Feynman's Lecture to U.S. Science Teachers on "What Is Science" and Today's Mistrust of Science

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Fifty years ago and three years before Apollo 11 landed on the Moon, physicist Richard Feynman addressed the nation's science educators in New York City about the nature of science.

Abstract:

Feynman, in his 1966 address to science teachers at the annual NSTA meeting in New York, did not presume to tell them how they should do their craft. He admitted he had given a lot of thought to this question, 'What is Science,' concluding, "I will present it in a very unusual way. I am just going to tell you how I learned what science is." He proceeded to spin out stories that mesmerized his audience - stories that explained the difference between knowing the name of a thing and knowing the thing itself, a deeper knowledge. He provided examples of how the question you ask as a teacher (or textbook) make such a difference in engaging the learner in thinking, noting also the critical nature of feedback in learning. Many gems of pedagogical wisdom can be inferred from Feynman's stories, yet he eventually answers, 'What is Science?' - encompassing "the value of the worldview created by science" and how, "The world looks so different after learning science." Feynman warns teachers of inflicting cultural errors on youth and points to another quality of science, "that it teaches the value of rational thought as well as the importance of freedom of thought; the positive results that come from doubting that the lessons are all true." Voicing skepticism about the value of social science research, he cautions the teachers, "…to have some hope and some self-confidence in common sense and natural intelligence. The experts who are leading you may be wrong." And this was long before the long reign of error of No Child Left Behind and corporatized public education. That reign of error and other factors have led many observers to claim that our society has cultivated a mistrust of science (Gawande, 2016), and that, "Mistrust of science comes not so much from poorly educated people, but from otherwise well educated people." For examples, pollsters report that 74% of Republicans in the U.S. Senate and 53% in the House of Representatives deny the validity of climate change despite the findings of the National Academy of Sciences and the World Meteorological Organization which has just warned of "fundamental change" unfolding in the global climate (John, 2016). Other works cite a "growing and disturbing trend of anti-intellectual elitism" in our culture.

Finding: A Growing Mistrust of Science

Many Americans have been losing faith in our country's institutions. How often have you heard complaints about Congress, unions, or the mainstream media? Those typically are cited as the least popular of our institutions. Certainly the schools are often criticized too. But how does science rate? A recent Pew study comparing the attitudes of scientists and the public reveals a big difference between the two on issues such as climate change, genetically modified food and pesticide use, animal research, and overpopulation (Funk & Raine, 2015). For example, 88% of scientists express that it is generally safe to eat GM foods but only 37% of the general public do, a difference of 51 percentage points. As to climate change, almost all scientists (97%) agree that the earth is getting warmer due to human activity while just 57% of adults consider this the case, a difference of 40 percentage points, and the gap is nearly as large in terms of evolution. As many as 4 in 10 American adults doubt that it occurs. The only issue of the 13 the study compared where there were only modest differences between the two groups had to do with the space program, which is supported by 64% of the public and 68% of scientists. When asked if these gaps were a concern, 84% if scientists said the public's lack knowledge about science was a major problem for the field.

Even young Americans exhibit mistrust of science. According to a 2015 Harvard Public Opinion Project, 23 percent of young adults when asked about their stance on climate change selected the option: "Global warming is a theory that has not yet been proven." Among those identifying as Republicans the percentage was higher, 42 percent of respondents. (Estes, 2015)

Another study, by sociologist Gordon Gauchat of the University of Wisconsin-Milwaukee, also found that the public's mistrust in the scientific community has increased, but Gauchat goes further and seeks an explanation. Since 2006, the National Science Foundation has funded a biennial General Social Survey, a nationally representative, face-to-face survey covering a broad range of behavior and attitudes conducted by the National Opinion Research Center at the University of Chicago (http://gss.norc.org). Gauchat used data from the Survey of Public Attitudes Toward and Understanding of Science and Technology on two key questions: How the public feels about the use of scientific information to decide government policy, and how they feel about federal funding of scientific research. He examined how people viewed these in terms of their left-right ideologies and other beliefs, psychological factors, and personal identities that underlie their politics. He found that most people agree that science should contribute to public policy decisions, and that scientific research should get federal funding. But he found considerable differences, not so much between the political left and right, but in terms of people's religious beliefs. What emerged as the biggest factor as to why some Americans distrust the role of science in influencing policy was religion rather than political ideology. Gauchat (2015) notes that, "The 'direct effect' of liberal-conservative orientation is spurious once the distinct belief systems that underlie those identifications are accounted for." Biblical fundamentalists who believe scripture literally tend to reject the theory of evolution, which is a foundation of modern science. They also recognize how strongly the scientific community supports evolution, but feel threatened because of their religious beliefs. There is also scientific consensus about climate change being human caused, yet in a 2014 poll, 77% of white Evangelical Christians attributed extreme weather to "what the Bible calls 'end of times'" (Jones, Cox & Navarro-Rivera, 2014). That study found that just 43 percent of white Americans expressed concern at all about climate change.

Why does religious belief hold sway when there is this perceived conflict with science? A study on conspiracy theories has been offered as an explanation (Wood, Douglas & Sutton, 2012). Psychologists have found that conspiracy theorists can hold on to their beliefs in the face of contradictory facts because of a process called *global coherence*, by which people selectively chose to believe only those facts which supported their worldview. Incompatibility between a scientific claim is dwarfed by coherence with broader beliefs about the world which form a encompassing ideological system. In the same way, political ideology and religion may shape how willing people are to accept the claims of science.

Still another explanation as to why the public mistrusts science comes from scientist Tom Hartsfield (2016), who writes, "The truth is that many scientists pick political sides, look down their noses at the public, and play politically correct games. I think the public is on to something. I wouldn't trust us either. The condescension is the worst part." Further, hubris can undermine trust among affected publics. Sometimes scientists are reluctant or unwilling to include lay expert input concerning issues they claim belong exclusively in their domain. So if the public perceives scientists as belonging to an elite group, or one that may intentionally misinform for the purpose of promoting an agenda, then "guilt by association" occurs and all science is subject to mistrust. As Robin Ertl recently noted, "The resistance to scientific evidence is exacerbated when it is politicized." (2016, p. 2) People pay attention when politicians question science and that encourages public distrust, as has been the case regarding climate change and a number of other issues like genetically modified crops and treatments for disease.

Ertl goes on to say that scientists have been lax in communicating their work to the public, which adds to the problem:

> One of the problems is that it is hard to summarize a complex argument quickly. Thousands of articles are written each month but those who have the greatest knowledge in the field often fail to summarize the findings in a balanced way that the public can understand and use. Thus, it is left up to the news media and other people with less knowledge of the intricacies to interpret the research. When the implementation of scientific discoveries creates problems it engenders a lack of public trust. (2016, p. 2)

The challenge, then, is what to do about this mistrust, and how to uphold science as a better way to explain the world.

A Voice from the Past: Feynman Speaks to Teachers

As a science teacher, I had read about Richard Feynman and his Nobel Prize winning work in Quantum Electrodynamics in publications like *Scientific American* and *Discover* magazine, though as a biologist I had only a superficial understanding of the work. His fame came not only from his Nobel work, but also from his reputation as a great teacher – his classes at Cal Tech were always overflowing. But in the 1980s I discovered another side of Feynman, how he was as a person and how he thought about things. This occurred when I watched the BBC production of *The Pleasure of Finding Things Out*, an interview with Feynman broadcast on television by PBS. The interview was filmed in 1981 and was such a delight and inspiration that it made an impression. Later I purchased the videotape and still later the DVD and always ended my graduate course on the Nature of Science by showing it to my students. Feynman is a master at telling stories, and his tales about his childhood, his work on the atomic bomb at Los Alamos, and how he learned about science from his father, who was an ordinary man and a tailor, offer many insights into the mind of this great scientist both in his work and daily life. The Nobel Prize winning chemist, Sir Harry Kroto, said of the BBC production that it was "…the best science program I have ever seen. This is not just my opinion - it is also the opinion of many of the best scientists that I know who have seen the program... It should be mandatory viewing for all students whether they be science or arts students." (Feynman, 1981-82)

As a neophyte high school teacher in 1970 in Delaware County, Pennsylvania, I met Dr. Jim DeRose, the Science Supervisor for the nearby Marple Newtown School District, who was a friend of my Department Chair. I knew DeRose had been president of the National Science Teachers Association earlier, when I was still in college. Being in charge of NSTA's fifteenth annual meeting in New York City in 1966, DeRose invited Richard Feynman to present the keynote address. I didn't hear the address in person, but Feynman's was a memorable keynote and is now available in print and audio media

(Feynman, 2005). DeRose specified that Professor Feynman would address the question, "What Is Science."

To his credit, Feynman, never pedantic and always self-effacing, did not presume to tell the assembled science teachers how they should enact their craft. However, he did extol the quality of students that had been coming to him from the nation's schools. He praised the science teachers for their good work and he admitted he had given a lot of thought to this question of *What is Science*, and told them, "I am going to tell you what science is like by how I learned what science is like." (2005, p. 174) And then Feynman proceeded to describe to the teachers how his father, who had no formal education, but who had a deep interest in nature, taught him to think about things. One thing that comes out is the critical role that feedback plays in learning, in the home, classroom and in science itself. These and many more gems of pedagogical wisdom can be inferred from the several stories that Feynman threaded through his keynote speech, many being about his father, who played the principal role in his early science education.

Feynman's stories captivated the audience and illustrated his distinct views on the nature of science. He went on to explain the difference between knowing the name of a thing and knowing the thing itself, telling the teachers that this is "a deeper knowledge." To explicate this idea, Feynman proceeded to analyze a child's first grade science textbook lesson on energy. He shared examples with the teachers of how questions can asked (by teachers or the textbook) in a way that engages a learner more productively in thought (questioning, we all know as teacher educators, is a very important science teaching skill). The first grade textbook was attempting to teach about energy using an example of a wind-up toy. Feynman described how the textbook ended up giving a definition of energy but did not help the child think about the concept more productively. Science, in fact doesn't help much in nailing down an explanation of what energy *is*, but rather does well in identifying the relationships in which energy is found. Here is Feynman explaining how his father would have had the child think about this:

> (My father) would say, "It moves because the sun is shining," if he wanted to give the same lesson.
>
> I would say, "No. What has that to do with the sun shining? It moved because I wound up the springs."
>
> "And why, my friend, are you able to move to wind up the spring?"
>
> "I eat."
>
> "What, my friend, do you eat?"
>
> "I eat plants."
>
> "And how do they grow?"
>
> "They grow because the sun is shining."
>
> And it is the same with the [real] dog.
>
> What about gasoline? Accumulated energy of the sun, which is captured by plants and preserved in the ground. Other examples all end with the sun. And so the same idea about the world that our textbook is driving at is phrased in a very exciting way.

> All the things that we see that are moving, are moving because the sun is shining. It does explain the relationship of one source of energy to another, and it can be denied by the child. He could say, "I don't think it is on account of the sun shining," and you can start a discussion. So there is a difference. (Later I could challenge him with the tides, and what makes the earth turn, and have my hand on mystery again.)
>
> That is just an example of the difference between definitions (which are necessary) and science. (2005, pp. 180-181)

Feynman didn't mention Vygotsky's concept of the "zone of proximal development" (ZPD) to the teachers, but that clearly relates to what he was talking about in critiquing the textbook and describing effective questioning (Vygotsky, 1978). Also, here he distinguishes between *knowing* (knowledge and belief 'about' something) and *understanding* (tacit knowledge or intuition). While not using those terms, he makes the point that science is about more than just knowing things or applying a 'scientific method.' This is a significant insight and at variance with the received view of science, which would have been the beliefs dominant in his audience. Feynman was disagreeing with the common view even today that science *is* its methods. To Feynman, 'science' is located in breaking with how "we are told how to experience nature from the collective knowledge of the past." In other words, "'evidence' and 'observation' are historically loaded terms." (Trubody, 2017) This is more than just about being skeptical. Feynman describes this 'judgement' as the skill to,

> …pass on the accumulated wisdom, plus the wisdom that it might not be wisdom […] to teach both to accept and reject the past with a kind of balance that takes considerable skill. Science alone of all the subjects contains within itself the lesson of the danger of belief in the infallibility of the greatest teachers of the preceding generation. (2005, p. 188)

In talking to the teachers Feynman opts for the word 'wisdom' instead of 'tacit knowledge' or intuition, but he means the same thing. To Feynman 'understanding' expresses a deeper relationship than knowing something. In the BBC program interview, he gave the example of knowing that a particular animal had the name of a 'brown thrush' compared to being aware of the niche and habitat of that bird. Further Feynman believed that *how* one thinks matters more than *what* one thinks. Again, his viewpoint contrasts with the received view of science as methodology and/or accumulated knowledge. As Ben Trubody (2017) notes, "if science is not based in its form, method, past exemplars, or the beliefs and knowledge it generates, for it is these that change when great discoveries are made, there has to be a tacit element to doing science."

Early in his speech Feynman said that science textbooks offer a "kind of distorted distillation and watered-down and mixed-up words of Francis Bacon" (2005, pp. 172-3). He quoted William Harvey as rejecting Bacon's inductivist model of science, saying that a scientist can't just observe nature, but that a judgement is involved about what s/he has to pay attention to. He continued, "And so what science is, is not what the philosophers have said it is and certainly not what the teacher editions [science textbook] say it is." (2005, p. 173) Feynman proceeded to quote a children's poem about a toad asking a centipede how the centipede runs. The centipede tries to explain how he runs but falls over in trying to follow his own instructions. Feynman equated the question 'what is science?' to the centipede in the poem, such that an explanation can be more confusing than just *doing* it. So, for Feynman science is a lived endeavor that eludes a precise description, and it involves trained judgments as to what to attend to.

Feynman returned often to his assigned topic, “What is Science?” He ultimately answered the question. More crucially, he spoke about, “the value of the worldview created by science” and the aesthetic value of science, “the beauty and wonder of the world that is discovered through the results of these new experiences.” (2005, p. 185) He spoke as well about the value of science in fostering citizenship. Feynman is right to have noted those aspects of science, which are not peripheral aspects. I can attest to this in my own experience, that “The world looks so different after learning science.” (p. 186)

Towards the end of his talk to the science teachers Feynman attempted a definition of science, but then hesitated, noting from his own experience that science is neither its *form* nor its *content*. He did not characterize science as a particular method, though while that is one of the many ways science develops, it is itself not what science is. He finally answered the question, ‘what Is science’ this way, that it is, “...the result of the discovery that it is worthwhile rechecking by new direct experience, and not necessarily trusting the [human] race[‘s] experience from the past. I see it that way. That is my best definition.” (2005, p. 185) And then he went on to tell them, “…learn from science that you must doubt the experts…When someone says science teaches such and such, he is using the word incorrectly. Science doesn’t teach it; experience teaches it.” (Feynman, 2005, p. 187)

Feynman warned the science teachers of inflicting cultural errors on youth and pointed to another quality of science, “that it teaches the value of rational thought as well as the importance of freedom of thought; the positive results that come from doubting that the lessons are all true.” (p. 186) All of this points to the fact that Feynman had a deep understanding of the nature of science and that he tried to share it with the teachers. His is an understanding that is not easily communicable in straightforward prose. This nuanced view of science was gained after extensive experience and thinking. I wonder how many of the teachers who heard him really listened and “got it” – to do so would have demanded a change in most of his listeners’ relationship to knowledge, their *rapport au savoir* – a kind of change, a world-view kind of change that has been the focus of my previous work over the years in collaboration with Stephen Fleury, a teacher educator at LeMoyne College. We most recently discussed this idea in a paper on ‘creative-critical constructivism’ (Bentley & Fleury, 2017).

As a science teacher educator myself, reading Feynman’s keynote, I can imagine that many in his audience had to wonder if, when, and how, they had communicated any of these ideas and values in their own classrooms, much less Feynman’s perspective of the nature of science. Feynman knew what it means to really know something. At the end of his presentation, he admitted his lack of respect for the quality of research typically published in the social sciences, and particularly in the field of education, and he told the teachers that they should, “…have some hope and some self-confidence in common sense and natural intelligence. The experts who are leading you may be wrong.” Certainly he was right about that! And he had not even experienced what the rest of us have endured through the years of the awful ‘reign of error’ – that is, corporatized neoliberal public education as exemplified in No Child Left Behind and Race to the Top, programs which were critiqued so well by Diane Ravitch in her book (2013).

Unfortunately, that ‘reign of error’ obscured Feynman’s sage advice to the science teachers in 1966. That ‘reform’ regime and other factors have led to the cultivation of a mistrust of science in American society. Ironically, Gawande (2016) advises that, “Mistrust of science comes not so much from poorly educated people, but from otherwise well educated people.” To this point, pollsters report that 74% of Republicans in the U.S. Senate and 53% in the House of Representatives deny the validity of climate change despite the findings of the National Academy of Sciences and the World Meteorological Organization which has warned of “fundamental change” now occurring in the global climate (John, 2016). Other work has cited a “growing and disturbing trend of anti-intellectual elitism” in our culture. Susan Jacoby (2008) in *The Age of American Unreason* and Mark Bauerlein (2008), in *The Dumbest Generation*, both blame the rise of video culture over print culture and other factors such as, “the fusion of anti-rationalism with anti-intellectualism.” Catherine Liu (2011) in *American Idyll: Academic Antielitism as Cultural Critique*, notes, "We don't educate people anymore. We train them to get jobs." And Patrick Deneen (2016), a professor at Notre Dame, actually sees the “pervasive ignorance of our students” as an intentional outcome of our educational system.

Concluding: Promoting Better Science in the Classroom

The challenge still remaining is what should be done about the growing mistrust of science. How can science be defended as a sounder approach to understanding the world? I would contend that if more science teachers adjusted their *rapport au savoir*, integrating a deeper understanding of the nature science into their pedagogical theorizing, and incorporating more sophisticated questioning skills and discourse strategies into their teaching, that gradually science would become more trusted again in our society. It would follow that more and better science teacher education and K-12 teacher professional development would be an effective approach to addressing mistrust of science.

There is psychological research on misinformation available, but there are also useful resources out there. One that is now freely available online (in pdf format) that offers practical strategies on effective ways to reduce the influence of myths about science and “fake news.” *The Debunking Handbook* has been compiled by John Cook of the Global Change Institute at the University of Queensland and his colleague Stephan Lewandowsky, a cognitive scientist at the University of Western Australia (Cook & Lewandowsky, 2012, 2011). Intended as a guide on multiple topics, not just climate, and targeted to writers and speakers likely to encounter scientific misinformation, the handbook condenses research into a concise, useful summary of approaches to issues. Cook and Lewandowsky argue, and offer evidence, that just rebutting bad science is not only ineffective, but often simply backfires. By sharing facts that contradict an unscientific belief that misconception actually becomes exposed to new audiences and for the believers just strengthens their convictions. Misinformation sticks because of the inherent neural wiring in our brains: we tend to get our backs up when told what’s wrong with our ideas because we are likely to take criticism as a personal attack. The misconceptions that are the bad science get assimilated into the mental models we have of how things work. Our brains don’t like gaps in our mental models, and especially don’t like having no model at all. So, in dealing with misinformation, disproving the bad science should be eschewed in favor of asserting what the correct science is. It is also effective to report the context of the research or background or history regarding the science. Another effective tactic is to expose how the bad science is being used by vested interests to mislead people, such as how particular misinformation about climate change benefits corporate fossil fuel profits. But bad science, like fake news, must be addressed. Every case of misinformation deserves a proactive response. Initiatives like improving teacher education and depoliticizing scientific theories are the kind of actions needed to restore public confidence in science.

Feynman, who died of cancer in 1988 after four decades on the Caltech faculty, was named the seventh greatest physicist of all time in a poll taken by *Physics World*, a British journal of 130 of the world’s leading physicists (Tindol, 1999). He was the only American to appear on the list and the only one who worked mostly in the second half of the 20th century. The others were (1) Albert Einstein, (2) Isaac Newton, (3) James Clerk Maxwell, (4) Niels Bohr, (5) Werner Heisenberg, (6) Galileo Galilei, (8) Paul Dirac, (9) Erwin Schrödinger, and (10) Ernest Rutherford.

This year Donald Trump took office as President of the United States, and has chosen many individuals to serve in his Cabinet and in key positions who have publicly expressed their disbelief in anthropogenic climate disruption. Some reject evolution as well. This is the most anti-science U.S. administration since Ronald Reagan put James Watt in charge of the Department of the Interior and Anne Gorsuch Burford in charge of the Environmental Protection Agency. With the support of the like-minded Republican dominated Congress, much damage to the global ecosystem may be inflicted by eviscerating environmental regulations and energy and resource extraction policies enacted in the years ahead. It would be wise if we heeded the words of Robin Ertl:

> As the consequences of human activity and disease become greater and greater the public needs to trust science in order to make sound decisions in a timely fashion. If society refuses to consider scientific warnings, it may affect human existence on the planet. This seems extreme but nuclear disasters, climate change, environmental pollution, alterations of the human genome can have far reaching effects… Science needs to make the evidence clear to the public and indicate how much weight can be given to any piece of data and how it fits into the overall picture." (Ertl, 2016, p. 3)

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