"A KIND OF VESSEL IN WHICH THE STRUGGLE FOR ETERNAL TRUTH IS PLAYED OUT": Albert Einstein and the Role of Personality in Science

Don Howard
Department of Philosophy
University of Kentucky

Introduction

Start with indisputable truths. Albert Einstein was a genius, probably the greatest scientific genius of the twentieth century; and the history of twentieth-century physics would have been quite different without him. But while indisputable, these are not very interesting truths. More interesting, to me at least, is the specific nature of Einstein's genius and the specific difference he made in the history of science in our century. I am also interested in the reasons why our culture needs to manufacture the genius as icon and in the consequences of our public celebration of genius, especially the pedagogical consequences.

Regarding Einstein's place in the history of twentieth-century physics, I will argue that, had there not been an Einstein, the fine-structure of twentieth-century physics would have been quite different, but that the macro-structure would have been largely the same. However, the reasons for this will have rather less to do with the power of truth to triumph over error, and rather more to do with the way young scientists are educated, socialized, and enculturated. Concerning the nature of Einstein's genius, I will argue that what made Einstein the genius he was, apart from an obvious intellectual capacity, unusual powers of concentration, and some quirky personal habits, was a certain way of doing physics distinguished by its methodological and philosophical sophistication, this in important measure the result of his training and independent reading in the history and philosophy of science.

In answer to the question why our culture needs to construct the genius as icon, I will argue that we confront here a mixture of estimable and questionable psychological and ideological factors, ranging from a com-

In J.H. Langdon and M.E. McGann, eds., *The Natural History of Paradigms*.
Indianapolis: University of Indianapolis Press. Pp. 111-137.

mendable desire to inspire the young to emulate their heroes, to a more troubling tendency in our culture to valorize an authoritarian and anti-democratic conception of intellect. Finally, concerning the pedagogical consequences of our celebration of genius, I will argue that it makes not more, but less likely the production of new young Einsteins, because it removes an Einstein from the realm of the merely human and thus from the realm of what we can aspire to for ourselves and our students.

The Einstein who emerges from this discussion will probably not resemble much the Einstein whose heroic, larger-than-life image we all carry around with us. My aim is not to belittle Einstein and his achievements. Rather, I want to try to humanize Einstein and his accomplishments, both as a gesture of respect to his memory and as something necessary for our learning the real lessons of his legacy.

The Place of Genius in History

Einstein *was* a genius, and the history of twentieth-century physics would have been quite different without him. Born in 1879, he came of age at the turn of the century, a moment when the grand structure of classical Newtonian mechanics and Maxwellian electrodynamics was about to fall apart. By 1905, a bare five years after completing his university studies, at the young age of twenty-six, he had secured for himself a place in history as the discoverer of the special theory of relativity and one of the architects of the quantum theory, the two basic theories that, to this day, define the framework of fundamental physics. Ten years later, in 1915, he capped off these earlier achievements with the establishment of the general theory of relativity. Black holes, worm holes, dark matter, and the big bang; the atomic bomb, atomic power, superconductors, and supercomputers—all trace their genealogies back to Einstein in one way or another. No thinker in the thirty-eight years since his death has displayed the range and originality of Einstein; no one can claim to have shaped our understanding of nature to such an extent as he. But what is this genius? And how did it change the world?[1]

How better to start our inquiry into the nature of genius and its place in history than with Einstein's own thoughts on these subjects? And where else to look than to his remarks about perhaps his own greatest scientific hero, Isaac Newton, the seventeenth-century English thinker who established the formal basis of mechanics and the fundamental conceptions of space and time that reigned for over two hundred years, until being overthrown by relativity theory. In March of 1927, on the two hundredth anniversary of Newton's death, Einstein wrote in the German scientific periodical, *Die Naturwissenschaften:*

> We feel impelled at such a moment to remember this brilliant genius, who determined the course of western thought, research, and practice like no one else before or since. . . . The figure of Newton has, however, an even greater importance than his genius warrants because destiny placed him at a turning point in the history of the human intellect (Einstein 1927: 253-254).

And on the three hundredth anniversary of Newton's birth, in December 1942, Einstein wrote about Newton in the *Manchester Guardian:*

> To think of him is to think of his work. For such a man can be understood only by thinking of him as a kind of vessel in which the struggle for eternal truth is played out. Long before Newton there had been virile minds who conceived that it ought to be possible, by purely logical deduction from simple physical hypotheses, to make cogent explanations of phenomena perceptible to the senses. But Newton was the first to succeed in finding a clearly formulated basis from which he could deduce a wide field of phenomena by means of mathematical thinking, logically, quantitatively and in harmony with experience. . . . How did this miracle come to birth in his brain? Forgive me, reader, the illogical question. For if by reason we could deal with the problem of the "how," then there could be no question of a miracle in the proper sense of the word. It is the goal of every activity of the intellect to convert a "miracle" into something which it has grasped. If in this case the miracle can be overcome, our admiration for the mind of Newton becomes only the greater thereby (Einstein 1942: 219-220; translation corrected).

Einstein's Newton is "a kind of vessel in which the struggle for eternal truth is played out"; he is important beyond what his mere genius warrants, "because destiny placed him at a turning point in the history of the human intellect."

There is a curious tension between such remarks and what Einstein elsewhere says about the nature of the scientific intellect. For Einstein is famous for insisting that all scientific theory is the "free creation of the human mind" (see, for example, Einstein 1921: 234). The exercise of the creative imagination is what distinguishes the theoretical physicist (a type of thinker that was first being invented by Einstein and his contemporaries) from the experimentalist. The need to secure a place for freely-created theory was what led Einstein to repudiate the stringent verificationist demands of logical positivism (Howard 1994). But how is one to reconcile the *active* image of the freely-creating scientific intellect with the more modest, *passive* image of a Newton who is merely "a vessel in which the struggle for eternal truth is played out?"

To begin with, what are the scope and limits of the theoretician's creative freedom? Sometime around 1909, Einstein read one of the most important and influential works of turn-of the-century philosophy of science, Pierre Duhem's *La Théorie physique. Son objet et sa structure [The Aim and Structure of Physical Theory]* (Duhem 1906, 1908). Duhem is famous for defending a point of view about the nature of scientific theory called *underdeterminationism*, the main idea of which is that any body of empirical evidence can be equally well explained by any of a number of theories, which, for that very reason, count as *empirically equivalent.* One's choice among these empirically *underdetermined* theories may be guided, in the absence of determining empirical evidence, by aesthetic criteria, like simplicity; but that choice still has the logical status of a *convention.*

Let me illustrate with an example invented by another influential conventionalist philosopher of science, Henri Poincaré, and published in his *La Science et l'hypothèse [Science and Hypothesis]* (Poincaré 1902b), which was also read by the young Einstein. Assume that we try to determine the geometry of physical space by means of a cosmic triangulation and find that the sum of the angles of a triangle formed by a diameter of the earth's orbit and a distant star is slightly greater than 180°. Do we then have determining empirical evidence for the claim that the geometry of physical space is non-Euclidean? No. That could be the case, but it also could be that we were wrong when we assumed, implicitly, that the light rays we use in such a triangulation follow straight-line paths. In other words, we could equally well explain the results of our observations by at least two different total bodies of theory: (1) non-Euclidean geometry plus ordinary physical optics (straight-line trajectories of light rays); or (2) euclidean geometry plus non-standard physical optics (curved trajectories of light rays). The latter option will require the postulation of new, very complicated forces to explain the bending of the light rays, and so will be more complicated that the first "theory." But, from a purely empirical point of view, the two "theories" are equivalent, and so the choice between them is not dictated by experience. Our choice therefore has the status of a convention.[2]

Einstein was heavily influenced by his reading of Duhem, underdeterminationism becoming a central feature of his mature philosophy of science. Einstein followed Duhem in using underdetermination as a powerful argument against the emergent logical positivism that we often associate, in its early stages, with the name of Ernst Mach. Like Duhem, Einstein worried about the characteristic positivist demand for the empirical

verification not merely of whole theories—something Einstein and Duhem, as good empiricists did not deny—but of each individual statement in a theory. Their worry was that this demand for piecemeal empirical verification was too much an experimentalist's philosophy of science, that it would restrict the progress of science by denying the creative theorist the freedom to invent new ways of seeing the world. If one settles, instead, for the empirical confirmation of whole bodies of theory—hence the other common name for Duhem's position, *holism*—then there may be room in one's theory for some pieces that are, themselves, only indirectly tied to experience. And this is important, because, in Einstein's mind, it was at the level of deep theory, only indirectly tied to experience, where one finds those fundamental insights that yield the unified understanding of nature that is the goal of all physics.[3]

Einstein actually once drew a picture of this conception of theory (Figure 1). It is found in a letter to his old friend, Maurice Solovine of 7 May 1952 (Einstein 1987: 134-139). The system of axioms, *A*, is tied to experience only indirectly, through the derived statements, *S*; and even these are connected to experience only "intuitively," as Einstein tells us elsewhere (Einstein 1936: 316). It is at the level of the *A* that one will find the unified understanding provided by a general theory of relativity, a quantum theory, or a grand-unified theory.

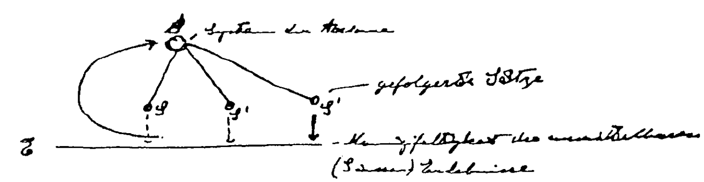

Fig. 1.

In this letter, and in many other writings, Einstein expressed the basic Duhemian point about the failure of empirical evidence or experience, *E,* to determine uniquely our choice of a body of theory, the *A* in this case, by writing: "There is no logical route leading from the *E*'s to the *A*'s, but only an intuitive connection" (Einstein 1987: 136). Einstein insisted on the absence of a logical connection, because it is precisely here that the theorist's creative imagination is needed. One requires the insight, the genius of the theorist, if you will, to make the leap from observation to deep theory.

But to return to our puzzle, how can it be that a freely-creating scientific genius is merely a "vessel in which the struggle for eternal truth is played out?" In some of the essays where Einstein talked about the absence of any determining, logical relationship between experience and theory, he added an interesting qualification. He said that, "in principle," there is no such determining logical relationship, but that, "in practice," it almost always *appears* as though there is. Thus, in a 1918 address in honor of the sixtieth birthday of Max Planck, another of Einstein's heroes as a pioneer theoretical physicist, Einstein wrote:

> The supreme task of the physicist is . . . the search for those most general, elementary laws from which the world picture is to be obtained through pure deduction. No logical path leads to these elementary laws; it is instead just the intuition that rests on an empathic understanding of experience. In this state of methodological uncertainty one can think that arbitrarily many, in themselves equally justified systems of theoretical principles were possible; and this opinion is, *in principle*, certainly correct. But the development of physics has shown that of all the conceivable theoretical constructions a single one has, at any given time, proved itself unconditionally superior to all the others. No one who has really gone deeply into the subject will deny that, in practice, the world of perceptions determines the theoretical system unambiguously, even though no logical path leads from the perceptions to the basic principles of the theory (Einstein 1918: 31).

So the freely-creating theorist is, in principle, not logically constrained by experience in the construction of deep theory. Yet, in practice, there is the appearance of such constraint. How can this be?

In another place, Einstein provides us a clue. We find it in a 21 May 1917 letter to Moritz Schlick. The immediate subject was a criticism of Mach's positivism in Schlick's monograph, *Raum und Zeit in die gegenwärtigen Physik [Space and Time in Contemporary Physics]* (Schlick 1917). Einstein largely agreed with Schlick, but he suggested a clarification:

> The second point to which I want to refer concerns the reality concept. Your view stands opposed to Mach's according to the following schema:
>
> Mach: Only impressions are real.

> Schlick: Impressions and events (of a phys[ical] nature) are real.
>
> Now it appears to me that the word "real" is taken in different senses, according to whether impressions or events, that is to say, states of affairs in the physical sense, are spoken of.
>
> If two different peoples pursue physics independently of one another, they will create systems that certainly agree as regards the impressions ("elements" in Mach's sense). The mental constructions that the two devise for connecting these "elements" can be vastly different. And the two constructions need not agree as regards the "events"; for these surely belong to the conceptual constructions. Certainly only the "elements," but not the "events," are real in the sense of being "given unavoidably in experience."
>
> But if we designate as "real" that which we arrange in the space-time-schema, as you have done in the theory of knowledge, then without doubt the "events," above all, are real.
>
> Now what we designate as "real" in physics is, no doubt, the "spatio-temporally-arranged," not the "immediately-given." The immediately-given can be illusion, the spatio-temporally arranged can be a sterile concept that does not contribute to illuminating the connections between the immediately-given. *I would like to recommend a clean conceptual distinction here* (EA 21-618).

Note that the "events" spoken of here are spacetime events, the points of the spacetime manifold, hence the most basic elements of the ontology of general relativity. Note also—as if it needed mention—that the Schlick of 1917 was a very different Schlick from the one who, a few years later, founded the Vienna Circle.

Two different peoples can devise "vastly different" mental constructions—different theories—for connecting the Machian "elements of sensation." But under what circumstances? If they "pursue physics independently of one another." Einstein's anthropological image suggests a situation in which there is no history of cultural contact between the "two peoples." What else could be meant by their having pursued physics "independently of one another"? What is missing is a shared culture. Its absence makes possible their creating different theories. But if there were a shared culture, if they had not pursued physics independently of one another, what would follow? The likelihood that they would not devise "vastly different" theories.

In other words, Einstein seems to be saying that what brings about the appearance, in practice, of experience uniquely determining our choice of theory is precisely our participation in a common scientific culture. And this makes good sense. We may be free, logically, to devise all manner of radically different theoretical representations compatible with a given body of empirical evidence. But if we come from the same schools, read the same journals, have our grant proposals refereed by the same colleagues, and idolize the same scientific heroes, then it is not unlikely that we will bring to the task of theory creation more or less the same set of stock images, models, metaphors, and heuristics. This is just Kuhn's point about the power of paradigms in the socialization of the scientist.

Duhem made the same point in *La Théorie physique,* albeit in a more "florid" manner:

> Contemplation of a set of experimental laws does not, therefore, suffice to suggest to the physicist what hypotheses he should choose in order to give a theoretical representation of these laws; it is also necessary that the thoughts habitual with those among whom he lives and the tendencies impressed on his own mind by his previous studies come and guide him, and restrict the excessively great latitude left to his choice by the rules of logic. . . . On the other hand, when the processes of universal science have prepared minds sufficiently to receive a theory, it arises in a nearly inevitable manner and, very often, physicists not knowing each other and pursuing their reflections at a great distance from each other generate the theory at the same time. One would say that the idea is in the air, carried from one country to another by a gust of wind, and is ready to fertilize any genius who is disposed to welcome it and develop it, as with pollen giving birth to a fruit wherever it meets a ripe calyx. . . . Logic leaves the physicist who would like to make a choice of a hypothesis with a freedom that is almost absolute; but this absence of any guide or rule cannot embarrass him, for, in fact, the physicist does not choose the hypothesis on which he will base a theory; he does not choose it any more than a flower chooses the grain of pollen which will fertilize it; the flower contents itself with keeping its corolla wide open to the breeze or to the insect carrying the generative dust of the fruit; in like manner, the physicist is limited to opening his thought through attention and reflection to the idea which is to take seed in him without him (Duhem 1906: 255-256).

Here is the solution to our puzzle then. To the extent that the scientist is part of a common scientific culture, even the genius is little more than a passive "vessel in which the struggle for eternal truth is played out," a flower waiting for the pollen. And we are all, even an Einstein, part of a common culture. The measure of our freedom, practically speaking, is the measure of our independence from that culture; but this independence can never be complete.

Something more is suggested by the image of the "vessel," or even better by the Duhemian image of the flower. It is that, come what may, a vessel or a flower will be found; if not Newton, if not Einstein, then someone else. In no way is the originality of an Einstein diminished by this suggestion. As we shall see, there were good reasons for Einstein being the flower upon which was deposited the pollen of relativity. But if he were not there, the bee would have found another flower. It may have hesitated between several less attractive flowers; it may have taken longer; but eventually a place for the pollen would have been found.

The very fact that one is part of a common scientific culture helps to guarantee this. Consider the case of Einstein and relativity. Legend celebrates the lonely genius, struggling in scientific isolation as a clerk in the Swiss Federal Patent Office. Relativity springs newborn from an act of creative insight. The truth is more mundane. Virtually every piece of the puzzle of relativity was to be found in the physics literature in 1905. The basic idea of relativity was as old as Newton himself; Newton's contemporary, Christian Huygens, made crucial use of the idea of transforming from the lab frame to the center-of-mass frame to derive the laws of impact. The Lorentz transformations together with the mathematical equivalents of length contraction and time dilation had been well known for ten years in H.A. Lorentz's electrodynamics. The key insight about the definition of distant simultaneity can be read out of an 1898 essay of Poincaré's, "La Mesure du temps" ["The Measure of Time"] (Poincaré 1898). Even the velocity-dependence of mass was a commonplace in the literature on the electron theory of matter, although it was derived from premises rather different from Einstein's.[4] Einstein was the first to put all of these pieces together, but if he had not done it, someone else would; and that probably sooner, rather than later.

Another physicist's theory of relativity may well have looked a little different; the pieces may have been put together in a slightly different way. But that's exactly what one would expect if Duhem's underdeterminationist picture of the relation between theory and evidence is correct. It is in the nature of the case that there will be many different ways to put the pieces of the puzzle together, all of them, in the end, yielding theories that equally well explain the evidence at hand. And some of the pieces may actually have been different. After all, we know that one could construct a theory empirically equivalent to general relativity but preserving a four-dimensional Euclidean geometry of physical spacetime; one need only postulate unusual forces to make it possible. But, again, it would have happened. Indeed, the fact that the resultant theory need not have looked exactly like *Einstein's* theory of relativity, the fact that a multiplicity of different theories could have done the same work, this fact makes it all the more likely that someone else would have come along in a very few years proposing an empirically-equivalent alternative to Einsteinss theory.[5]

Notice, by the way, that I am not arguing that the truth will triumph, finding one or another human vehicle for its expression. Quite the contrary. Whereas the scientific realist assumes the existence of one truth toward which scientific inquiry inevitably converges, Duhemian underdeterminationism implies a view of inquiry as an ever-ramifying tree structure, with an every growing multiplicity of theoretical possibilities at every juncture in history. The Duhemian view entails the existence of many truths, all of them different, but all of them equally capable of making sense of experience. This is not radical relativism; it is not the claim that anything goes. For the Duhemian, as much as the positivist or the realist, insists upon the control of theory by experience. It is just that the Duhemian sees that control working in a less determinative way.

The Nature of Genius

Einstein was the first to receive the pollen of relativity. Why? Because he was different. In what way was he different?

Start with the plainer facts. To begin with, Einstein had a first-class training in physics at the Swiss Federal Polytechnical Institute (Eidgenössische Technische Hochschule—ETH), where he studied from 1896 to 1900. And, even though he frequently skipped the more boring lectures, relying on the notes of his friend, Marcel Grossmann, he nevertheless pursued his education with a passionate intensity, often spending long hours outside of the classroom reading the latest literature in the leading physics journals, like the *Annalen der Physik*. Then too, he had extraordinary powers of concentration. Reputedly he could simply think about a problem straight through for hours on end, even days at a time. If interrupted, whether for a few minutes or an hour, he could instantly pick up his train of thought where he left it. I have no reason to doubt these claims, though they smack of hagiography. But even if they are true, they don't begin to give us the measure of Einstein's genius.

One might think to look for a psychological explanation. On at least two occasions, Einstein was questioned closely about the manner of his thinking, once by the psychologist, Max Wertheimer, and once by the mathematician, Jacques Hadamard. On both occasions, Einstein stressed the fact that he did not think in words, but in visual or even "muscular" images, the translation into words being a later, and often very difficult step

(Hadamard 1949: 184; Wertheimer 1945: 142-143). But as important as this might be, it is not at all clear that a nonverbal way of thinking in any way distinguishes an Einstein from lesser thinkers. On the contrary, thinking in images is probably the norm.

What did Einstein lack? His mathematical talents were limited, to say the least. One of his teachers, the mathematician, Hermann Minkowski, remembered him as a rather undistinguished student. In later years, Einstein came to regard the pursuit of mathematical simplicity as a high road to truth in physics; but his knowledge of mathematics was limited, as was his facility in calculation. He was in awe of David Hilbert's ability to work out a new mathematical framework for general relativity in the space of a couple of months, when he, himself, had struggled with the problem for eight years, and had been forced to turn to his former classmate, Grossmann, for elementary instruction in differential geometry. Einstein also lacked a sense of detail. Small mathematical errors are not uncommon in his early papers, which he seems never to have proofed.

More interesting are some facts about Einstein's personal habits and social and professional circumstances. Einstein was a very independent person, especially in his younger, most productive years. Partly by personal inclination, but also partly by force of circumstance, he was cut off from the normal career path of a young physicist. Denied an expected position as assistant to his major professor, H.F. Weber, at the ETH, Einstein spent the first year and a half after graduation in undistinguished temporary jobs, first as a temporary, replacement teacher of physics at the technical high school in Winterthur, and then, briefly, as a tutor at a private school in Schaffhausen. We remember him best working for over seven years, from 1902 to 1909, far out of the professional mainstream as a clerk in the Swiss Federal Patent Office in Bern. It was here that he did all of his best early work on relativity, the quantum, and brownian motion. No doubt such professional isolation made possible an independence of judgment that would have been harder to maintain if Einstein had had to contend with the pressures of a position as assistant to a senior physicist. Challenging the received wisdom of a whole generation of one's elders is no recipe for success in a probationary appointment.

But Einstein's isolation in those early years was not total. He was regularly reading the physics journals. He struck up a relationship with some of the physics faculty at the University of Bern. He had scientifically literate friends on whom he could test his evolving ideas about relativity, most importantly his ETH classmate, Michele Besso. He found intellectual companionship with the other members of an informal, weekly reading group that named itself the "Olympia Academy." And let us not forget that he was then married to another of his ETH physics classmates, Mileva

Marić, although, sadly, after their two sons were born, Albert and Mileva talked physics less and less.

The sociologist, Lewis Feuer, has made an interesting, but unconvincing attempt to relate Einstein's originality to the influence of the bohemian and politically radical student culture of turn-of-the-century Zurich (Feuer 1974). Not that such an influence couldn't incline one to originality. The problem is, rather, that Einstein seems not to have felt the influence all that much. He was later famous as a socialist, pacifist, and Zionist. But those convictions were planted either early, as in the case of his pacifism, or late, as in the case of his socialism and Zionism. In his student days, he moved in a small circle of friends, most of them fellow physics students, like Grossmann, Besso, and Friedrich Adler, or Serbian friends of Mileva. The only convincing case I have seen for Einstein's contact with Zurich political culture concerns not political refugees, like Lenin or Rosa Luxemburg, but the Zurich branch of the Ethical Culture Society (see Steinmüller 1992)!

The roots of Einstein's originality must be sought elsewhere. And Einstein, himself, tells us where to look. In late November 1944, Einstein received a letter from Robert A. Thornton, a brand-new, African-American physics and philosophy of science Ph.D. from the University of Minnesota, just then starting his first job at the University of Puerto Rico. Thornton wanted Einstein's opinion on the importance of including the history and philosophy of science in the science curriculum. On 7 December, Einstein wrote the following in reply:

> I fully agree with you about the significance and educational value of methodology as well as history and philosophy of science. So many people today—and even professional scientists—seem to me like somebody who has seen thousands of trees but has never seen a forest. A knowledge of the historic and philosophical background gives that kind of independence from prejudices of his generation from which most scientists are suffering. This independence created by philosophical insight is—in my opinion—the mark of distinction between a mere artisan or specialist and a real seeker after truth (EA 61-574).

There is more than a little autobiography in these words. For if any one trait distinguishes Einstein from many of his scientific contemporaries and ours, it was the extraordinary sophistication of his understanding of scientific methodology.

We have already touched upon some of Einstein's readings in turn-of-the-century philosophy of science, specifically the works of Duhem and

Poincaré. Even more important in teaching Einstein to be skeptical about the prejudices of his generation were the writings of Ernst Mach, including his *Die Mechanik [The Science of Mechanics]* (Mach 1897), *Die Analyse der Empfindungen [The Analysis of Sensations]* (Mach 1900), and *Die Principien der Wärmelehre [The Theory of Heat]* (Mach 1896).[6] Einstein was never a friend of Mach's doctrine of the elements of sensation, the hallmark of positivism, later to become, in a subtly transformed version, the centerpiece of the logical empiricist epistemology of the Vienna Circle. What Einstein prized in Mach was, instead, Mach's doggedly critical attitude toward the received conceptual apparatus of physics. Einstein learned from Mach the habit of subjecting all fundamental concepts to a searching analysis of their historical origins and epistemological warrant. It was this habit of mind that enabled Einstein first to understand what was wrong with the traditional conception of absolute distant simultaneity, an insight crucial to the development of special relativity. It was the same habit of mind that led him to be skeptical of the way the concept of probability was introduced into turn-of-the-century statistical physics, resulting in his invention of the modern form of the ergodic hypothesis that equates time averages and ensemble averages and a consequent deepening of our understanding of the Boltzmann principle, $S = k \log W$, a move crucial to progress in the early quantum theory.

Einstein tells us that it was Mach from whom he learned this way of thinking. In a 1916 obituary, Einstein praised Mach's "independence of judgment," adding about his legacy:

> Concepts that have proven useful in ordering things easily achieve such an authority over us that we forget their earthly origins and accept them as unalterable givens. Thus they come to be stamped as "necessities of thought," "*a priori* givens," etc. The path of scientific advance is often made impassable for a long time through such errors. For that reason, it is by no means an idle game if we become practiced in analyzing the long commonplace concepts and exhibiting those circumstances upon which their justification and usefulness depend, how they have grown up, individually, out of the givens of experience. By this means, their all-too-great authority will be broken. They will be removed if they cannot be properly legitimated, corrected if their correlation with given things be far too superfluous, replaced by others if a new system can be established that we prefer for whatever reason (Einstein 1916: 102).

If one is to practice well this style of conceptual criticism, one must be well read in the history and philosophy of science. And if anything stands out as an unusual feature of Einstein's youthful preparation for a career in physics, it is this. Already in his teens, Einstein studied Immanuel Kant's *Kritik der reinen Vernunft [Critique of Pure Reason]* (Kant 1878), and at the ETH he enrolled in a required lecture course on Kant.[7] On his own while at the ETH, Einstein read the mentioned works of Mach, as well as David Hume's *Treatise of Human Nature* (Hume 1895) and various of the writings of Arthur Schopenhauer.[8]

Most revealing, however, is the reading list that Maurice Solovine gives us for the Olympia Academy, whose meetings were a fixture of Einstein's life during the first several years of his stint in Bern. Einstein and Solovine began with Karl Pearson's *The Grammar of Science* (Pearson 1900). After they were joined by Conrad Habicht, they read, among other things, John Stuart Mill's *Logic* (Mill 1872), Spinoza's *Ethics* (Spinoza 1887), several essays and lectures by Hermann von Helmholtz, André-Maurice Ampère's *Essai sur la philosophie des sciences [Essay on the Philosophy of Science]* (Ampère 1834), Bernhard Riemann's "Ueber die Hypothesen, welche der Geometrie zur Grunde liegen" ["On the Hypotheses that Form the Basis of Geometry"] (Riemann 1854), certain chapters of Richard Avenarius' *Kritik der reinen Erfahrung [Critique of Pure Experience]* (Avenarius 1888, 1890), William Kingdon Clifford's "On the Nature of Things in Themselves" (Clifford 1903), and Richard Dedekind's *Was sind und was sollen die Zahlen? [What Are and What Should Be the Numbers?]* (Dedekind 1893). It was in this setting that Einstein seems first to have read Poincaré, and here he once more read his Mach.[9]

When one turns to Einstein's personal library, one finds additional titles of interest, including Friedrich Albert Lange's *Geschichte des Materialismus* [*History of Materialism*] (Lange 1873), Eugen Dühring's *Kritische Geschichte der Principien der Mechanik* [*Critical History of the Principles of Mechanics*] (Dühring 1887), and Ferdinand Rosenberger's *Isaac Newton und seine physikalischen Principien* [*Isaac Newton and his Physical Principles*] (Rosenberger 1895). Of course, the mere presence of a turn-of-the-century title in Einstein's library is no guarantee that he read the book as a young man; but such titles bespeak the same interests that we find expressed in the Olympia Academy reading list.

We see here the beginning of a lifelong engagement with the best literature in the philosophy of science. In later years, this engagement developed into personal friendships and acquaintances with the leading philosophers of science themselves. As early as 1910, during a trip to Vienna, Einstein made a pilgrimage to the home of the semi-invalid Mach. Starting around 1915, he struck up a warm friendship with Moritz Schlick. His friendship with Hans Reichenbach dates from the latter's auditing Einstein's Berlin lectures on relativity in 1919. He corresponded with Hans

Vaihinger, a neo-Kantian famous for his *Philosophie des Als-Ob [Philosophy of As-If]* (Vaihinger 1911), and with the even more influential neo-Kantian, Ernst Cassirer. In the 1940's, he got to know Bertrand Russell, with whom he had a series of discussions in Princeton, and he contributed a lovely essay, "Remarks on Bertrand Russell's Theory of Knowledge" to the Russell volume in the Library of Living Philosophers (Einstein 1944). Even the not-so-famous were favored with Einstein's attention if they had something to teach him about matters philosophical, as evidenced by his acquaintances with the minor neo-Kantians, Otto Büek and Ilse Rosenthal-Schneider, and the minor positivist, Joseph Petzoldt.[10]

Einstein also wrote frequently on topics in the philosophy of science. One finds everything from book reviews, such as those of works by Alfred Elsbach (Einstein 1924b), Josef Winternitz (Einstein 1924a), and Emile Meyerson (Einstein 1928), to major public addresses, like his 1933 Herbert Spencer lecture, "On the Method of Theoretical Physics" (Einstein 1933) and long, sophisticated philosophical essays, like his 1936 "Physics and Reality" (Einstein 1936). And let us not forget that the Einstein volume in the Library of Living Philosophers (Schilpp 1949), to which Einstein contributed an intellectual autobiography and a series of replies to the critical essays it contains, was entitled *Albert Einstein: Philosopher-Scientist,* a title to which Einstein did not object.

Einstein's engagement with the philosophy of science yielded a number of dividends, one of the most important for an understanding of his way of doing science being his reflections on the place of so-called "principle theories" and "constructive theories" in physics. Einstein first introduced this distinction in a 1919 article in the *Times* of London, although the associated method was at work in his physics from at least 1905. If anything explains Einstein's singular capacity to make progress where others were blocked, it is his stress on the relative importance of principle theories.

The "principles" constituting a principle theory are high-level empirical regularities, like the Boltzmann principle, the conservation of energy, or, most important for Einstein, the principle of relativity and the light principle. Ultimate understanding in physics is provided by a constructive theory, which provides an ontology and a model, a picture, for the physical processes we seek to understand. Nineteenth-century mechanical models of the ether would be good examples; in the same category go the big-bang theory, the liquid-drop model of the nucleus, and the Copernican, geocentric model of the planetary system. But Einstein believed that there was too much premature model building in physics. The problem is that there are so many possible models (remember the lesson of Duhemian underdeterminationism) that one does not know how to choose, and so the inertia of past practice takes over, inclining one to comfortable old models quite apart from their intrinsic scientific merits. Just think how long it took physicists to overcome their need for mechanical models of the ether.

Progress is more likely to be made, on Einstein's view, by first identifying a set of principles, like conservation of energy or the relativity principle, that can then act as constraints in the search for constructive models. Thus, for example, whereas Lorentz's electrodynamics is constructive from the start, replete with assumptions about the fundamentally electrical nature of all matter and about the ether that is to be the medium in which electromagnetic energy lives, Einstein sets out to create an "Electrodynamics of Moving Bodies" (the title of his first 1905 paper on special relativity) not with an ontology, but with a pair of empirically well-confirmed principles, the relativity principle and the light principle. The relativity principle says that the laws of physics should take the same form in all reference frames moving relative to one another with a constant velocity. The light principle says that, if the velocity of light in one frame is c, then its velocity in all frames moving with a constant velocity relative to the first will be the same, so that the velocity of light will be independent of the state of motion of the source. The apparent incompatibility between these two principles is resolved by introducing the Lorentz transformations in place of the Galilean transformations. And then one has one's constraints. For now any acceptable constructive theory must satisfy the relativity and light principles, along with all of their many consequences, including length contraction, time dilation, and the equivalence of mass and energy. Any constructive theory not satisfying these principles, like Max Abraham's electron theory of matter, can be ruled out from the start.

As employed by Einstein, the doctrine of principle theories was a powerful engine of progress in physics (Howard 1990b). The strategy that worked so well in the case of special relativity appears again and again: in his work on the foundations of statistical mechanics, his work on the photon hypothesis, his years-long struggle with the quantum theory, his development of general relativity, and his failed, but not fruitless search for a unified field theory.

There are other unique features of Einstein's intellectual style that time does not permit me to discuss here. Foremost among them is his commitment to a methodological principle of univocalness, according to which an acceptable scientific theory must determine for itself a unique model, or, failing that, the arbitrariness in the determination of models must be kept to a minimum (Howard 1992; Wertheimer 1945: 168-188). As with the doctrine of principle theories and constructive theories, we find that what helped Einstein to understand so clearly a very deep point about scientific

method was precisely his immersion in the literature on methodology and philosophy of science.

Need I point out that there is a lesson to be learned here by teachers of physics, or any science, for that matter. It is the lesson stressed by Einstein in his letter to Thornton: "A knowledge of the historic and philosophical background gives that kind of independence from prejudices of his generation from which most scientists are suffering. This independence created by philosophical insight is—in my opinion—the mark of distinction between a mere artisan or specialist and a real seeker after truth." If we want to train a new generation of young Einstein's, here is a necessary condition. We need to rethink, from the ground up, the way we teach science. Einstein would not have been Einstein were it not for his study of Mach and Hume, Kant and Poincaré, Duhem and Avenarius. We need to teach our students to do more than solve problems; we need to teach them how to think, and think deeply. That requires philosophical sophistication.

Why Do We Need Geniuses?

What about the antecedent of the last conditional, "if we want to train a new generation of Einstein's?" Do we? Most of you will probably say that training geniuses is a foolish and unrealistic goal, which it is. But I hope that, like me, you feel a moment of discomfort and embarrassment when you give that answer. I hope that you notice and then are somewhat shamed by the sense of dread, the sense of urgency with which you repudiate that goal. Why do we feel this way? Something more is at work here than pedagogical common sense.

The image of the genius is not found in every culture, nor has it always been a part of ours. It has its roots in the Romantic period. Part of the reaction against the Enlightenment, the image of the genius developed in the writings of Schelling and Schlegel exalts the heart over the head, feeling over reason. Still, it has a cognitive aspect, for the product even of artistic genius is often thought, as by Schopenhauer, to be a kind of understanding or insight, deeper and more profound than what reason alone can attain. Great poetry, great paintings, great music are distinguished by their giving us new ways of apprehending the world. The kind of insight thus attained is thought to involve a directness, an immediacy that distinguishes it from the mediated knowledge produced by the apparatus of the senses or the principles and categories with which reason operates. In this respect, the understanding that is the product of genius is like the direct knowledge of God sought by the mystic. So it is not surprising that the vocabulary of genius borrows heavily from the mystical, gnostic, and kabbalistic traditions. Like the mystic, the genius is carried outside of himself (I mean deliberately to use a gendered vocabulary here). For all that the heart is ruling the head, the bodily sense dissolves before the intellectual or spiritual union with the one, the all, *die blaue Blume*, or whatever. Millenarian imagery also comes to the fore—peace, harmony, the union of opposites. All of these features are carried along when the imagery of genius is transplanted from the realm of art to the realm of science.

One other feature stands out in our culture's manipulation of the image of the genius. It is that the genius is always an individual, a lonely figure acting alone. Inspiration, like God's grace, falls upon the individual, not the community. Great art, like great science, is not committee work. It is, instead, the fruit of the isolated artist's lonely labors, late at night, alone in the garret. That is certainly part of the Einstein legend. But the individualism of genius is not the possessive individualism at the heart of the democratic political tradition deriving from seventeenth-century thinkers like John Locke. No, it is the authoritarian individualism whose ugly side we know only too well in the twentieth century. The artistic genius, and the scientific genius, is the Nietzschean blond beast, the new Christ, vouchsafed a glimpse of God's truth and bending the will of generations in its name. And so the image of the genius is coeval with the great man theory of history in the hands of thinkers like Thomas Carlyle. Here we confront the unsavory side of the Romantic reaction to the Enlightenment.

The connection to authoritarian individualism perhaps explains why the vocabulary of "power" so commonly attaches itself to the figure of the genius. The genius has a powerful intellect. Genius produces powerful images, powerful theories. Einstein's genius gave us power over nature. Hitler's genius gave him power over people.

It is the power of genius that, I think, explains why most of us idolize the Einsteins of the world. Let us be frank with one another. Most of us are namby-pamby, pusillanimous, liberal intellectuals who can't bend even our colleagues, our children, or our wives to our wills, let alone whole nations. We would love it if we could command large audiences for our theorizing, but most of us would be grateful if we could just pry a few dollars out of NSF. Why do we idolize an Einstein? Why do we identify with him? What more gratifying fantasy of prestige, power, authority, and control? Why do I want to be like an Einstein? Why, so that everyone will look up to me and defer to my judgment. So that nature will yield itself to palpation by my mind. This is the "padron" syndrome in the life of the mind. It is not unrelated to the child's fascination with dinosaurs.

Does it trouble you that I spoke, a moment ago, about "bending our wives to our will?" The gendered discourse is, again, deliberate. I think it a fact, and a telling fact, that women are not drawn to the image of the genius in the same way as men, for the genius embodies a characteristically male

fantasy of intellectual power and control. Perhaps it is best that we not ask, at the moment, about the anxiety that energizes this fantasy.

I prefer a less authoritarian, more communitarian model for the life of the scientific mind, not only for moral and political reasons, but also because it is closer to the truth about how the scientific intellect functions. Einstein was no lonely genius, struggling by himself in his garret at night, waiting for that moment of inspiration or mystical insight. That is not what made him a great thinker. He was very much part of a community, a circumstance essential to his accomplishing what he did. He profited from reading the work of others in the scientific journals. Even during his loneliest years at the patent office, he sought out others on whom he could try out his ideas. There is frustratingly inconclusive evidence of Mileva Marić's having collaborated on some of the earliest work on relativity (Stachel, et al. 1987: xxxix,225,282). In later years, he always worked with the help of an assistant, frequently coauthoring papers, almost always debating his ideas at length with those whose judgment he respected.

I do not mean to recommend a communitarian model of inquiry. I hated group projects in college, as did many of you, I imagine. And the idea of a People's Theoretical Physics Collective is not very appealing. Insisting on seeing an Einstein in a social-professional context is not to call for intellectual communism. But I do think that we need to ask ourselves why we celebrate individual intellectual accomplishment over the kind of collaboration that is essential even in the work of an Einstein.

In being so harsh with the image of the genius, I do not mean to disparage the obvious value of Einstein as an inspiring model, as someone to emulate. One of the main reasons why I began a career in science was because I was fascinated by the image of the brilliant, wooly, white-haired sage of Princeton. I read everything I could about his life and work. We need models to emulate. That is the way character is shaped, personality formed; but emulating a noble or heroic figure is not the same thing as indulging in the fantasy of genius.

There is another unfortunate consequence of our idolizing the figure of the scientific genius. To the extent that we endow the genius with mystical, superhuman capacities—and a genius would not be a genius without such capacities—to that extent we guarantee that the achievements of genius will be forever beyond our merely human reach and the merely human reach of our students. We let ourselves off the hook in two ways. First, we have an excuse for our own failures. Did I fail to become the Einstein of my generation? That is okay. Lacking an Einstein's superhuman capacities, I could not have become an Einstein in the first place, no matter how hard I studied, no matter how hard I worked. Second, we have an excuse for failing to train our students better than we do. So what if none of my students have won the Nobel Prize? So what if none of them got into graduate school at Cal Tech? That is okay. We all know that no amount of training will do the trick if they do not have within them that spark of genius. It is not my fault.

For those of us who are teachers, it is important, therefore, that, so far as is possible, we *humanize* the achievements of an Einstein. When I sketched above some of the key ingredients of Einstein's distinctive way of doing physics, nowhere did I stop and say, "And here is where we confront a stoke of genius." Everything that I mentioned—his power of concentration, his excellent training in physics, his wide reading in the philosophy of science, his ideas about principle theories and constructive theories—all of these are either normal human capacities or clearly human achievements. And when one studies any one of his papers closely, nowhere does one find a discontinuity explainable only by the operation of genius. When one takes the arguments apart, step by step, one sees where every little piece comes from. That is not to say that you or I could duplicate the achievements of an Einstein. Far from it. He was different, and we are not his intellectual equals. But he was not different by virtue of any superhuman endowment. Each of his capacities was a very human capacity. If he was a vessel in which the struggle for eternal truth was played out, then he was a flawed vessel. He made mistakes, both large and small. He fathered at least one illegitimate child. He treated his wives and children badly. His romantic affairs were numerous and legendary. Of course, he had his good side too. He could be a steadfast friend. He was generous and unfailingly helpful to younger colleagues. He was untiring in his efforts on behalf of peace, racial harmony, and social justice. Again, these are all of them, good and bad, quite human traits.

What made him different was the way he did physics. I would like to understand the way he did physics, so that I can learn to think the way an Einstein thinks. And I would like to help my students learn to think in that way too.

Acknowledgments

I would like to thank John Langdon and Terry Kent for the invitation to deliver this paper as part of the College of Arts and Sciences Institute on "The Natural History of Paradigms: Science and the Process of Intellectual Evolution" at the University of Indianapolis, May 13, 1993. My sincere thanks also go out to the many participants in the Institute; their comments and criticisms have improved the paper in many important ways. I wish to thank also The Hebrew University of Jerusalem, which holds the copyright, for permission to quote from Einstein's unpublished correspondence. Items

from the Einstein Archives are cited by their numbers in the Control Index, after the form: EA xx-xxx.

Notes

1. For more on Einstein's life and work, see Bernstein 1973; Clark 1971; Hoffman and Dukas 1972; Pais 1982.
2. See Poincaré 1904a. For the sake of this discussion, I have altered somewhat the details of Poincaré's thought experiment. Poincaré's own preference was to retain Euclidean geometry, owing to what he regarded as its inherent simplicity, vis à vis its non-Euclidean rivals, even if that meant a slight complication of one's physics.
3. For more on the nature and extent of Duhem's influence upon Einstein, see Howard 1990a.
4. For more on the conceptual background to special relativity, see, for example, Miller 1981.
5. For an interesting recent study detailing an actual historical example of two empirically-equivalent theories, see Cushing 1994, where the theories in question are orthodox quantum mechanics under the Copenhagen interpretation and the Bohm-Vigier type hidden variable theories.
6. For Einstein's reading of Mach, see Stachel, et al. 1989:43.
7. For Einstein's reading of Kant, see Stachel, et al. 1987: lxii; Talmey 1932: 164. For Einstein's study of Kant at the Swiss Federal Polytechnical Institute, see Stachel, et al. 1987: 46,49.
8. For Einstein's reading of Hume, see Stachel, et al. 1989: xxiii-xxiv. For his reading of Schopenhauer, see Howard 1993.
9. See Solovine 1987:8-9. For more detailed references on the readings and further background on the Academy, see Stachel, et al. 1989: xxiv-xxv.
10. For documentaton of Einstein's acquaintance with these philosophers: with Mach, see Wolters 1987:130-134; with Schlick, see Howard 1984; with Reichenbach, see Howard 1994; with Vaihinger and Cassirer, see for example, Einstein to Vaihinger, 3 May 1919 (Bibliothek der Hansestadt Bremen, Autuogr. XXI, 7: C, Vi-1), and Einstein to Cassirer, 5 June 1920 (EA 8-386); with Russell, see Russell 1968; with Rosenthal-Schneider, see Howard 1994; with Büek and Petzoldt, see Howard 1992.

References

Ampère, André-Maurice 1834. *Essai sur la philosophie des sciences ou exposition analytique d'une classification naturelle de toutes les connaissances humaines.* Paris: Bachelier, 1834.

Avenarius, Richard 1888. *Kritik der reinen Erfahrung.* Vol. 1. Leipzig: O.R. Reisland.

__________ 1890. *Kritik der reinen Erfahrung.* Vol. 2. Leipzig: O.R. Reisland.

Bernstein, Jeremy 1973. *Einstein.* Harmondsworth, Middlesex: Penguin.

Clark, Ronald 1971. *Einstein: The Life and Times.* New York and Cleveland: World Publishing.

Clifford, William Kingdon 1903. *Von der Natur der Dinge an sich.* Hans Kleinpeter, transl. and ed. Leipzig: Johann Ambrosius Barth.

Cushing, James T. 1994. *Quantum Mechanics, Historical Contingency, and the Copenhagen Interpretation.* Chicago: University of Chicago Press. [Forthcoming.]

Dedekind, Richard 1893. *Was sind und was sollen die Zahlen?* 2nd ed. Braunschweig: Friedrich Vieweg und Sohn.

Duhem, Pierre 1906. *La Théorie physique. Son objet et sa structure.* Paris: Chevalier & Rivière. [Originally published in the Revue de Philosophie 4(1904): 387-402, 542-556, 643-671; 5(1904): 121-160, 241-263, 536-569, 635-662, 712-737; 6(1905): 25-43, 267-292, 377-399, 519-559, 619-641.] Page numbers are cited from the English translation of the 2nd. ed. (1914), *The Aim and Structure of Physical Theory.* Philip P. Wiener, transl. Princeton: Princeton University Press, 1954, reprnt. New York: Athaneum, 1962.

__________ 1908. *Ziel und Struktur der physikalischen Theorien.* Friedrich Adler, trans., foreword by Ernst Mach. Leipzig: Johann Ambrosius Barth. [Translation of Duhem 1906.]

Dühring, Eugen 1887. *Kritische Geschichte der Principien der Mechanik*, 3rd ed. Leipzig: Fues's Verlag (R. Reisland).

Einstein, Albert 1916. Ernst Mach. Physikalische Zeitschrift 17: 101-104.

__________ 1918. Motive des Forschens. In *Zu Max Plancks sechzigstem Geburtstag. Ansprachen, gehalten am 26. April 1918 in der Deutschen Physikalischen Gesellschaft.* Karlsruhe: C. F. Müller. Pp. 29-32.

__________ 1921. *Geometrie und Erfahrung. Erweiterte Fassung des Fest-vortrages gehalten an der Preussischen Akademie der Wissenschaften zu Berlin am 27. Januar 1921.* Berlin: Julius Springer. Page numbers and quotations from the translation in Einstein 1954, pp. 232-246.

__________ 1924a. Review of Winternitz 1923. Deutsche Literaturzeitung 45: 20-22.

__________ 1924b. Review of Elsbach 1924. Deutsche Literaturzeitung 45: 1685-1692.

__________ 1927. Newtons Mechanik und ihr Einfluss auf die Gestaltung der theoretischen Physik. Die Naturwissenschaften 15: 273-276. Page numbers and translation taken from the version published as "The mechanics of Newton and their influence on the development of theoretical physics," in Einstein 1954, pp. 253-261.

__________ 1928. Review of Meyerson 1925. Revue philosophique de la France et de l'étranger 105: 161-166.

__________ 1933. *On the Method of Theoretical Physics.* The Herbert Spencer Lecture, Delivered at Oxford, 10 June 1933. Oxford: Clarendon.

__________ 1936. Physik und Realität. Journal of The Franklin Institute 221: 313-347.

__________ 1942. Isaac Newton. Manchester Guardian, 24 Dec., sect. 4, pp. 6-7. Page numbers taken from the reprinting in *Out of My Later Years.* New York: Philosophical Library, 1950, pp. 219-223.

__________ 1944. Remarks on Bertrand Russell's theory of knowledge. In Paul Arthur Schilpp, ed., *The Philosophy of Bertrand Russell.* Evanston, IL: Northwestern University Press. Pp. 278-291.

__________ 1954. *Ideas and Opinions.* Carl Seelig, ed. Sonja Bargmann, trans. New York: Bonanza Books.

__________ 1987. *Letters to Solovine.* New York: Philosophical Library.

Elsbach, Alfred 1924. *Kant und Einstein. Untersuchungen über das Verhältnis der modernen Erkenntnistheorie zur Relativitätstheorie.* Berlin and Leipzig: Walter de Gruyter.

Feuer, Lewis S. 1974. *Einstein and the Generations of Science.* New York: Basic Books.

Hadamard, Jacques 1949. *The Psychology of Invention in the Mathematical Field,* enl. ed. Princeton: Princeton University Press.

Hoffmann, Banesh and Dukas, Helen 1972. *Albert Einstein: Creator and Rebel.* New York: Viking.

Howard, Don 1984. Realism and conventionalism in Einstein's philosophy of science: The Einstein-Schlick correspondence. Philosophia Naturalis 21: 618-29.

__________ 1990a. Einstein and Duhem. Synthese 83: 363-384.

__________ 1990b. "And I shall not mingle conjectures and certainties": The roots of Einstein's principle theories/constructive theories distinction. Paper delivered at the 1990 Osgood Hill Conference "Einstein, the Early Years," North Andover, MA, 4-6 October 1990.

__________ 1992. Einstein and *Eindeutigkeit*: A neglected theme in the philosophical background to general relativity. In *Studies in the*

History of General Relativity. Proceedings of the Second International Conference, Marseilles-Luminy, France, 6-9 September 1988. Jean Eisenstaedt and A. J. Kox, eds. Boston: Birkhäuser. Pp. 154-243.

__________ 1993. A peek behind the Veil of Maya: The historical background of the conception of space as a ground for the individuation of physical systems. Paper delivered in the Twenty-third Annual Lecture Series, Center for Philosophy of Science, University of Pittsburgh, 12 February 1993.

__________ 1994. Einstein, Kant, and the origins of logical empiricism. In *Language, Logic, and the Structure of Scientific Theories: The Carnap-Reichenbach Centennial.* Wesley Salmon and Gereon Wolters, eds. Pittsburgh: University of Pittsburgh Press; Konstanz: Universität Konstanz. [Forthcoming.]

Hume, David 1895. *Ein Traktat über die menschliche Natur.* Part 1, *Über den Verstand.* E. Köttgen, trans. Theodor Lipps, ed. Hamburg: Leopold Voss.

Kant, Immanuel 1878. *Kritik der reinen Vernunft. Text der Ausgabe 1781 mit Beifügung sämmtlicher Abweichungen der Ausgabe 1787,* 2nd ed. Karl Kehrbach, ed. Leipzig: Philipp Reclam jun.

Lange, Friedrich Albert 1873. *Geschichte des Materialismus und Kritik seiner Bedeutung in der Gegenwart.* Book 1, *Geschichte des Materialismus bis auf Kant.* O.A. Ellissen, ed. Leipzig: Philipp Reclam jun.

Mach, Ernst 1896. *Die Principien der Wärmelehre. Historisch-kritisch entwickelt.* Leipzig: Johann Ambrosius Barth.

__________ 1897. *Die Mechanik in ihrer Entwickelung historisch-kritisch dargestellt*, 3rd impr. and enl. ed. Leipzig: Brockhaus.

__________ 1900. *Die Analyse der Empfindungen und das Verhältniss des Physischen zum Psychischen*, 2nd ed. Jena: Gustav Fischer.

Meyerson, Émile 1925. *La Déduction relativiste.* Paris: Payot.

Mill, John Stuart 1872. *A System of Logic Ratiocinative and Inductive: Being a Connected View of the Principles of Evidence and the Methods of Scientific Investigation.* 2 vols. 8th ed. London: Longmans, Green, Reader, and Dyer.

Miller, Arthur 1981. *Albert Einstein's Special Theory of Relativity: Emergence (1905) and Early Interpretation (1905-1911).* Reading, MA: Addison-Wesley.

Pais, Abraham 1982. *"Subtle is the Lord . . ." The Science and the Life of Albert Einstein.* Oxford: Clarendon; New York: Oxford University Press.

Pearson, Karl 1900. *The Grammar of Science*, 2nd ed. London: Adam & Charles Black.

Poincaré, Henri 1898. La Mesure du temps. Revue de Métaphysique et de Morale 6: 1-13.

__________1902a. L'expérience et la géométrie. In Poincaré 1902b, pp. 92-109.

__________1902b. *La Science et l'hypothèse.* Paris: Ernest Flammarion.

__________1904. *Wissenschaft und Hypothese.* Ferdinand and Lisbeth Lindemann, trans. Leipzig: B.G. Teubner. [Translation of Poincaré 1902b.]

Riemann, Bernhard 1854. Ueber die Hypothesen, welche der Geometrie zu Grunde liegen. Königliche Gesellschaft der Wissenschaften und der Georg-Augusts-Universität (Göttingen). Mathematische Classe. Abhandlungen 13 (1867): 133-152. Lecture, Göttingen, 10 June 1854.

Rosenberger, Ferdinand 1895. *Isaac Newton und seine physikalischen Prinzipien. Ein Hauptstück aus der Entwickelungsgeschichte der modernen Physik.* Leipzig: Johann Ambrosius Barth.

Russell, Bertrand 1967. *The Autobiography of Bertrand Russell.* Vol. 2, *1914-1944.* Boston: Little, Brown & Company.

Schilpp, Paul Arthur, ed. 1949. *Albert Einstein: Philosopher-Scientist.* The Library of Living Philosophers, vol. 7. Evanston: The Library of Living Philosophers.

Schlick, Moritz 1917. *Raum und Zeit in den gegenwärtigen Physik. Zur Einführung in das Verständnis der allgemeinen Relativitätstheorie.* Berlin: Julius Springer.

Solovine, Maurice 1987. Introduction. In *Albert Einstein: Letters to Solovine.* New York: Philosophical Library. Pp. 5-15.

Spinoza, Baruch 1887. *Die Ethik.* J. Stern, trans. Leipzig: Philipp Reclam jun.

Stachel, John, et al., eds. 1987. *The Collected Papers of Albert Einstein.* Vol. 1, *The Early Years, 1879-1902.* Princeton: Princeton University Press.

__________ 1989. *The Collected Papers of Albert Einstein.* Vol. 2, *The Swiss Years: Writings, 1900-1909.* Princeton: Princeton University Press.

Steinmüller, Karlheinz 1992. Tracing back the sources of Albert Einstein's political convictions: The movement for ethical culture. Paper delivered at the conference "Albert Einstein—Life and Work," Haus der Begegnung, Ulm, Germany, 13-16 March 1992.

Talmey, Max 1932. *The Relativity Theory Simplified and the Formative Period of its Inventor.* New York: Falcon Press.

Vaihinger, Hans 1911. *Die Philosophie des als ob. System der theoretischen, praktischen und religiosen Fiktionen der Menschheit auf*

Grund eines idealistichen Positivismus. Mit einem Anhang über Kant und Nietzsche. Berlin: Reuther & Reichard.

Wertheimer, Max 1945. *Productive Thinking.* New York: Harper & Brothers.

Winternitz, Joseph 1923. *Relativitätstheorie und Erkenntnislehre. Eine Untersuchung über die erkenntnistheoretischen Grundlagen der Einsteinschen Theorie und die Bedeutung ihrer Ergebnisse für die allgemeinen Probleme des Naturerkennens.* Wissenschaft und Hypothese, vol. 23. Leipzig and Berlin: B. G. Teubner.

Wolters, Gereon 1987. *Mach I, Mach II, Einstein und die Relativitätstheorie. Eine Fälschung und ihre Folgen.* Berlin and New York: Walter de Gruyter.

COMMENTS

Burnell: Is the kind of self-analysis that Einstein seemed to go through uncommon among these other people that we consider to be geniuses? Is it a product of his immersion in the philosophy of science?

Howard: I do not know. He would have denied that there was anything distinctive about the way he thought.

Cise: I am struck by his detachment from the concrete. It was almost as though he could transcend ordinary thinking. If he were still alive, what would he be thinking? Where would he be carrying all of this?

Howard: He had a program of research all worked out. He wanted to pursue some of the fundamental questions about unified field theory.

The idea of the concrete is another interesting tension in Einstein's life. He was quite self-conscious from a young age about his psychological need to live in that almost Platonic realm of ideas. He speaks of the peace and beauty of being lost in the world of thought. That kind of talk comes to the fore usually with some sort of deep personal emotional crisis. It almost is an escape from his human failings.

There is another side to this. He also took a great deal of satisfaction from the concrete contact with the material world. He held numerous patents for all sorts of crazy inventions. For decades he worked as a consultant to a German manufacturer of gyroscopes.

Geekie: You spoke of the necessity of making insights and intuitive connections across disciplines. Do we do our students a disservice by channeling them into becoming students of one particular discipline? It is so hard to master a science. Do you really have time to master a second field?

Howard: I agree. The broader your experience and training, the more you enrich your storehouse of images and metaphors and models and ideas that will then yield dividends in areas far removed from those in which they originally developed. Einstein's own early training in physics had more breadth. He also worked in a variety of domains. But we cannot conclude there is something rotten about the way we train our students. People are quite right about the knowledge explosion. If you prepare a student in one of a variety of fields, the amount of knowledge he or she must master is immense. We face a need to train specialists. Maybe we need to rethink our whole culture. Maybe we do not need to train specialties in the way we think we do. Maybe we would be better off if we slowed down our progress in these specialized areas a little bit to allow for some more generalized thinking.

Langdon: To what extent does the notion of genius elevate an individual beyond the capacity of other individuals?

Howard: Clearly there was something special about Einstein. He is beyond the norm. But to say that is not to say there is something superhuman about this individual. If we look at that cluster of capacities that put him off the normal scale, any one of those capacities is a human capacity. Any one of those capacities you could find manifested in any of a number of other individuals. Part of what is different is that he combines so many of these capacities. But again, what I want to stress is that each of those capacities is a merely human capacity. There is nothing that makes him in principle different from the rest of us. I want to deny the thesis that there is this "spark of the divine" about him. To that extent, it becomes legitimate for us to ask about ourselves and our teaching, is this a human capacity than can be nurtured in our students or in ourselves?

That is the danger. The tendency is so to romanticize the image of Einstein that we get ourselves off the hook. We find an excuse for not asking ourselves, "How can we try to nurture this capacity in our students? How can we try to foster this capacity in ourselves?"

Zimmerman: I am struck by the amount of creativity and curiosity he demonstrated. What does it take to increase the possibility that an individual with this potential will have that opportunity to flower?

Howard: I do not have an answer to that question. Einstein hated the first 17 years of his education. He simply left Germany because he could not abide the Prussian system of education. He then went to a school which was known as one of the most progressive schools of its day. It featured an individualized curriculum, a lack of structure in the curriculum, a lot of freedom, a lot of choice, a close relation between the teachers and students. He really blossomed in this environment.

FURTHER READING ON EINSTEIN AND GENIUS

Don Howard

A. Einstein's Own Writings

Ideas and Opinions. Carl Seelig (ed.). Sonja Bargmann (trans.). New York: Bonanza Books, 1954.

Relativity: The Special and the General Theory. A Popular Exposition. Robert W. Lawson, trans. New York: Crown Publishers, 1961.

The Collected Papers of Albert Einstein. 1987-1993. Princeton: Princeton University Press.

Vol. 1, *The Early Years, 1879-1902.* John Stachel et al., eds. , 1987.

Vol. 2, *The Swiss Years: Writings, 1900-1909.* John Stachel et al., eds.

Vol. 3, *The Swiss Years: Writings, 1909-1911.* Martin Klein et al., eds. [Forthcoming.]

Vol. 5, *The Swiss Years: Correspondence, 1902-1914.* Martin Klein et al., eds. [Forthcoming.]

B. Autobiography and Biographies

Bernstein, Jeremy 1973. *Einstein.* Harmondsworth, Middlesex: Penguin.

Clark, Ronald 1971. *Einstein: The Life and Times.* New York: World Publishing.

Einstein, Albert 1979. *Autobiographical Notes: A Centennial Edition.* Paul Arthur Schilpp, trans. and ed. La Salle, IL: Open Court.

Hoffmann, Banesh, and Helen Dukas 1972.. *Albert Einstein: Creator and Rebel.* New York: Viking.

Pais, Abraham 1982. *'Subtle is the Lord . . .' The Science and the Life of Albert Einstein.* Oxford: Clarendon; New York: Oxford University Press.

C. Critical Studies

Schilpp, Paul Arthur, ed. 1970. *Albert Einstein: Philosopher-Scientist.* The Library of Living Philosophers, Vol. 7. La Salle, IL: Open Court.

D. Studies of Genius and Creativity

Gardner, Howard 1993. *Creating Minds.* New York : Basic Books.

Hadamard, Jacques 1949. *The Psychology of Invention in the Mathematical Field,* enl. ed. Princeton: Princeton University Press.

Wertheimer, Max 1945. *Productive Thinking.* New York and London: Harper & Brothers.