CSCanada
Studies in Sociology of Science
Vol. 4, No. 3, 2013, pp. 1-9
DOI:10.3968/j.sss.1923018420130403.2796

ISSN 1923-0176 [Print]
ISSN 1923-0184 [Online]
www.cscanada.net
www.cscanada.org

Mind Bombs: Searching for Truth in the Great Debate Between Einstein and Bohr

Timothy McGettigan[a],*

[a]Ph.D, Full Professor, Department of Sociology, Colorado State University - Pueblo, United States.
*Corresponding author.

Received 16 June 2013; accepted 20 September

Abstract

Albert Einstein is regarded by many as perhaps the greatest scientist of the 20th century. Yet, one of his most enduring legacies is the monumental debate that he lost over the issue of quantum mechanics. Time and again, Einstein focused every bit of his extraordinary intellect on numerous efforts to undermine quantum mechanics only to fail on each and every occasion. While Einstein's reputation among his fellow physicists may have suffered as a result, his efforts, nonetheless, did much to advance the field of physics—and also, I argue, to sustain a commitment to good science.

Key words: Einstein; Bohr; Quantum mechanics

Timothy McGettigan (2013). Mind Bombs: Searching for Truth in the Great Debate Between Einstein and Bohr. *Studies in Sociology of Science*, *4*(3), 1-9. Available from: URL: http://www.cscanada.net/index.php/sss/article/view/j.sss.1923018420130403.2796
DOI: http://dx.doi.org/10.3968/j.sss.1923018420130403.2796

INTRODUCTION

For many, it might come as a surprise that Albert Einstein, a name that is synonymous with genius, formulated many of his greatest scientific breakthroughs while employed as a patent clerk (Isaacson, 2007). During his lifetime, Einstein became the world's most recognizable academic, but his fabled career got off to a rocky start. As an undergraduate, perhaps due to an unshakeable confidence in his own intellect, Einstein failed to display the type of deference that his professors expected from their students. As a result, keen as he was to embark on an academic career, none of Einstein's professors were willing to support his bid for graduate studies. Being denied his foremost career preference, Einstein was forced to pursue other options (Ohanian, 2008).

Following an extended job search, Einstein landed a position as a patent clerk. So bleak had his employment prospects become that Einstein received news of the clerkship with great enthusiasm. Though the Swiss patent office was less illustrious than his academic aspirations, Einstein found patent work to be a pleasant diversion. Also, Einstein's modest workload left the greater part of his mental energies untaxed. As a result, even while fulfilling his duties as a patent clerk, Einstein could embark on extended contemplations of the most puzzling issues in theoretical physics.

So it was that Einstein labored in anonymity until 1905, Einstein's annus mirabilis, or his miracle year (Kaku, 2004). With the publication of four major papers during 1905, Einstein revolutionized scientific conceptions of the physical universe. In the first miracle year paper, Einstein argued that rather than flowing in unbroken streams, light energy was split into minuscule packets, called quanta. In the next paper, Einstein argued that the inexplicable Brownian motion of dust motes in fluids was due to the impact of particles that were so minute (i.e., atoms) few scholars had been willing to believe such infinitesimals could exist. In his third miracle year paper, Einstein introduced his theory of special relativity: a theory postulating that space and time are relative. And in the fourth paper, Einstein revealed the scientific equation that has come to immortalize his stunning theoretical achievements, E=mc2. With this equation, Einstein established the fundamental equivalency of matter and energy and, what's more, he drew attention to the awesome and terrifying energy locked within atomic particles (Rhodes, 1986).

Though academic physicists might have been inclined to sneer, Einstein was fortunate that Max Planck was among the first readers of his revolutionary manuscripts. Max Planck, a renowned physicist and the Associate Editor of the Annalen der Physik, immediately recognized the genius in Einstein's theoretical inspirations. In part, because Einstein drew upon Planck's groundbreaking work in the realm of quantum physics, but also because of the sheer brilliance that Einstein exhibited in his articles, Planck dutifully published Einstein's submissions and, as a result, the physical universe has never looked the same since.

Prior to Einstein, Newtonian mechanics had dominated scientific conceptions of the physical universe (Hawking, 1988). In Newton's mechanical universe, time and space were fixed and believed to be measurable from an absolute perspective. In addition, until Einstein's miracle year, physicists had searched in vain for ether, the essential substrate of the cosmos. Ether was presumed to exist because, since light was understood to behave like a wave, Newtonian conceptions of matter and energy asserted that waves could only be propagated through a medium. Thus, for distant starlight to reach earth, space must be filled with ether. The problem was, try as they might, scientists were unable to locate the existence of ether. Though unthinkable, it almost seemed as if in the deep, dark void of space there was no ether.

In Einstein's universe, ether was not only non-existent, but it was unnecessary. Einstein dispensed with this key feature of the Newtonian universe by asserting that light exhibited properties of both waves and particles. In addition, Einstein repudiated Newton's conviction that time and space were fixed by envisioning an entirely new convergence of matter and energy. Einstein argued that, though the speed of light was always constant, space and time could be warped depending upon one's relative velocity. Consequently, all that had once been certain in Newton's mechanical universe had suddenly become relative. Einstein had literally redefined the fabric of reality.

1. PARADIGM CRISIS: FROM NEWTONIAN ABSOLUTISM TO EINSTEINIAN RELATIVISM

Just as many great thinkers had done before, Einstein encountered an inescapable dissonance between his observations of the empirical universe and established scientific theories—in this case, Newtonian mechanics. Faced with this dilemma, Einstein drew upon his exceptional creativity to construct new theories that would render previously inscrutable phenomena intelligible. So, like other great thinkers, Einstein stretched the theoretical boundaries of his discipline in order to bring scientific knowledge into closer accord with the parameters of the known universe. In so doing, one could argue that Einstein developed a more truthful lens through which to view the physical universe.

On the other hand, in sweeping aside Newton's mechanical universe, one could also argue that Einstein illustrated that science is a fundamentally relativistic endeavor (Ladyman, 2002). In other words, for over two hundred years, Newton's mechanical paradigm had represented The Truth about the physical universe. Yet, in the short span of his Miracle Year, Einstein undermined many of Newton's key presuppositions. After 1905, there was a new standard for determining truth in the cosmos. Newton was old news. Essential as such a paradigm shift may have been, nevertheless, the transition from Newton's to Einstein's ideas cast a troubling light on the role of truth in science. Essentially, one had to ask, was there anything especially truthful about scientific truths? In other words, if universal truths are only valid relative to particular scientific paradigms and, in turn, if paradigms are fleeting and disposable, then do scientific truths represent anything more than intellectual fads?

Perhaps the simplest definition of truth is "knowledge that unbiased, undistorted, or pristine" (McGettigan, 2006). Thus, truth can be understood as knowledge that describes an unvarying quality of the empirical universe. For example, Einstein's 1905 discourse on the photoelectric effect asserts that the most elemental unit of luminous energy is a particle-like quantum known as a photon. The importance of this or any other statement of truth is that, first of all, the statement reveals something useful, intelligible and demonstrable about the universe: light travels in, and can be measured in photons. Another crucial feature of scientific truth is that it must represent knowledge that remains valid across time and space. Whether on earth, Mars, or in the Andromeda galaxy, light must travel in quantum-sized photons. Therefore, regardless of the time or place, truth must be universal and unvarying.

Getting back to the transition from Newtonian mechanics to Einstein's relativity, one must wonder: if science is, first and foremost, an endeavor concerned with the pursuit of truth, then how can scientific paradigms be disposable? That is, many of the truths touted by Newtonian mechanics (e.g., time and space are fixed) are, according to the relativity paradigm, demonstrably false. Consequently, if the knowledge contained in any particular scientific paradigm is demonstrably false, then what guarantee is there that the truths touted by any paradigm, including Einstein's relativity perspective, are any more reliable? Indeed, critics of science have argued that, given the limitations of human cognition and the imperfections in the knowledge systems that we create, it is simply impossible for science to capture universal, unvarying truths (Denzin and Lincoln, 1994; Foucault, 1980). No matter how earnest scientists may be in their pursuit of truth, the limitations on the human ability to conceive and represent Ultimate Truth makes it impossible to generate knowledge that approximates what is really, finally, universally true. Indeed, critics of science have pointed to the common occurrence of paradigm shifts as an illustration of this problem: the most fundamental truths endorsed by one paradigm (e.g., time and space are fixed, or the void of space is filled with ether, or the earth is the center of the universe, etc.) are often viewed as examples of rustic ignorance by succeeding paradigms. As such, critics of science have argued that far from representing timeless, transcendent knowledge, any truths that science may proclaim are strictly relative to, and delimited by, the dominant paradigms of the day (Lemert, 1991).

2. REALISM, TRUTH, AND REDEFINED REALITIES

It is indisputable that the scientific truths of one era often tend to be the butt of jokes in the next. From the perspective of the 21st century, it seems laughable that anyone could ever have believed that the earth was flat (Garwood, 2008), or that it lay at the center of the universe. Yet, in spite of the relative impermanency of scientific truths, I argue that it is possible to identify at least a grain of truth in even in the most antiquated scientific paradigms. For example, the ancient Greeks believed that the universe was constituted of four basic elements: earth, air, fire and water (Bakalis, 2005). Of course, contemporary periodic tables illustrate that there are far more elemental substances than the ancient Greeks could ever have imagined. Nevertheless, were the Greeks completely deluded to think that there were only four basic elements? In fact, I would argue that the ancient Greek paradigm was relatively truthful in that each of the four elements manifested demonstrable properties of "creation," e.g., a mixture of water and earth brought forth life in farmers' fields, volcanic fire routinely created new land masses, and air was indisputably essential to sustain life. Certainly, in the 21st century, we know a great deal more about the elemental forces that shape the universe, but I think it is still fair to say that the Greeks were not delusional when they asserted that the universe was constituted of four basic elements. Rather, they were merely operating within a paradigm that was designed to make sense of the available evidence at the time.

That scientific paradigms are imperfect is not a matter of dispute. No matter how cherished, no matter how seemingly flawless, no matter how groundbreaking, the simple fact is that every scientific paradigm that humans have ever invented—or, I would hazard, that humans ever will invent—is flawed. This is the case, quite simply, because no matter how exacting scientific research may be, the human capacity to observe and conceptualize truths is limited. The universe is boundless and full of surprises, whereas the minds that seek to compass that selfsame infinitude are limited and flawed. Thus, scientific paradigms can never incorporate the "entire truth." There will always be more to know. If scientists do their work properly, scientific paradigms will always be short lived.

That said, I disagree with those who argue that science is an utterly relativistic endeavor. In contrast with Einstein's relativity paradigm, relativism is a perspective which asserts that all knowledge is equally (in) valid. Relativists assert that there is no such thing as truth (Seidman, 1991; Richardson, 1998; Clough, 1994). Such an assertion is patently false. First of all, it must be understood that there is a distinction between truth and its subsequent perception and representation by humans. Though solipsists would insist otherwise, it is important to acknowledge that there is a reality "out there" (Lyng and Franks, 2002; Popper, 1983). Just try to deny it the next time you bump your head on a tree branch. In brief, Karl Popper has noted that such intellectual discord is rooted in the fundamental dissonance between realist and idealist philosophy. Popper (1983) asserts that realist philosophers accept that empirical reality exists independently of the perceptions of individual observers. In other words, realists believe that there is a real world out there. By contrast, idealists argue that reality is only accessible via subjective perceptions. As a result, it is impossible to demonstrate that anything real, substantive or empirical exists outside an observer's subjective perceptions. In the most extreme version of such an idealist perspective, the universe is presumed to be nothing more than a figment of the imagination of individual observers (Clegg, 2009). Interestingly, Einstein's negative reaction to such a perspective in the field of physics led to one of the greatest scientific debates in the twentieth century.

3. QUANTUM ENTANGLEMENT

By building upon Max Planck's discoveries, Einstein pointed the way toward an entirely new intellectual frontier in the realm of sub-atomic physics. While Einstein devoted the bulk of his attention to developing his theory of general relativity, a generation of trailblazing young physicists surged into the bizarre landscape of quantum physics. Chief among this new breed of physicists was Niels Bohr, who established an institute at the University of Copenhagen that was entirely devoted to the advancement of quantum physics. As Bohr and his institute attracted many of the greatest physicists of his age, their collaborations ultimately produced what has come to be known as the Copenhagen interpretation of quantum mechanics. Once established, the Copenhagen interpretation became the dominant paradigm in the field of quantum physics, but as the details of this new theoretical perspective came to light they were greeted with deep skepticism by a towering figure in physics, none other than Albert Einstein.

Essentially, the Copenhagen interpretation endeavored to account for the puzzling duality, or what Bohr would later identify as the complementarity, of phenomena at the sub-atomic level. Again, Einstein was among the first to recognize such elemental dualities. For example, though it seemed to defy reason, Einstein postulated that light exhibited qualities of being both a wave and a particle. Up to the time of Einstein's astounding discovery, classical physicists were convinced that physical phenomena had well-defined, distinct and consistent properties. Thus, there had previously been a clear separation between matter and energy, electricity and magnetism, time and space, particles and waves, etc. However, many of Einstein's breakthroughs revealed that each of these phenomena, distinct as they may have seemed, were nevertheless, integrally related. Willing as Einstein may have been to acknowledge such mind-bending dualisms in his own work, he was nonetheless discomfited by the conclusions drawn by Bohr and his collaborators about quantum phenomena. Early on, the most objectionable elements of the Copenhagen interpretation for Einstein derived from Heisenberg's (1930) uncertainty principle.

Heisenberg argued that, from the perspective of classical physics (meaning physics before Einstein), every object in the universe was presumed to have a precise mass and momentum. These facts could easily be established through observation: mass and momentum could be specified by using straightforward measurement procedures. Furthermore, classical physics asserted that objects, such as billiard balls, would maintain their mass and momentum regardless of whether they were subject to direct observation or not. For example, if someone were to fire a cannon, though observers might not be able to examine the projectile in flight, it would still be possible to infer the cannon ball's trajectory by taking issues such as mass, acceleration and gravity into account. The final proof of the projectile's flight could be established by traveling to the impact site and recovering the cannon ball. Although Heisenberg was willing to concede that the above statements were generally true for conventionally observable phenomena, Heisenberg asserted that everything changed at the level of the quantum.

To begin with, quantum phenomena are not observable in the conventional sense. Although we can observe billiard balls with our eyes, quantum particles are so minute that they defy optical observation. Thus, the only way to observe quantum particles is to employ measurement techniques that interfere with the particles. As a result, Heisenberg argued that precise measures of a quantum particle's position tend to interfere with a particle's momentum, whereas measures of momentum tend to modify position. Though the idea initially made him squeamish, Heisenberg (1930) concluded that the exactitude of classical physics must yield to uncertainty in the quantum realm: it is impossible to determine both the precise momentum and position of quantum particles. In turn, as Bohr expanded upon Heisenberg's uncertainty principle, the Copenhagen interpretation opened a chasmic philosophical divide in the physics community.

At the 1927 Solvay Conference, Bohr unveiled his full-blown theory of quantum mechanics. Bohr introduced this radical new perspective by making the relatively banal assertion that the only way to establish a quantum object's characteristics (e.g., position vs. momentum, or wave vs. particle) was to make observations. However, according to Bohr's (1928) quantum postulate, in every case, the act of observation modified the dualistic characteristics of the quantum phenomenon in question. Put somewhat differently, Bohr argued that there was no clear separation between observers and the phenomena that they observed. As such, Bohr added that there was no longer any way to assert the unequivocal existence of objective reality, " . . . an independent reality in the ordinary physical sense can neither be ascribed to the phenomenon nor to the agencies of observation" (Bohr, 1928, p.54). Thus, Bohr asserted that studies which were designed to search for the wave-like features of quantum particles generally produced results which indicated that quantum particles were wave-like. The same was true for studies designed to focus on the particle-like qualities of quantum phenomena. As a result, Bohr reformulated Heisenberg's uncertainty principle to make the more outlandish assertion that it was the observation process itself that modified quantum phenomena. It was almost as if quantum particles somehow "knew" that observers were intent upon witnessing a particular type of quantum activity and then modified their behavior accordingly. As if that weren't enough, Bohr still had one more nail to hammer into the coffin of realism. Bohr's coup de grace was to argue that, because quantum states are dependent upon and vary in relation to observation, if a particle is not subject to observation then one should not assume that it has either position or momentum. Even more, Bohr's newly codified Copenhagen interpretation adopted the anti-classical position that, "An unobserved electron does not exist" (Kumar, 2008, p.262).

For Einstein, Bohr's final lurch into solipsism was too much to bear. Einstein was convinced that the physical universe was more objective, solid and precise than the Copenhagen interpretation proposed. Further, Einstein believed that the singular purpose of science was to unlock the secrets of the physical universe. Years later, Einstein affirmed this conviction in a letter to Max Born, "You believe in a God who plays dice, and I in complete law and order in a world which objectively exists" (Kumar, 2008, p.331). In short, Einstein was a realist and he insisted that an objective universe must exist independently of the cognition of individual observers. For example, even though Einstein had not witnessed the eclipse that Arthur Eddington used to test his theory of relativity, Einstein was convinced that the eclipse had actually taken place: the eclipse was a real phenomenon in an objective universe that was governed by universal physical laws. From Einstein's perspective, even though quantum particles might be substantially smaller than the earth, sun, and moon, nevertheless, quantum particles were every bit as real as larger physical objects. Therefore, if the earth, sun and moon had identifiable properties of position and momentum, then the same also had to be true of quantum phenomena. Consequently, Einstein was convinced that, if Bohr and his collaborators were not able to determine both the position and momentum of quantum particles, then quantum mechanics could not be a complete theory. Further, when objectively-minded physicists decided to develop a complete theory of quantum mechanics, Einstein insisted, all that was fuzzy in the empirical universe would become crystal clear.

For their part, Bohr, Heisenberg and other supporters of the Copenhagen interpretation argued that quantum mechanics was a complete theory. In other words, due to the essential dualisms that were intrinsic to quantum reality, supporters of the Copenhagen interpretation argued that quantum mechanics offered as final and thorough a statement on the quantum realm as it was possible to articulate. Unsatisfied with that response, Einstein drew upon his vast intellect to design one fiendishly clever thought experiment after another. Each of the thought experiments was intended to emphasize the incompleteness of the Copenhagen interpretation. Einstein was convinced that a more complete theory would surely re-introduce sanity into the conceptual morass that was quantum physics.

In spite of Einstein's insistence upon a realistic interpretation of quantum mechanics, his primary antagonist, Neils Bohr, successfully deflected each of Einstein's conceptual assaults on the Copenhagen interpretation. Strangely, the more insistently that Einstein defended his realistic principles, the more Einstein came to be viewed as a stodgy old has-been. After settling in at Princeton University, Einstein confided to Max Born that, among his new colleagues, he was "considered an old fool" (Born, 2005, p.128)

4. THE THOUGHT EXPERIMENT FROM HELL

Still, Einstein stuck to his guns. Making one last titanic effort, and working with two collaborators, Einstein designed a thought experiment that even Bohr was never able to fully debunk (Einstein, Podolsky and Rosen, 1935). As noted above, Einstein objected to the quantum-mechanical notion that, in the absence of measurement, particles had neither position nor momentum. Thus, in his EPR collaboration, Einstein set out to demonstrate that it was possible to determine, whether subject to observation or not, particles possessed real physical properties, such as position and momentum. Importantly, the EPR argument accepted the quantum-mechanical contention that it was not possible to specify position and momentum simultaneously. Instead, the EPR argument simply endeavored to affirm that position and momentum were real properties of real particles in an objective reality. If the EPR paper could establish that particles were imbued with real, identifiable properties for which quantum-mechanics could not account, then Einstein would finally be able to prove that quantum-mechanics was an incomplete theory.

Thus, the EPR thought experiment involved two particles, or systems that interacted for a period of time and then flew off in different directions. Once the particles were separated, it would arguably be possible to obtain precise measures of particle I without interfering with particle II. Einstein insisted that this was the case because of a phenomenon that he referred to as locality. In other words, Einstein believed that for particles to interact, they needed to be in the same vicinity. According to Einstein's concept of locality, once particles have separated, they no longer have any direct influence upon each other: after separation, modifications to the position or momentum of particle I would have no influence on particle II. To suggest that separated particles might continue to interact would imply that particles were somehow endowed with the "spooky" ability to communicate instantaneously over great distances. Not only would such bizarre interaction defy common sense, but it would also require faster than light communication, which would violate Einstein's theory of relativity. Ergo, EPR concluded that instantaneous action-at-a-distance was not a reasonable feature of reality.

Proceeding from Einstein's assumptions about locality, after particles I and II have become separated, any measurement of particle I would presumably have zero impact on particle II. Therefore, EPR asserted that, equipped with knowledge about the original particle interaction, it would be possible to measure particle I's position and then make precise inferences regarding particle II's position. The same would also be true for measures of momentum. Certainly, EPR conceded, it would not be possible to make precise simultaneous measurements of particle I's position and momentum. Nevertheless, EPR asserted that, because quantum mechanics asserted that it was possible to establish either the precise position or momentum of particle I, then it must also be possible to establish that particle II possessed those same attributes. As a result, EPR drew the conclusion that, even though particle II was unobserved (and therefore undisturbed), its position, momentum and its very existence were confirmed elements of objective reality. Since quantum mechanics denied that unobserved particles existed in an objective reality, and therefore could not account for such phenomena, EPR concluded that quantum mechanics was an incomplete theory.

Upon publication of the EPR paper, Einstein once again succeeded in sending shock waves throughout the physics community. Although Einstein was perceived by many physicists as a tiresome curmudgeon (Folsing, 1997, p.699), Bohr approached Einstein's EPR critique as a mind-bending but essential test of quantum mechanics. In the end, Bohr replied to Einstein in much the same way that Hamlet addressed his naive compadre, Horatio: "There are more things in heaven and earth, Horatio, Than are dreamt of in your philosophy." While Bohr was willing to concede that spatially-distant particles might not be able to disturb each other mechanically, nevertheless, Bohr insisted that the process of observing the position or momentum of one particle had what he referred to as an "influence on the very conditions which define the possible types of predictions regarding the further behavior of the system" (Bohr, 1935, p.700, italics in original). That is, Bohr believed that particles, such as those Einstein described in his EPR thought experiment, that interacted at one point in time would remain entangled in a single system, and, thus, would exert a mysterious but nonetheless instantaneous influence on each other even when the particles became distantly separated. Again, Bohr linked this type of quantum entanglement to observation; arguing, that humans modify reality—often in the most puzzling and unexpected ways—in the process of observing reality. Thus, Bohr rejected the EPR argument on the basis of his quantum postulate: for humans, reality does not exist until we find a way to observe it, and in the process of observing reality, humans invariably modify it.

To say the least, Einstein was not impressed. He and Bohr were clearly at an impasse. More than once, Einstein spoke disparagingly of Bohr's suggestion that separated particles could somehow influence each other, referring to such quantum entanglement as "spooky action at a distance" (Born, 2005). For Einstein, the universe was neither the product of individual imaginations, nor was it subject to change based upon the vagaries of human perception. In short, God did not play dice with Einstein's universe. Einstein was convinced that a right-minded God would only create a universe that was logically consistent from the behavior of the smallest sub-atomic particles to the largest supra-galactic phenomena. What's more, God's version of the universe should ring true with Einstein's expectations of reality, or else, Einstein was convinced, there was something wrong with reality!

For his part, Bohr was swayed by the troubling, but nonetheless, compelling complementarity of quantum phenomena. There seemed to be no way around it: at the quantum level, the universe was a wacky place. Interestingly, as much as Einstein insisted that his was a more reasonable, and scientifically orthodox definition of the universe, the facts (strange as they were) tended to affirm Bohr's version of quantum mechanics. Again and again, experimental results have supported the Copenhagen interpretation of quantum mechanics. Yet, although Einstein grudgingly acknowledged that quantum mechanics was the best available theory to explain sub-atomic physical phenomena (Einstein, 1950), he remained insistent that it was an incomplete theory. Einstein and Bohr remained conceptually and collegially at loggerheads until their final days: Einstein whiled away his final years contemplating an elusive unified field theory, while Bohr literally drew his last breath while wrestling with one of Einstein's more nettlesome thought experiments (Kumar, 2008, p.327).

5. COMPLEMENTARY REALITIES

So, the question remains: Which of these two titans of modern science was correct? Certainly, their ideas regarding quantum reality were contradictory and mutually exclusive. Consequently, in a rational universe, one would expect that one of the two, either Bohr or Einstein, would have to be correct, while the other was demonstrably wrong. However, in the finest tradition of quantum complementarity, I believe that, precisely because of their irreconcilable differences, Bohr and Einstein were each both right and wrong.

Just as quantum particles exhibit dualistic and yet complementary characteristics, I believe the same is also true for the theories that describe quantum reality. Though Einstein and his supporters may have been loath to admit it, Bohr's version of quantum mechanics has been supported again and again by scientific observation. Irrational as it may seem, quantum particles consistently exhibit spooky action at a distance (Clegg, 2006; Kumar, 2008, p.350). Precisely why such a phenomenon should exist remains a mystery, but the accumulated evidence of repeated observations is difficult to deny. The act of observation seems to influence the phenomena that are the subject of observation. While such an idea has troubling implications for those who believe in an independent, objective reality, Bohr's quantum postulate does expose a fundamental truism about science. Knowledge and facts are intellectual constructs: we know only those things that our minds are capable of perceiving. What humans experience as reality is essentially a figment of the imagination. Thus, reality may exist out there, but, then again, it may not. However unlikely, there is no way to prove that reality is anything more than that which the mind perceives. That being the case, it stands to reason that, at least on some level, phenomena must always be influenced by the processes of observation. This is as true for quantum particles as it is for human social behavior (Landsberger, 1958). Observation influences reality.

True as that may be, it is still easy to appreciate Einstein's antipathy for quantum mechanics. The idea that, on any level, objective reality might not exist independently of observation, or that reality might be subject to modification at the whim of observers is dissatisfying. Can observers truly exercise so much power over the constitution of reality? The idea seems to defy common sense. Rather than transforming to comply with observers' hopes and expectations, reality tends to yield only grudgingly in the face of individual initiative. For example, try as I might, I have never been able to melt the frost off of my windshield by dreaming of balmier weather. Thus, there is abundant evidence to support faith in an observer-independent reality: just because I take my eyes off of the sun does not mean that it will cease to exist. Whether our name happens to be Horatio or not, humans regularly encounter new phenomena that do not fit within our current philosophy. Thus, as Einstein argued, it is the task of science to explain the endless peculiarities of an objective universe over which humans have only limited understanding and control. Science is a knowledge-seeking enterprise that is forever in a process of reinventing itself. Thus, Einstein was actually less troubled by the bizarre behavior of quantum particles than he was by Bohr and Heisenberg's suggestion that quantum mechanics was a complete theory.

To suggest that quantum mechanics is a complete theory is to conclude that science has arrived at the final, ultimate truth about quantum reality. Again, due to the uncertainty associated with quantum phenomena, Bohr and Heisenberg believed that it would never be possible to develop more precise knowledge about the quantum realm than the Copenhagen interpretation would allow. Einstein objected to this conclusion largely because the theory of quantum mechanics itself acknowledges that it can provide at best an imperfect description of quantum phenomena. Thus, Einstein was willing to concede that quantum mechanics might be the best available theory to describe quantum phenomena, but he felt certain that, due to its inherent limitations, quantum mechanics offered by no means the final word on quantum reality. If quantum mechanics offered an imperfect description of quantum reality, then Einstein believed that scientists bore the responsibility of developing better theories. Though he became an object of ridicule in the physics community—indeed, Clauser reported that colleagues regularly assured him that Einstein's objections to quantum mechanics were evidence that he had gone senile (Bertlmann and Zeilinger, 2002, p.72)—Einstein remained adamant that scientific journeys did not end with mysteries, rather, he insisted that's where they should begin.

Although I am not a physicist, I support Einstein's principled objection to the idea that quantum mechanics is a complete theory. However, my objection does not derive from any specific objection to quantum mechanics, rather I object on the grounds that any theory that has been constructed by imperfect intellects must, by its very nature, be imperfect—or, in the language of the EPR debate, incomplete. By this, I do not mean to suggest that science is an utterly futile endeavor, i.e., since humans cannot generate perfect or truthful knowledge, then there is no point in even attempting to do so. Far from it, I agree with Karl Popper who argued that knowledge acquisition is a never-ending process. Whatever we know now, regardless of the field of endeavor, is less than we can eventually learn and, therefore, represents less than we ought to know. As science advances, humans benefit in myriad and often unexpected ways. Science is at its best when its practitioners assume that all existing knowledge is incomplete. Thus, by doubting the completeness of quantum mechanics, Einstein was neither deluded nor senile, he was simply being a good scientist. Nonetheless, all too often, knowledge-seekers who challenge beliefs that other scientists hold sacred tend to encounter violent opposition rather than collegial encouragement.

Any truth-seeking endeavor will cease and fail at the very moment that knowledge-seekers decide that they have arrived at final, ultimate truths. This is the case because, first of all, it is simply impossible for imperfect minds to compass universal, ultimate truths. This point is particularly well-illustrated by the fact that earthlings currently enjoy only an imperfect understanding of a minuscule fraction of the universe (Clegg, 2009; Overbye, 2006). Perhaps even more problematic: those who assume that they have captured final, ultimate truths often intentionally close their minds to further inquiry (Popper, 1957). Thus, not only do true-believers invest faith in knowledge that represents anything but the Ultimate Truth, but they also refuse to entertain ideas that might challenge their preferred assumptions. Nothing could be more antithetical to the goals of good science.

Like all creatures, for humans to survive, they must adapt. However, human adaptation is tied to pursuing problematics that tend to modify the very nature of truth and reality. Bohr was right: observers redefine reality—and often in ways that they might neither choose, nor prefer. As Einstein discovered, new truths can often be traumatizing, however, the greatest scientists pursue the truth no matter where it leads, and no matter what the implications might be for their cherished beliefs or scholarly reputations. As Popper argued so persuasively, solutions are naught but the gateways to new problems (Popper, 1965, 1999). Those who are convinced that existing knowledge is far from perfect will always be the wisest of us all.

6. (R)EVOLUTIONARY TRUTH

Of necessity, truth must remain an evolving target. As the boundaries of the known universe expand, the paradigms that extend scientific frontiers must keep pace. Humbling though it may be, the surest route to scientific progress is to assume that the existing state of knowledge is lamentable. Whether we like it or not, the grandest truths that we cling to today will eventually seem as quaint as the once firmly held conviction that earth was flat. Indeed, the mere suggestion that any scientific discipline may be nearing an "ultimate theory" (Greene, 1999) is exceedingly curious. No scientific discipline can brag of greater accomplishments than those achieved by physicists. Nevertheless, given that physicists currently acknowledge the universe is permeated by vast quantities of inscrutable "dark" substances (Panek, 2011), I believe it is premature (to say the least) to assert that ultimate theories lie just around the corner. In fact, rather that being on the verge of an ultimate theory, I would assert that such fragmentary conceptualizations of dark matter and energy auger an impending paradigm shift of epic proportions. When such a paradigm shift inevitably takes place, those who have predicted "the end is near" will be wearing egg on their faces, however, everyone else will benefit from science having taken, yet again, one small (but tantalizing) step toward compassing the universe's far-flung mysteries.

Without doubt, the greatest threat to science is the presumption that any particular paradigm might somehow encapsulate the final, ultimate Truth. In every case where humans have claimed ownership of final truths, agency has been forced to cower in the face of bloody-minded ideology (Barnett, 2006; Bergin, 2006). If scientists are ever unwary enough to presume that their intellectual journey has arrived at its final destination, then in that very moment science, the quest for knowledge and intellectual integrity itself will suffer extinction.

The life of science is necessarily dependent upon an enduring commitment to intellectual evolution. That being the case, scientists can only preserve their enterprise by maintaining a steadfast commitment to agency. In other words, scientists must always maintain a stronger commitment to their own doubts than the "certainties" paradigms tout; scientists must stubbornly seek anomalies that, ultimately, are certain to undermine the cherished paradigmatic beliefs upon which their careers have been founded. This is essential not purely for the purposes of tearing down scientific aspirations--as postmodernists were wont to do. Rather, the goal of accumulating anomalies is to force confrontations between established paradigms and the Truths that transcend those paradigms. Science is at its best when it remains singularly committed to the goal of evolving paradigms and, in so doing, focusing scientists' unwavering aspirations on the Truths that extend perpetually beyond their wildest imaginations.

REFERENCES

Bakalis, N. (2005). *Handbook of Greek philosophy: From thales to the stoics*. Victoria, B.C.: Trafford.

Barnett, V. (2006). Understanding stalinism: The "Orwellian Discrepancy" and the "Rational Choice Dictator". *Europe-Asia Studies*, May.

Bergin, M. (2006). Junk science. *World Magazine*, *21*(8).

Bertlmann, R. A., & Zeilinger, A. (Eds.). (2002).*Quantum [Un] speakables: From bell to quantum information*. Berlin: Springer.

Bohr, N. (1928). The quantum postulate and the recent development of atomic theory. In *The philosophical writings of Niels Bohr: Volume 1—Atomic theory and the description of nature*. Woodbridge, CT: Ox Bow Press.

Born, M. (2005).*The born—Einstein letters 1916-1955: Friendship, politics and physics in uncertain times*. New York: Macmillan.

Clegg, B. (2006). *The God effect: Quantum entanglement, science's strangest phenomenon*. New York: MacMillan.

Clegg, B. (2009). *Before the Big Bang: The prehistory of our universe*. New York: St. Martin's Press.

Clough, P. T. (1994). *Feminist thought: Desire, power and academic discourse*. Cambridge, MA: Blackwell.

Denzin, N. K., &Yvonna, S. L. (1994). *Handbook of qualitative research*. Thousand Oaks: Sage Publications.

Einstein, A. (1950). *Out of my later years*. New York: Philosophical Library.

Einstein, A., Podolsky, B., & Rosen, N. (1935). Can quantum-mechanical description of physical reality be considered complete? *Physical Review*, *47*, 777-780.

Folsing, A. (1997). *Albert Einstein: A biography*. London: Viking.

Foucault, M. (1980). *Power/Knowledge: Selected interviews and other writings 1972-1977*. C. Gordon (Ed.). New York: Pantheon Books.

Garwood, C. (2008). *Flat earth: The history of an infamous idea*. New York: Thomas Dunne Books.

Greene, B. (1999). *The elegant universe: Superstrings, hidden dimensions, and the quest for the ultimate theory*. New York: W. W. Norton.

Hawking, S. W. (1988). *A brief history of time: From the Big Bang to Black Holes*. New York: Bantam Books.

Heisenberg, W. (1930). *The physical principles of the quantum theory*.C. Eckart & F. C. Hoyt. (Trans.). Chicago: University of Chicago Press.

Isaacson, W. (2007). *Einstein: His life and universe*. New York: Simon & Schuster.

Kaku, M. (2004). *Einstein's cosmos: How Albert Einstein's vision transformed our understanding of space and time*. New York: W. W. Norton.

Kumar, M. (2008). *Quantum: Einstein, Bohr, and the great debate about the nature of reality*. New York: W.W. Norton.

Ladyman, J. (2002). *Understanding philosophy of science*. New York: Routledge.

Landsberger, H. A. (1958). *Hawthorne revisited: Management and the worker: Its critics, and developments in human relations in industry*. Ithaca, NY: Cornell University Press.

Lemert, C. (Fall, 1991). The end of ideology, really. *Sociological Theory, 9*(2), 164-172.

Lyng, S., & David, D. (2002). Franks.*Sociology and the Real World*. Lanham, Maryland: Rowman and Littlefield.

McGettigan, T. (2006). Redefining reality: A resolution to theoretical paradox in the field of sociology. *Electronic Journal of Sociology*, *Tier One*. Retrieved from www.sociology.org/content/2006/tier1/mcGettigan_RedefiningReality.pdf

Ohanian, H. C. (2008). *Einstein's mistakes: The human failings of genius*. New York: W.W. Norton & Company.

Overbye, D. (2006, October 24). Knowing the universe in detail (Except for That Pesky 96 Percent of It). *New York Times*. Retrieved from www.nytimes.com/2006/10/24/science/-space/24essa.html

Panek, R. (2011). *The 4% universe: Dark matter, dark energy, and the race to discover the rest of reality*. Richmond: Oneworld.

Popper, K. (1957). *The poverty of historicism*. New York: Harper Torchbooks.

Popper, K. (1965). *Conjectures and refutations: The growth of scientific knowledge*. New York: Basic Books.

Popper, K. (1983). *Realism and the aim of science*. Totowa, New Jersey: Rowman and Littlefield.

Popper, K. (1999). *All life is problem solving*. (Trans. by P. Camiller.). New York: Routledge.

Rhodes, R. (1986). *The making of the atomic bomb*. New York: Simon & Schuster.

Richardson, L. (Fall, 1991). Postmodern social theory: Representational practices. *Sociological theory, 9*(2), 173-179.

Seidman, S. (Fall, 1991). The end of sociological theory: The postmodern hope. *Sociological Theory, 9*(2), 131-146.