations of science's most ubiquitous tool—experimentation. The world is complex, but if one can simplify it enough that much of the complexity is tamed, eliminated, and controlled; if all the extraneous influences on the system are handled; and if one can manipulate just a few of the suspected causes and observe their effects, greater clarity on the role those causes play

14. Oreskes, *Why Trust Science?*, 55–59.

15. Laurel Smith-Doerr, Sharla N. Alegria, and Timothy Sacco, "How Diversity Matters in the US Science and Engineering Workforce: A Critical Review Considering Integration in Teams, Fields, and Organizational Contexts," *Engaging Science, Technology, and Society* 3 (2017): 139–53, https://doi.org/10.17351/ests2017.142.

can be ascertained. This is complicated to be sure, but experimentation has been one of the hallmarks of good science. By controlling all the important variables possible, randomizing what cannot be controlled, and noting the resulting effects, scientists have been able to verify some causal aspect of the world. Again, the way this typically proceeds is that one sets up experiments, based on falsifiable hypotheses, and tries to find ways to reject those hypotheses. The longer an individual hypothesis survives under this assault of repeated attempts to falsify it, the more warrant one has to suspect it is true.

Notice there is a severe weakness in this. When we abstract and isolate processes, we never get the full story because often—and, in fact, I'd argue usually—the processes we isolate do not behave the same way they would in the presence of all the variables we restricted to make the experiment manageable. Nancy Cartwright has written an influential book on the philosophy of science, *How the Laws of Physics Lie*.[16] She points out that even in the most law-like processes, we only get information about the particular regularities we are studying in a given situation. The laws we discern are likely only incomplete abstractions of processes reflecting multiple influences. She prefers the idea of regularities and capacities rather than "laws." Experiments always leave things out, so we are left with incomplete information. Still, these experiments can be useful. They can offer a high probability of representing a sound way to view the world, but it must be recognized that the factors being investigated might have other stories to tell in a different set of circumstances or under the influence of a larger set of factors.

This suggests we should have some humility in the presence of our experiments, but it does not let us get away with the sort of skepticism that would allow us to label it all worthless or uninformative. A well-designed experiment should eliminate many possibilities. If I drop cannonballs from towers and measure the rate of acceleration under

16. Nancy Cartwright, *How the Laws of Physics Lie* (Oxford University Press, 1983).

gravity, it is not advisable to argue we've learned nothing about gravity because there might be other forces at play—for example, nearby mountains, wind, surface anomalies on the cannonballs, a certain spin on the hunk of metal, inaccuracies in our timing device, and so on and on. Although we don't get the full picture, we still learn something about gravity. The skeptical claim that we have learned nothing because we did not capture everything is wrong. We have learned much about the general way gravity works under *ceteris paribus* (all things being equal) conditions as well as about the overall tendencies of things in a gravitational field. We also get a sense in the measurement of error about how much deviance from the norm we can expect. All of this contributes to our knowledge of gravity.

Observation

Observation is also critical to science, especially for systems to which we do not have direct access, like distant stars and galaxies. In these kinds of studies, the variables are not controllable in the same sense as in a typical laboratory experiment. For these systems, patterns are noted and quantified. Hypotheses take the form of speculating about how processes create the pattern, then looking for observations that support that possibility. For example, a hypothesis on how a galaxy of a particular kind forms might be confirmed by further observations that subsequently find a galaxy of the type predicted. As such are located, they provide evidence that a researcher is onto something. As further confirmatory observations of galaxies of the predicted type are found floating in the cosmos, they add weight to the hypothesis. Evolution by natural selection is like this. Such evolution is one of our most well-established theories and has contributed more to our understanding of life than any other single idea in the life sciences. Darwin predicted that fossils would continue to be found in a certain order from most primitive to more advanced, and that species ought to be more closely related if they are not separated by great distances from each other.

DNA as the genetic code of life on earth was a vital discovery confirming evolutionary descent from common ancestors. Geology and many of the ecological sciences also rely on this kind of observation and prediction strategy.

Modeling

Modeling is an important tool in science. It is often a form of theory generation and has been highly productive. Isaac Newton, for example, by making simple assumptions, was able to model the motion of heavenly bodies and make stunningly accurate predictions of planetary motion with some simple equations. Mathematical modeling (and its more recent sister tool, computer simulation modeling) has been very useful in performing quantitative experiments in systems that would be too messy otherwise. Modeling brings together observation and experimentation in important ways, allowing clearer mathematical, statistical, and other quantitative assessments of the universe's behavior.

Peer Review

Peer review is one of the chief tools that help science maintain its robustness and productivity. When a scientific paper is ready to be exposed to the world, the editor of a journal will send it to several others (usually three to five) in the same disciplinary area, often to those with whom the paper's authors are intellectually in disagreement, to evaluate the scientific work displayed in the paper. The reviewers will examine the methods to make sure institutional norms were observed or, if they were not, to validate the reasons for deviation (not everything is neat in science, and sometimes innovative approaches are necessary). The reviewers will also examine models used, how the data were analyzed, the rigor of the reasoning used by the researchers to argue for their conclusions, and how those conclusions impact and improve the discipline. Studies found wanting in any of these areas or findings that make trivial or too minor advances are rejected or sent back to the author for clarifications or improvements, sometimes with the request for more data to be gathered. This can be a brutal process, but this policing ensures that best practices are followed and that each paper makes a genuine contribution to advancing open questions within the discipline.

The process is not perfect. Friends can end up as reviewers, despite the process being blind, and often one can recognize who the paper's author is from familiarity with their previous papers and not apply the rigor expected from peer reviewers. Detractors from a body of work might argue against a paper that threatens their own position. Or reviewers might not understand the discipline well enough to make a good assessment. But overall, peer review provides a screen that prohibits unworthy work from calling itself science. High-prestige journals might accept only from 2 to 5 percent of those submitted, with lower-regarded journals accepting 50 percent of papers offered. This creates a healthy hierarchy of scientific worth that militates against mediocrity. Often the number and prestige of journals in which one publishes weighs in academic advancement and retention decisions. This creates an environment in which scientists are highly motivated to produce excellent work that passes the significant hurdles that scientific claims need to leap to enter scientific discourse.

A Final Word on Epistemological Stances in Science: How Science Creates Knowledge

Ultimately science is about gaining knowledge. Jürgen Renn provides a description of how knowledge is acquired, used, and stored:

> Knowledge is a problem-solving potential, that is, the capacity of an individual or a group to solve problems and to mentally anticipate corresponding actions. Knowledge is based on experience and encoded in mental, material, and social structures. It is generated by reflection on environmentally embedded actions and serves as a potential for

> the anticipation and control of actions. Knowledge is internally represented by cognitive structures that enable the connection between past and current experiences. It is shaped (but not determined) by the material culture and existing social relations, and ultimately arises from experiences accumulated in socially constrained material practices.[17]

Two perspectives of scientific engagement with the world are often discussed, each with different assumptions about how science works.

Antirealism

One is constructive empiricism. Bas van Fraassen, one of the principal articulators of this view, argues that deep reality is largely unknowable; our models of things like subatomic structure are constructions that allow us to work with whatever realities underlie the observable universe, including observable with instruments.[18] He argues that when we represent electrons in our scientific models, we are only talking about those representations, not actual entities. This view suggests that if, for example, we encountered aliens with very different brains and methods of observation, they might have a different view of the subatomic world of electrons than we do. Their science of electrons might do all the same work that our electron-talk does.[19] They may look at our periodic table of elements and be completely baffled by what we are doing but have, what seems to us, an equally baffling conception of chemistry that works just as well for them, but one of which we can make neither heads nor tails. Our science would play the same role in making explanations

17. Jürgen Renn, *The Evolution of Knowledge: Rethinking Science for the Anthropocene* (Princeton University Press, 2020), 64.

18. Bas C. van Fraassen, *Scientific Representation: Paradoxes of Perspective* (Oxford University Press, 2008), 269–90.

19. Ian Hacking, *The Social Construction of What?* (Harvard University Press, 1999), 74–75.

and predictions as theirs, but theirs conceives of a universe made of radically different entities and processes.[20]

Realism

The second view, and more common among scientists like biologists, geologists, and engineers, is scientific realism. This is the view that, while our representations are always imperfect, they are capturing the truth of an underlying reality. All representations are about something, and in science we hope that we are capturing an accurate, or at least adequate, aspect of the physical world. When we try to represent a rabbit population in our model of the things we see while studying conies in the field, we aim to talk about aspects of genuine rabbit populations, not our model.

Methodological Physicalism

Another assumption science makes is methodological physicalism—that the things we have chosen to study have causal explanations involving matter and its associated fields, such as electromagnetic fields, and that data comes from a physical world that is measurable and objectively observable. Science assumes that there is a world and that its processes, regularities, patterns, capacities, fields, and materials act in ways such that we can discover rules of conduct for the stuff of the universe. By assuming methodological physicalism, science puts up front its stance that the physical world is causally constructed and that we can gain knowledge about the way it works. Science assumes that no ghosts or fairies or other ethereal powers act on the material aspects of

20. Emiliano Trizio, "How Many Sciences for One World? Contingency and the Success of Science," *Studies in History and Philosophy of Science* 39, no. 2 (2008): 253–58, https://doi.org/10.1016/j.shpsa.2008.03.017. Also see this collection of explorations of science that is contingent on its historical or developmental path: Léna Soler, Emiliano Trizio, and Andrew Pickering, eds., *Science as It Could Have Been: Discussing the Contingency/Inevitability Problem* (University of Pittsburgh Press, 2015).

the universe. This assumption is critical for science. If there are divine or genuinely miraculous influences, then they cannot be investigated by science and indeed should not be. However, a caveat is warranted: If there are phenomena in need of explanation, sometimes physical causes might not appear readily at hand, and some humility and patience might be necessary before a physical explanation is proffered. For example, an extrasolar object recently whizzed through our solar system on its journey through interstellar space. Dubbed ‘Oumuamua, it had strange behavior not seen before in comets or asteroids. Avi Loeb, former chair of Harvard’s astronomy department, prematurely declared the only explanation was an alien spacecraft and wrote a popular book on the subject.[21] However, more patient scientists, working with the data collected from the object as it passed by, made a detailed case that a fragment of a Pluto-like dwarf planet containing methane ice rather than water ice completely explained all of the strange behavior of ‘Oumuamua.[22] The mystery was solved based on what we know about the universe without resorting to extraordinary and unlikely claims.

Do not confuse methodological physicalism with ontological physicalism, however. The latter assumes that material forces are the only kind of influences that there are—everything that does or can exist is only matter in motion and its associated fields. Methodological physicalism, in contrast, just uses physicalism as a working assumption to allow science to proceed. However, keep in mind that Latter-day Saints should be completely comfortable using methodological physicalism,

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21. Avi Loeb, *Extraterrestrial: The First Sign of Intelligent Life beyond Earth* (Houghton Mifflin Harcourt, 2021).

22. Alan P. Jackson and Steven J. Desch. “1I/‘Oumuamua as an N2 Ice Fragment of an Exo-Pluto Surface: I. Size and Compositional Constraints,” *Journal of Geophysical Research: Planets* 126, no. 5 (2021): e2020JE006706, https://doi.org/10.1029/2020JE006706; Steven J. Desch and Alan P. Jackson, “1I/‘Oumuamua as an N2 Ice Fragment of an Exo-Pluto Surface II. Generation of N2 Ice Fragments and the Origin of ‘Oumuamua,” *Journal of Geophysical Research: Planets* 126, no. 5 (2021): e2020JE006807, https://doi.org/10.1029/2020JE006807.

because they make the same assumption as science in a host of daily activities. I would wager almost everyone fully expects their mechanic to be such a physicalist. When someone takes their car in to find out why it is not running, they are counting on the mechanic to talk in terms of pistons, carburators, belts, and straightforward mechanical causes of the problem. If the mechanic repairing the car says the problem is interstitial elves from the land of Fantomia, the customer would likely find a new mechanic. When a customer takes a car in for service, they expect it to be handled using only methodological physicalism. So do we in science. This does not mean that things like God, angels, divine interventions, blessings, or the grace we find in our relationship with God are not real. It just means science is not an appropriate way to study these things. They are outside its domain of concern. Harvard paleontologist Steven J. Gould called this idea nonoverlapping magisterium, which captures the idea that science and religion are often focused on different concerns.[23]

Scientific Ethics

To understand science, one must examine the ethical stances that undergird its activities. The normative activities of science condition how discovery proceeds. It is these, I believe, that give science its power to discover truths about the world and are responsible for the progress we see in science. There are three main stances I want to highlight: (1) Scientists ought to have openness to revision and to hold all results as tentative, allowing for the possibility that findings might be revised in light of new data or better analyses; (2) Scientists ought to be a part of discipline-specific research programs that provide institutional standards of rigor and training among its disciplines; and (3) All results should, after peer review, be archived in scientific journals that provide

23. Steven Jay Gould, *Rocks of Ages: Science and Religion in the Fullness of Life* (Ballantine Books, 1999), 5–59.

details on all aspects of scientific research. Let's look at each of these in turn.

Transparency and Openness to Revision

Scientists are required to share their findings. All data and their analyses are open for inspection—for public and institutional review—once claims have been made in an appropriate scientific venue. This means that scientists are obligated to reveal how the data were obtained, what experimental protocols were used, how models were constructed and implemented, and how information was statistically analyzed. In short, the procedures for making scientific claims ought to be replicable by other competent scientists. Often, once data are published, they should be made available to other researchers qualified to understand the data, its generation, and its analysis, or at least archived so that such can be done at a later time if desired. Sometimes there are proprietary issues with data, such as when aspects of a scientist's own analyses might not be completed or when there are patent or security concerns that keep data from being released. This does not mean that hard-won data must be handed over to people who do not have the proper tools for their interpretation. This is especially true when complex datasets are used for multiple analyses, and papers may continue to be written for years on the same dataset. But for the most part, it should be crystal clear what went into making any scientific claim. This openness means that scientific findings never arise out of a black box that hides key features about where the claims come from. Another aspect of openness in science is revealing a research project's sources of funding. This helps ensure there are no hidden biases or influences that might affect outcomes. In addition, there is an especially strong effort to examine startling findings to ensure they are not anomalous and to find and expose attempts at fraud like the one perpetrated in the vaccine-autism deception.[24]

24. Sarah Geoghegan, Kevin P. O'Callaghan, and Paul A. Offit, "Vaccine Safety: Myths and Misinformation," *Frontiers in Microbiology* 11 (2020): 2.

All scientific claims are tentative. This means that scientific claims are continually challenged, reformulated, refined, and nuanced as new studies are made. Because science is a human activity, this is a messy process. People have favorite theories, perspectives, and biases. But as more eyes examine a problem, there is a trend toward progress and a better understanding of the world. In fact, nineteenth-century philosopher Charles Sanders Peirce argued that truth was just the asymptotic convergence of scientists doing their work and coming to an agreement.[25]

Maintenance of Research Programs

All science takes place within disciplinary research programs. These programs often have worldwide scope and stretch across multiple institutions such as schools, universities, private companies, and governmental agencies. These programs establish best practices for the way science is done within a given discipline. These practices are often established after long periods of trial and error and establish traditions of laboratory procedures that have been shown to produce robust scientific results.

These programs also establish how students are trained, apprenticed, and credentialed. These institutions dictate the nature of the formal, rigorous training found in obtaining advanced degrees. Also policed within programs is what counts as proper data gathering protocols, standards of exactness and cleanliness, which instruments are used and how they are calibrated, what constitutes a proper statistical data analysis, and what is to be reported in a standard scientific journal paper under assurances that disciplinary norms have been followed.

There is a temptation among those not involved in science to see these institutional and program boundaries as providing conditions

25. Charles Sanders Peirce, *Illustrations of the Logic of Science*, ed. Cornelis de Waal (Open Court, 2014), 79–107; Francis E. Reilly, *Charles Peirce's Theory of Scientific Method* (Fordham University Press, 1970).

to foster "groupthink." This is possible, and that is not an unreasonable worry. There are examples where such occurs. For well-established research programs, it is often hard to introduce revolutionary thinking that undermines entrenched ideas. For example, when continental drift theory was introduced and data analyses were slowly eating at the boundaries of the idea that continents are static and immobile, there was considerable resistance to change from dominant geological research programs.[26]

Two things protect research programs from this kind of conspiratorial sameness. First, research programs are in constant competition for things like funding, students, research grants, and space in peer-reviewed publications. This creates an interesting dynamic of collaboration and competition that requires constant disciplinary refinement and advancement and that improves every aspect of the scientific enterprise. A Darwinian selection-like process ensures that those institutions and individuals that are most innovative, productive, and able to show progress receive the lion's share of scientific research and prestige. Those whose inventiveness allows them to find new results and discoveries or those who can take down prevailing paradigms and expose wrongheaded ideas are generally rewarded with more opportunities for doing science. This selection process ensures that research programs are never static and are constantly making advances that improve our understanding of the world. In fact, one of the important ways that pseudoscience is recognized is by a static research program. For example, when was the last time an academic journal reported that someone discovered a new method or finding or analysis that improved astrological forecasts?

Second, programs are usually self-correcting. When things do not work right, it is from within the institution that corrections are likely to come. They are most aware of problems, and when those problems

26. Oreskes, *Why Trust Science?*, 80–87.

become obvious enough, investigations specific to the problems are explored. Because institutions are the ones with relevant expertise and are closest to the methods and the data, it is here that problems are most often recognized, tackled, and corrected. The many eyes on the scientific enterprise tend to uncover biases and methodological mistakes.

This is not to say research programs are faultless. They do have challenges. It is often hard to break into their purview with innovative ideas or novel insights and to be recognized if one is tackling problems outside of disciplinary boundaries. These considerations require discussion and acknowledgment within the scientific community.

Archiving

All results, after being peer reviewed, should be archived in scientific journals. This gives access to current researchers and future scientists about what data previous scientists have collected and analyzed. This is how ideas recorded are not lost to history. This is where our arguments, discussions, and thoughts are preserved in perpetuity. This allows scientists to build knowledge and ensure it is maintained and curated in ways such that hard-earned information is not lost. Libraries and data archives play a vital role in all aspects of human knowledge generation. In science this is no exception. Funding for this effort must be maintained if science is to remain the vital practice that it is to culture and society.

Conclusions

I have left out many things in my overview of science. A short list might include creativity, bouncing ideas off others near the water fountain, laboratory manuals, internships, education, pondering, accidents, serendipity, dreams, networking, long hikes in cool mountains, skepticism, doubt, belief, humility, reading groups, staying abreast of the literature, attending scientific meetings to report new work, offering new context or critique for older work, friends, being able to interrogate questions on a long-held stance, imagination, integrating knowledge, detractors, understanding other fields, training students, keeping a notebook both formal and informal, and many, many other things that define what it means to be a scientist.

Science, even with all its imperfections, is the best thing people have invented to explain the natural world. Pillars of science—including evolution, major branches of medicine, and even Einstein's theory of relativity—are well established and unlikely to be overturned. As members of the Church of Jesus Christ of Latter-day Saints, we have nothing to fear from good science. I have argued that good science can be trusted by members of the Church at least as much as by scientists.[27] Science is always skeptical in the sense of embracing its findings tentatively, but enthusiastically when warranted, as they show us how to make a reasonable wager about how the world works.

27. Peck, *Science the Key to Theology*.

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