

The Education of Albert Einstein

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The Physics Department at Princeton University, close by the Institute for Advanced Study where Einstein spent his last years, sponsors afternoon tea parties for the faculty and the graduate students. Robert Oppenheimer, the third Director of the Institute, once said of these occasions that

Tea is where we explain to each other what we don't understand.¹

Oppenheimer did not add—he doubtless thought it too obvious for comment—that like most physicists, he explained what he did not understand with enormous self-confidence and verve. I am reluctant to compare a mere afternoon tea with the august institution that is the St. John's University Faculty Colloquium. Nevertheless, I too will be talking about matters that I am not sure I entirely understand. So please feel free to raise questions, after the talk if they can wait, during the talk if they can't. Just yell or throw something if I don't see you.

INTRODUCTION

Our usual picture of Albert Einstein is as he appeared at Princeton: white-haired, elderly, perhaps a little ruffled.² It was a much younger Einstein who in 1905 published a series of papers that set the course of twentieth-century physics. But the Einstein to whom I wish to introduce you tonight is younger yet, and much less familiar. In 1894, at the age of 15, he had dropped out of 'high school'—a classical gymnasium in Munich—and had spent the next year or so with his family in Italy.³ In 1895, he took and failed the entrance examination at the Eidgenössische Technische Hochschule (hereafter the ETH) in Zurich—Federal Institute of Technology would be a loose translation. He then spent a year in a Swiss high school, from which he graduated in the spring of 1896. That diploma permitted him to enroll in the ETH, which he attended until his graduation in the summer of 1900.

He did not distinguish himself in the eyes of his teachers at the ETH, and his prospects upon graduating were poor. His determined efforts to attain a university assistantship were utterly unsuccessful. Equally unsuccessful were his efforts to find

a job teaching in a secondary school. He survived for several years in a series of temporary teaching and tutoring jobs. Finally, in mid-1902, the father of his friend Marcel Grossmann helped him obtain a position as a patent examiner (Technical Expert 3rd class, to begin) at the Swiss Patent Office in Bern, where he remained until 1909.

His personal life was also in turmoil during much of this period. By 1900, he was deeply involved with Mileva Marić, a fellow student and a Serbian from southern Hungary, who had come to the ETH to study mathematics and physics. Alas, Einstein's family thoroughly disapproved of Marić; for that matter, her parents did not think a whole lot more of him. The culture shock when Einstein's German Jewish family collided with Marić's Serbian Orthodox one must have been spectacular. Their letters are filled with despairing speculation on how they would overcome such obstacles. In the end, they were married early in 1903—after the birth of a child early in 1902. That event, too, must have caused their families considerable alarm, and the two of them considerable commotion. (This baby has, apart from her existence, vanished from the historical record; we don't know what happened to her. Whatever happened—an early death, the child left to be brought up by relatives—we just don't know—must also have been difficult and painful for them.)

In recent years it has been suggested that Marić made important, even central, contributions to the work on relativity and the quantum. The title of one article gives us the tone of these suggestions: “Mileva Einstein-Marić: The Woman Who Did Einstein's Mathematics.”⁴I will return to this debate later in the talk.

This description of the young Einstein is not altogether edifying. We expect our heroes to be more heroic! Yet these were the formative years for Einstein. They culminated in 1905, when he published a series of papers in the *Annalen der Physik* that—it is no exaggeration to say—set the context for twentieth-century physics. The paper on special relativity is perhaps the most widely known. Another paper examined Brownian motion—the random motion you see when you look through a microscope at objects such as pollen grains suspended in a drop of water. This paper was instrumental in persuading scientists of the real existence of atoms, a matter of some dispute at the turn of the century. Still another—the only one Einstein described as “revolutionary”—suggested that light acted in some circumstances as though it were a particle, not a wave.

How was it, then, that this unimpressive young person—passed over for university positions and apparently settled in an obscure civil service job—came to revolutionize 20th century physics? What do we know of the education of Albert Einstein? And what, if anything, does it tell us about the education of our own students?

Einstein's education takes on a special significance for us as teachers. His experiences in these years left him with a lasting dislike of his own education, and a lasting distrust of educators. In his *Autobiographical Notes* he tells us

... one had to cram all this stuff into one's mind for the examinations,

whether one liked it or not. This coercion had such a deterring effect that, after I had passed the final examination, I found the consideration of any scientific problem distasteful to me for an entire year.

It is, in fact, nothing short of a miracle that the modern methods of instruction have not yet entirely strangled the holy curiosity of inquiry; ... I believe that it would be possible to rob even a healthy beast of prey of its voraciousness, if it were possible, with the aid of a whip, to force the beast to devour continuously ...⁵

Nor did his later experiences as a university professor change his mind, to judge from this excerpt from a speech in 1933:

When I was living in solitude in the country, I noticed how the monotony of a quiet life stimulates the creative mind. ... Such occupations as the service of lighthouses and lightships come to mind. Would it not be possible to place young people who wish to think about scientific problems, especially of a mathematical or philosophical nature, in such occupations?⁶

Perhaps most devastating is this excerpt from a letter to a young woman who had written him expressing her frustration with her own teachers:

Incidentally, I am only coming to Princeton for research work, not as a teacher. There is too much education altogether, especially in American schools. The only rational way of educating is to be an example—if one can't help it, a horrible example.⁷

Thus Einstein's early years raise at least two interesting questions: How did this young person, a high school dropout and a less than successful university student, develop into one of the most important and most influential scientists of all time? And perhaps closer to home: How ought we to react to his denunciations of educators?

Einstein has not made it easy for us. In these same Autobiographical Notes he tells us very little about his personal life, at one point observing that

What is essential in the being of a man of my type lies precisely in *what* he thinks and *how* he thinks, not in what he does or suffers.⁸

Yet here and there, Einstein does tell us something about his education. There have been many biographies. And the recently published first volume of Einstein's papers includes a previously unknown collection of letters between Einstein and Mileva Marić in the years before their marriage in 1903.⁹

EINSTEIN'S FORMAL EDUCATION

Let me now turn to Einstein's formal education. We should first dismiss the myth that Einstein was initially a slow student. He tells us in his *Autobiographical Notes*¹⁰ that by the age of 12 he had worked out his own proof of the theorem of Pythagoras. He had taught himself calculus by the time he was 16. When he dropped out of gymnasium to follow his family to Italy, he took with him a certificate from his mathematics teacher testifying to his mathematical ability. Moreover, it appears that his grades were good, even in the required Latin and Greek that he detested.¹¹

Yet, if he was not a slow student, he was surely a difficult one. One biographer tells a story—probably heard from Einstein himself—that shows Einstein's attitude.

One day his teacher summoned him and told him that it would be desirable if he were to leave the school. Astonished at the turn of events, young Einstein asked what offense he was guilty of. The teacher replied: "Your presence in the class destroys the respect of the students."¹²

We have all had *those* sorts of students in the back row!

Einstein fully returned these sentiments. He later described his Munich education as "drill, external authority, and ambition,"¹³ and many of his biographers have spoken with horror of rigid "Prussian" educators. But in fact the south German city of Munich was hardly Prussia. Indeed, Einstein's gymnasium had the reputation in the years he was there as a progressive and humane institution, one that many of its graduates spoke of with affection.¹⁴ Einstein's reaction may simply have been a determined refusal to concern himself with subjects like the mandatory Latin and Greek, and his equally strong reaction to German nationalism. After he had left Germany to follow his family to Italy, he renounced his German citizenship in order to avoid compulsory military service.

By leaving gymnasium without a degree, Einstein had closed himself off from university education in Germany. He was, however, able to take an entrance examination at the ETH in Switzerland. He failed. Yet his performance in mathematics and physics impressed his examiners, and he was encouraged to spend a year in the Swiss cantonal school at Aarau, about 20 miles west of Zurich. On graduation, he would then be automatically admitted to the ETH.

Einstein did indeed attend Aarau, and by all accounts had a marvelous year. He attended the "technical division," which was not a classical gymnasium at all, but what was called an "oberrealschule" that did not require classical languages. The school was small and the atmosphere informal. In addition, it had recently opened a new and remarkably well-equipped physical laboratory. He still did rather badly in French that year, but nevertheless passed his final examinations and was consequently admitted to the ETH in the fall of 1896.¹⁵

The ETH was not, strictly speaking, a university. Rather, it was what Germans

(and German-speaking Swiss) called a “*technische Hochschule*.” The literal translation, “technical high school,” is entirely misleading. These schools were more like our engineering schools and institutes of technology. They had a lower status—in Germany, for example, they were not permitted to grant doctorates until 1899, and even then only over the strenuous objections of the universities.¹⁶ Einstein enrolled in Division VI, which prepared students to teach mathematics and physics in secondary schools.

It was, for all that, a rigorous program with an excellent reputation. (It should be noted that then, as now, European expectations for secondary school teachers were notably higher than our own!) Einstein’s physics professor, Heinrich Weber, had an outstanding reputation both as a teacher and an experimental physicist. The laboratory he established at the ETH, which specialized in the new electrical technology, was one of the best equipped in Europe.¹⁷ Einstein took his introductory physics course from Weber and did his senior thesis (as we would call it) under Weber’s direction as well. His grades in both were good.

Nevertheless, by the end of his time at the ETH, Einstein and Weber were not on good terms. One biographer tells us that “Einstein persisted in calling him ‘Herr Weber’ instead of ‘Herr Professor’, ” and adds that “Such trifles can often give rise to instinctive dislike.”¹⁸ There were more substantial reasons for this dislike, on both sides. The physics courses of Weber and others were badly out of date—they did not cover Maxwell’s theories of Electricity and Magnetism, for example. Perhaps in reaction, Einstein took to cutting classes fairly regularly. By neglecting his courses, he found time to he read on his own—often in the company of Mileva Marić—many of the classic works of 19th century physics, including those not covered in the ETH curriculum. He also spent a good deal of time in the laboratory, where, much to the dismay of his instructors he spent more time puttering about on his own than attending to the required exercises. His transcript carries a reprimand for lack of diligence in the laboratory! Then, as now, such behavior does not impress eminent professors. As one biographer remarked,

Perhaps it was on this account that Weber once said: “You’re a very clever boy [Junge] Einstein, an extremely clever boy, but you have one great fault; you’ll never let yourself be told anything.”¹⁹

Another of his instructors, Jean Pernet, urged him to try medicine, law, or perhaps philology, since he clearly had no talent for physics.²⁰

He made no better impression on Hermann Minkowski, from whom he took a number of mathematics courses. Minkowski, then in his mid-30s, was already an well-known mathematician [born 1864]—and unlike the physicists at the ETH, he was very much up to date. Einstein nevertheless seems to have taken an even more casual approach to mathematics. Minkowski, who, ironically enough, later developed the mathematical framework that we still use for special relativity, said sometime after 1905 that

For me it [Einstein's work] came as a tremendous surprise . . . for in his student days Einstein had been a lazy sluggard [Faulpelz]. He never bothered about mathematics at all.²¹

It did not help that Einstein was apparently none too shy about expressing himself. A fellow student remembered that in his last year at the ETH, on leaving one of Minkowski's lectures, Einstein remarked that it was the first lecture on mathematical physics he had heard at the Poly.²² Similar blunt observations abound in his correspondence. In a letter to Mileva Marić in December 1901, he speaks of Alfred Kleiner, a professor of physics at the University of Zurich who was encouraging him to work on a Ph.D. dissertation: "Since that bore Kleiner hasn't answered yet, I am going to take him to task on Thursday. . . . if he has the gall to reject my doctoral thesis, then I'll publish his rejection in cold print together with the thesis, and he will have made a fool of himself." A few days later, he writes again: "Today I spent the whole afternoon with Kleiner in Zurich and explained my ideas on the electrodynamics of moving bodies to him and otherwise talked to him about all kinds of physical problems. He is not quite as dumb as I had thought, and moreover he is a good guy." No wonder Marić was moved to say in a 1901 letter to a friend, ". . . it is unlikely that he will soon get a secure position; you know that my sweetheart has a very wicked tongue and is a Jew in the bargain." ²³

As a result of cutting classes and paying little attention to his courses, Einstein got through his graduation examination in 1900 only with the help of the careful lecture notes of his friend Marcel Grossmann. Even then, he finished dead last among the four people who took and passed the exam that year, in spite of having led his class in an intermediate exam two years earlier. Marić, who also took the exam that year, did not pass. It was this examination against which Einstein spoke so vehemently in his *Autobiographical Notes*: ". . . one had to cram all this stuff into one's mind for the examinations, whether one liked it or not." Let us put this statement in context: What were these horrible examinations like?

Max Born, a prominent 20th century physicist and in later years a close friend of Einstein, says in his autobiography that he took a rigorous examination at the end of secondary school; his next examination—not a very serious one, he tells us—was his final oral examination for his Ph.D. German universities in this period did not run heavily to examinations! In Born's own words,

But before I could plunge into this wide field of learning I had to finish my classical education by passing the school leaving examination (Abitur). It is the only serious examination which I have ever taken in all my life—for the doctor's degree was mainly given on the merit of a thesis, the oral being rather undemanding and easy. If you compare this with the number of competitive examinations which a student in England has to pass after the leaving certificate—one every term and a bigger one at the end of each year with finals for the first degree and more for each higher degree—you will understand the difficulties which I had and still have in

performing the duties of a British professor. I was accustomed to a less formal, more individualistic method of grading the merits of students, and I still think that it is by far the better method.²⁴

There was much more ‘academic freedom’ in Germany than in England; no fixed syllabus, no classes, no examinations apart from the finals (doctor’s degree and professional certificates), free choice of teacher, and therefore healthy competition among the professors . . .²⁵

Born also described his own approach to teaching:

I organized a three-year course in theoretical physics, consisting of six series of lectures corresponding to the six semesters. The students who attended were supposed to know calculus and analytical geometry; therefore most of them began our course in their second year after having taken one year of mathematics—but of course we did not ask them, nor care, where they had learned it. There was, as I have said before, complete freedom of teaching and learning at the German universities, with no class examinations, and no control of the students. The University just offered lectures and the student had to decide for himself which he wished to attend and whether he was able to follow them.²⁶(p 210)

Now the ETH, as we have seen, was not a university but a technische Hochschule, more oriented toward practical degrees and professional certification; and the Swiss system may have differed slightly from the German. In any case, Einstein was actually given grades in a full *one-quarter* of the courses listed on his final transcript!²⁷(I am not sure how these grades were determined; certainly neither Einstein nor any of his biographers mentions examinations in the courses.) Einstein did take an oral intermediate examination in 1898, and the oral graduation examination in 1900 that I have already described. The latter was required for certification as a secondary school teacher—that is, it was more in the nature of a professional certification exam. Such was the horrible gamut of examinations of which Einstein complained. One can only speculate how Einstein might have done in an American university, with its frequent examinations. One American academic, having heard Einstein’s story, responded with horror that at his own university,

Einstein would never have made the Dean’s List . . . I also doubt very much if he could have passed the college entrance examinations, and he would probably have been put on probation.²⁸

THE MAKING OF A PHYSICIST

We have followed Einstein to 1900, the year in which he graduated from the ETH. We have also seen that he learned much—perhaps most—of his physics on his own,

through independent reading and study. Let us pause for a moment and consider the state of the physics profession that Einstein was trying so hard to join.

We speak today of “classical physics”—physics as it was at the turn of the century. The phrase conjures up images of physicists seated under stately doric columns, serenely contemplating their own perfection. The eminent American physicist, Albert Michelson, observed in an 1894 address that

... it seems probable that most of the grand underlying principles have been firmly established ... the future truths of Physical Science are to be looked for in the sixth place of decimals.²⁹

This picture is not a little misleading. It is less frequently noted, for example, that Michelson was an outstanding *experimental* physicist, suspicious of new theories but supremely gifted in the measurement of the “sixth place of decimals”!

In fact, physics was—as usual—in some disarray. Mechanics—the laws governing matter and motion—had long been the core of physics. But the spectacular success of new theories of electromagnetism and heat were challenging this “mechanical world view.” Perhaps the basis of mass itself was electromagnetic, and mechanics was not fundamental at all.

To take another example: The work of James Clerk Maxwell in England and Ludwig Boltzmann in Germany argued strongly that the laws of thermodynamics—that is, the theory of heat—could be explained by the underlying motions of atoms and molecules. Yet many eminent scientists declined to agree that these atoms even existed, and wanted to divorce the study of heat from mechanical, atomic models. These disagreements were noisily debated not only in the rarified atmosphere of professional journals, but even in textbooks.

For example, Ludwig Boltzmann, who spent much time in his later years defending his atomic theories, noted sadly in his *Lectures on Gas Theory* that

I am conscious of being only an individual struggling weakly against the stream of time. But it still remains in my power to contribute in such a way that, when the theory of gases is again revived, not too much will have to be rediscovered.³⁰

Wilhelm Ostwald—a chemist, to be sure—was among the most vehement of Boltzmann’s critics. He loudly denounced mechanical, atomic models in his widely read *Textbook of General Chemistry*. In their place he substituted his science of “energetics”—his own less than rigorous theory of energy and its transformations that he thought would somehow eliminate the need for atomic models.

*all that we have until now been able to express by the ideas of Matter and Force—and much more besides—may actually be expressed by the idea of energy.*³¹

Ostwald spoke of the “dogmatic character” of the hypothesis that heat is motion. He described the formation of mechanical hypotheses as a “childhood state of the intellect,” and observed that Boltzmann’s kinetic theory

has led to progress only in few and relatively minor ways, in spite of the quite extraordinary expenditure of sagacity [Scharfsinn] and computational work that has been squandered on it³²

Even Max Planck was gently skeptical of atomic theories. In the preface of his *Lectures on Thermodynamics*, he observed that

Obstacles, at present unsurmountable, . . . seem to stand in the way of its further progress . . . due . . . principally to essential difficulties . . . in the mechanical interpretation of the fundamental principles of thermodynamics.³³

For all that, Planck was not an ally of Ostwald; he thought Ostwald’s energetics badly conceived, and as part of a vigorously conducted exchange in the *Annalen der Physik* in 1897, denounced Ostwald’s concept of volume energy as “a mathematical unthing.”³⁴ And Walther Nernst—another chemist and curiously, a protegé of Ostwald—thundered in his *Theoretical Chemistry* that

[The] molecular hypothesis, more than any other theoretical speculation, has given powerful and varied assistance to every branch of physical science Therefore, in the following presentation of theoretical chemistry, the molecular hypothesis will receive special consideration³⁵

It must have been more fun to study science in those days. Our textbooks today are by comparison a little dry.

Let us now return to Einstein, whom we left just after he had graduated from the ETH. As we have seen, he had not gotten much from his courses—it was the work of Boltzmann, Planck, Ostwald, Nernst, and others, from whom Einstein learned his physics. He had learned of the controversies as well. He tells us in his *Autobiographical Notes* that he had been impressed by the disarray in which physics found itself. That recollection is confirmed in his many references to his reading in the recently discovered letters to Mileva Marić.

As we have also seen, he had thoroughly alienated his ETH professors. Of the four students in his year who graduated, Einstein was the only one who was not offered an assistantship. His determined attempts to find one elsewhere met with utter indifference; in a despairing letter to Marić he observes that he would soon “have honored all physicists from the North Sea to the southern tip of Italy” with job inquiries.³⁶

Yet surely his professors were mistaken. His correspondence with Marić abounds with references both to his reading and to the directions that reading was taking him. Had he not, by this time, mastered physics on his own?

Alas, the evidence is that he had not. His first two papers, published in 1901 and 1902, applied thermodynamics and his own theory of molecular forces to problems involving surfaces between fluid states—the context, then, was the physical chemistry of surfaces. These papers have not been carefully studied. I have been trying to make some sense of them, but I haven't yet, and so for once I will resist the temptation to talk about things I don't understand—or at least, I won't talk about them much! In brief, his approach was not only unsuccessful, but unproductive—it does not appear to have lead him in interesting directions. He shows in one paper that he did not fully understand the second law of thermodynamics. It is even likely that for a while, he was under the influence of Ostwald's increasingly discredited energetics.³⁷ Einstein himself later referred to these papers as his “two worthless beginners' works.”

These early papers did serve the useful purpose of introducing Einstein to the scientific world. As the English physicist Lord Rayleigh once said, perhaps with tongue in cheek, but with a good sense of how scientific reputations are made,

... a young author who believes himself capable of great things would usually do well to secure the favorable recognition of the scientific world by work whose scope is limited, and whose value is easily judged, before embarking on greater flights.³⁸

But there is nothing in these papers that strikes one today as even suggesting what was to come. Nor did they excite any great interest. They were dead ends. I am not sure his professors can be blamed for failing to recognize his potential.

Similarly, his letters to Marić from this period show us an ambitious and enthusiastic young physicist. But if we did not know they had been written by Einstein, I am not sure they would suggest any great talent.

Then there is a change. Between 1902 and 1904 Einstein published three more papers, in which he reinvented a great deal of the molecular theory of heat that had been done by Ludwig Boltzmann in Austria and Josiah Willard Gibbs in the United States. These papers still lack the originality of Einstein's later work, but do show a clear growth in sophistication and understanding. That growth is all the more remarkable when we remember Einstein had a demanding schedule at the Patent Office. He was working in isolation from the physics community. He had only his reading and discussions with friends to rely on. And yet, he was beginning to explore not one but several new avenues that would change the course of 20th century physics.

THE ROLE OF MILEVA MARIĆ

At this point, given the time remaining, we have a choice. We can follow in detail the evolution of Einstein from the unsuccessful student of 1900 to the earthshaking revolutionary of 1905. This path is safe, well mapped out, fairly well understood—

entirely suitable for scholarly discourse. Or, we can ask ourselves about Mileva Marić: Who was she? Was she really the “woman who did Einstein’s mathematics”? What is the fuss that has made even the pages of the *St. Cloud Times* all about? This path is a little disreputable. The evidence is controversial. The dispute involves as much contemporary academic fashion as it does well-charted history.

Can there be a choice? With the shining example of Oppenheimer and the Princeton physics teas firmly in view, let me turn Marić, and explain to you what I don’t altogether understand!

Let me say at the outset that we have a fine line to tread. We must recognize that Mileva Marić must have been enormously determined, and at least reasonably capable, to pursue the study of physics and mathematics, as a woman in Austria-Hungary and Serbia at the turn of the century. We must recognize as well that her sex, her marriage, and her failure to graduate, effectively closed off any sort of career—she seems to have been preparing herself to teach mathematics and physics at a women’s gymnasium, and in fact, she applied for several such positions before her marriage to Einstein.³⁹

That said, we must also recognize that the evidence that she contributed substantively to Einstein’s thinking in 1905 is at best slim, and may tell us more about academic fashion in late 20th century America than it does about Einstein and Marić in 1900. Throughout his life, Einstein needed to talk through his ideas with whoever he could find to listen. In these years, that group included friends from the ETH, colleagues at the patent office, and the “Olympia Academy”, an informal discussion group of friends in Bern. It is now clear from his correspondence that this circle very much included Mileva Marić. But there is no evidence that any of them did much more than serve as sounding boards and sources of support and encouragement as he worked out his ideas. Having stated my position, so that you may look for holes in it as I continue, let me go on to outline the evidence.

THE SOURCES

With this sort of controversy, the nature of the sources is of crucial importance. I shall be drawing on several—with varying degrees of authenticity and persuasiveness:

- Peter Micheltore, *Einstein, Profile of the Man* (1962).⁴⁰

Micheltore appears to be a journalist and popular author—he does not seem to have a scientific background. His biography of Einstein is nevertheless interesting because it is based on extensive interviews in 1962 with Einstein’s oldest son, Hans Albert. He also did interviews with a number of Einstein’s friends and associates, and used a number of early biographies of Einstein. It is a popular treatment—there are no notes—and the reader is left to guess the source of any particular story. And of course, the recollections of Hans Albert, born in 1904, must be used with care in reconstructing Einstein’s and Marić’s lives from 1896 to 1905!

- Desanka Trbuhović-Gjurić, *In the Shadow of Albert Einstein: The tragic life of Mileva Einstein-Marić* (1969; 1983)⁴¹

The title is a translation. The book was first published in Serbian in 1969, and drew the usual attention that works published in that language attract in Europe and the United States! A German translation, with an introduction by the author, was published in 1983. It is still not widely known.

Trbuhović-Gjurić (1897–1983) was a Yugoslavian and I think, Serbian, mathematician and physicist who studied in Italy, Austria, and Switzerland, and taught in various Balkan gymnasia. She drew on conversations with Marić’s friends and acquaintances, as well as her correspondence. She also shows a close acquaintance with the biographies of Einstein published through the early 1960s. But like Micheltore (whose book she uses), she does not always give references, and one is often left to guess the source of a particular story or assertion. Moreover, she draws heavily on conversations with acquaintances of Marić, many years after the fact. It is nevertheless the only biography we have of Marić, written by someone only a generation or so younger, who must have known well and at first hand the obstacles she faced.

Trbuhović-Gjurić argues that Marić played a central role in the mathematical formulation of Einstein’s 1905 work.

- *The Collected Papers of Albert Einstein*, Vol. I (1987), which contains a number of letters of both Einstein’s and Marić’s through mid-1902. These letters include 51 previously unknown letters between Einstein and Marić in the years before their marriage:
 - 10 letters from Marić to Einstein
 - 41 letters from Einstein to Marić

It is clear from context that a good many of their letters have not been preserved. The letters we do have were saved by Marić, so it is not surprising that we have more of Einstein’s than hers.⁴²

 - In addition, there are 8 letters from Marić to her friend Helene Savić; some of these letters are not given in full in the Einstein papers.
- The 1955 recollections of Abram F. Ioffe, a Russian physicist. In a 1955 memoir, he recalled seeing the manuscripts of three of Einstein’s 1905 papers with the name “Einstein-Marić” on them.

Within the last few years two authors have used these sources to make sweeping inferences about Marić’s role: one is Senta Troemel-Ploetz, a Professor of German writing in the *Women’s Studies International Forum*; the other is Evan Harris Walker, a physicist, in two long letters in *Physics Today*, a general interest physics journal. Let’s see what their arguments are.

THE YOUNG MARIĆ

I will begin with a brief sketch of Mileva Marić's early years, drawing primarily on Trbuhović-Gjurić. Marić was born in 1875, in Titel, at that time a town in Austria-Hungary, and later in Yugoslavia. Given current headlines, I am not quite sure where it is now; but in any case, it is about 30 miles north of Belgrade. Her father was a noncommissioned officer in the Austro-Hungarian army, and later a civilian official in the Austrian civil service. Her mother's family was, I gather, fairly prosperous—Trbuhović-Gjurić describes her mother's house as "one of the most beautiful and richest in Titel." Both parents were Serbian by nationality (p 13). Her father spoke German as well, and both Serbian and German seem to have been spoken at home.

At the turn of the century, the border between Austria-Hungary and Serbia ran roughly east-west at the latitude of Belgrade (the Serbian capital), along the Sava and Danube rivers. Austria-Hungary seems to have encouraged the migration of various nationalities in this region—so it was not unusual to find people like Mileva's father, Miloš Marić, Serbian in nationality and perhaps in sympathies, but nevertheless in the service of Austria-Hungary. Marić was born in her mother's home in Titel, and spent her early years first in Kać, another village close to the larger town of Novi Sad, and then in Ruma, a town just south of Novi Sad.

Thus she began her schooling in Ruma, in 1882. She showed such promise that in 1886/87 she was in the Serbian Higher School for Young Women [Höheren Mädchenschule] in nearby Novi Sad (Neusatz). A friend recalled she was the best student in the school. The following year found her in a "realschule" in Mitrovica, another nearby town. She could not, it appears, go on to a gymnasium in Austria-Hungary; so in 1890 she moved on to the royal Serbian gymnasium in the town of Šabac, just across the Sava river in Serbia, and so still fairly close to home.

Two years later came yet another move, when her father was transferred to Zagreb, over 200 miles to the northwest of Ruma. Here she was able to enroll as a "private student" in the royal higher gymnasium. She had to take a special examination in Greek, which had not been taught at her previous school. She requested and received special permission to study physics in the same class with the "regular" students—presumably the men. Again she distinguished herself, especially in physics and mathematics. But once again she moved on. The fall of 1894 found her at the Higher Women's School [Höhere Töchterschule] in Zurich. The reasons appear to be dissatisfaction with both the school and the living conditions at Zagreb, where her health had suffered. The presence of a friend in Zurich seems also to have played a part. In any case, it would have been natural for her to go to Switzerland for further schooling. Swiss universities had admitted women for some years, and there was a substantial colony of Slavic students from Serbia and Russia in Zurich.

Marić graduated from the Higher Women's School in 1896. After a single term at the University of Zurich, in a pre-medical program, she transferred to the ETH as a physics and mathematics student. It was there, as we have already seen, that she met Einstein.

It is clear from this account that Mileva Marić must have had an enormous

determination and will to succeed. It is apparent as well that she must have had the encouragement and financial support of her family. Much less clear are the extent of her talent for mathematics and physics, and equally important, the quality of her early instruction. Trbuhović-Gjurić remarks that she had no real encouragement in her pursuit of mathematics and physics; and that (p. 28) “She made her way alone.” I suspect that even men might have found provincial Hungary and Serbia less than ideal places to pursue mathematics and physics.

Certainly that was the experience of Michael Pupin, another Serbian from this same part of Hungary, and later a physicist and inventor at Columbia University in this country. Pupin tells us in his autobiography that when he told his parents about Benjamin Franklin’s theory that lightning was an electric spark, his father angrily reminded him that thunder was caused by St. Elijah’s car as he drove across the heavens. Fortunately for his later scientific career, Pupin was saved by his mother, who reminded everyone that St. Elijah’s car was not actually mentioned in the Holy Scriptures, and so perhaps Franklin’s idea should not be rejected out of hand.⁴³ Marić, to be sure, came from a higher stratum of Serbian society, and probably did not have to defend herself against St. Elijah. Nevertheless Mileva Marić—a woman in the 1890s, faced with moving from school to school, far from the centers of European science—must have found it difficult indeed to persevere in her education.

MARIĆ AND EINSTEIN

Limitations of time prevent me from giving Marić’s background in more detail, or talking about how her relationship with Einstein developed. Suffice it to say that her record at the ETH was not a success. Like Einstein, she took two examinations at the ETH, both oral. On the first she finished second lowest in her group.⁴⁴(I don’t know the size of the group; Einstein had finished first out of six a year earlier.) She finished last, and did not pass, her final examination in 1900. A second attempt a year later, when she was several months pregnant, was also unsuccessful.

With this all too brief sketch of Marić’s early life as background, let us turn to the arguments pro and con about her possible influence on Einstein.

Marić as Einstein’s collaborator

Marić certainly had a background in physics and mathematics comparable with Einstein’s, and they had worked closely together as undergraduates. Moreover, there are suggestions in the letters that they were working together on research. In these letters, Einstein speaks of her as an equal, and refers several times to their common work. For example:

- From September 1900: “How proud I will be when maybe I’ll have a doctor for a sweetheart while I am myself still a totally ordinary man.”[Doc 75]
- From Oct 1900: “How lucky I am to have found in you a creature who is my equal, who is as strong and independent as I am myself!”[Doc 79]

- From March 1901: “How proud and happy I will be when we have brought our work on relative motion to a victorious conclusion.” [Doc 94]
- And in April 1901: ”I’ve got an extremely lucky idea that will make it possible to apply our theory of molecular forces to gases as well.”[Doc 101]

Furthermore, Truhović-Gjurić reports that when Mileva’s brother Miloš visited them in Bern in the summer of 1905, Einstein told him that “She [Mileva] first called my attention to the significance of the aether.”⁴⁵

Marić, on the other hand, never refers to their work as joint. In her 10 letters to Einstein, she rarely talks about physics at all, in sharp contrast to Einstein. There are, however, two references in letters from her to Helene Savić, about the material Einstein refers to as “our theory of molecular forces.” Neither letter so much as hints that the work was in part hers.

- From a Dec 1900 letter to Helene Savić: “Albert has written a paper in physics that will probably be published very soon in the physics Annalen. You can imagine how proud I am of my darling. This is not just an everyday paper, but a very significant one . . . We sent also a private copy to Boltzmann . . .” [Doc 85]
- From a Dec 1900 letter to Helene Savić: “Albert has written a magnificent study, which he submitted as his dissertation. He will probably get his doctorate in a few months. I read it with great joy and real admiration for my little sweetheart who has such a good head on his shoulders. . . . It deals with the investigation of the molecular forces in gases using various known phenomena.” [Doc 125]

Moreover, Einstein himself in the letters also regularly refers to “my” rather than “our” work. For example:

- From Oct 1900: “In physical chemistry I am now quite well versed. I am delighted by the accomplishments attained in this field over the last 30 years. You will enjoy it when we go over it together. . . .
 “The results on capillarity, which I recently found in Zurich, seem to be totally new despite their simplicity. When we come to Zurich, we shall seek to get empirical material on the subject . . . If a law of nature emerges, we will send it to Wiedemann’s Annalen.” [Doc 79]
- From Dec 1901: “I am now working very eagerly on an electrodynamics of moving bodies, which promises to become a first rate paper. I wrote to you that I doubted the correctness of my ideas on relative motion. But by doubts were based on a simple mathematical error. Now I believe in it more than ever.” [Doc 128]

- From Dec 1901: “Today I spent the whole afternoon with Kleiner in Zurich and explained my ideas on the electrodynamics of moving bodies to him . . .” [Doc 130]
- Finally, from an April 1901 letter to Marcel Grossmann, who had been in the same class with them at the ETH, and who know both well:
 “I am now convinced that my theory of atomic attraction forces can also be extended to gases . . .” [Doc 100]

This second set of excerpts suggests that the evidence of the letters is at best ambiguous. The collection of letters is certainly incomplete, and who knows what may turn up. But given what we have now, Einstein’s references to “our” work, taken in the context I have described, do not make a strong argument for any substantial collaboration.

Mileva Marić and Einstein’s Mathematics

There is also a claim that Marić helped Einstein with his mathematics. We know that Einstein at this time was not interested in pure mathematics. Philipp Frank, a physicist and biographer of Einstein, who knew him fairly well, says Einstein

believed that the most primitive mathematical principles would be adequate to formulate the fundamental laws of physics.⁴⁶

Truhović-Gjurić, followed by Troemel-Ploetz, argue that Mileva helped him with the math! There is certainly some evidence for this statement. Micheltore, presumably drawing on the recollections of Einstein’s son Hans Albert, notes that “Mileva helped him solve certain mathematical problems,” (p 45) and that she had checked over the special relativity manuscript “again and again.” And Truhović-Gjurić reports several recollections of Marić’s Serbian acquaintances who recall Einstein making similar, very general statements. Truhović-Gjurić also says that Mileva’s help stopped after the birth of their second son, in 1910 (p 89).

But Truhović-Gjurić goes considerably farther when she says (p 72) that Marić “was not the co-author of his ideas, . . . but verified his ideas, discussed them with him, and gave his theories on relativity and on the extension of Max Planck’s quantum theory their mathematical expression.” She gives no specific evidence for the last statement. It is these statements that Troemel-Ploetz has picked up and talked about in her article.

Perhaps part of the difficulty lies in what a physicist means by “primitive” mathematics! Einstein had taught himself the calculus by age 16. In his first two years at the ETH he took graded courses on calculus and differential equations, and did well. He also did well on the mathematics parts of his 1898 oral examination, scoring 5.5 out of 6. The mathematics in these courses, as developed and built on by the physics he was reading and studying, would likely have sufficed for most if not all of what he did in 1905; it is the physics that is spectacular, not the mathematics.

Not until he began work on General Relativity several years later did he find himself at a loss mathematically. And then he turned for help not to Marić but to Marcel Grossmann, another friend from the ETH.

I do not know Marić's grades in these early courses, or the specifics of her performance on the intermediate examination. On her failed final examination in 1900, Marić's grades were equal to or a little below Einstein's on every subject but mathematics ("function theory"), where she did very badly (2.5 of 6 compared to Einstein's 5.5 of 6).⁴⁷ Had she equaled his performance in mathematics, she might well have passed.

Thus it is entirely probable that Einstein and Marić talked over the substance of these early papers. Their discussions may well have included mathematical points. She may also have checked his work—both then and later, Einstein does not seem to have gone over his work carefully for errors of detail. But it is another matter altogether to suggest, as do Trbuhović-Gjurić and Troemel-Ploetz, that Marić was responsible for the mathematical formulation of the work. There is certainly no specific evidence that she did so. And we do know that Einstein was entirely capable of handling the straightforward mathematics involved in his work up to 1905.

For what it is worth, Evan Walker makes the opposite suggestion—that Marić supplied the ideas, and Einstein the mathematics! There is an equal lack of evidence for this position.

The Divorce Settlement

A more fanciful argument for Marić's contribution lies in the terms of the couple's divorce decree. When Einstein and Marić were divorced in 1919, one part of the agreement gave Marić the entire monetary proceeds of the Nobel Prize that Einstein was sure to get eventually. It has been suggested that this settlement should be read as Einstein's belated, albeit private, recognition of Marić's contributions.

When they separated in 1914, they had been in Berlin. Einstein remained there, and Marić returned to Zurich. Thus a much more likely explanation lies in the difficulty Einstein seems to have had getting money from Germany to Switzerland during and immediately after the first world war. It was all but certain that he would win a Nobel Prize in the near future, and it would have been easier to transfer funds from Sweden to Switzerland. And again, there is to my knowledge nothing in the divorce settlement itself or in any correspondence that remotely suggests the Nobel Prize money was given to Marić in private recognition of her contributions.

The Decline in Einstein's Work

Though divorced in 1919, Einstein and Marić were separated in the summer of 1914. Trbuhović-Gjurić, Troemel-Ploetz, and Walker all suggest that by the time of the separation, Einstein's greatest years were behind him. Was it Marić, working behind the scenes, that made these early successes possible?

First, Einstein's work on General Relativity, published in final form late in 1915, was at least as revolutionary as anything he published in 1905. He began to work

on the theory in a serious way in 1911. And according to Trbuhović-Gjurić, Marić had stopped working closely with him by 1910. They were separated in the summer of 1914, well before the last critical steps in the development of the theory had been completed. And even apart from Trbuhović-Gjurić, Einstein’s biographers suggest that relations between the two were strained in the last few years before they separated, and it thus seems unlikely that they would have been working closely in those years.

Furthermore, Einstein was active in the development and interpretation of quantum mechanics throughout the 1920s and 30s, and made several central contributions. Others did take the lead in developing quantum physics during this period, and Einstein’s work was certainly not as revolutionary as his contributions before 1916. Neither was it insignificant; Einstein would be remembered for this work had he never done anything else. And even an Einstein must be permitted to slow down eventually.

The 1955 account of Abram Ioffe

The reference is to the 1955 recollections of Abram F. Ioffe, a Russian physicist born in 1880. In 1905 he was working as an assistant to Wilhelm Roentgen, one of the editors of the *Annalen der Physik*. In his 1955 memoir, he recalls seeing the manuscripts of three of Einstein’s 1905 papers with the name “Einstein-Marić” on them. These manuscripts are no longer extant. Ioffe apparently interpreted this name as a hyphenated form referring only to Einstein. This interpretation may be correct, though people familiar with Einstein’s papers tell me that they know of no other examples of Einstein signing his name in this way. I have not examined this source myself; as far as I know, it has never been translated from the Russian, nor has it ever been talked about by historians familiar with the history of science of this period.⁴⁸

EINSTEIN’S EDUCATION REVISITED

What, then, are we to conclude from all of this? Certainly Mileva Marić was among those who contributed to the education of Albert Einstein—by listening, by talking through problems with him, by reading his manuscripts for detail, and by providing the support and encouragement he must have needed in those years. There is little evidence that she did more.

As we have seen, Einstein throughout his life needed to talk through his work with others. In these early years Einstein was talking through his ideas with friends and with colleagues at the patent office as well as with Marić. He even mentioned one of them, Michelle Besso, in the 1905 relativity paper, where he said that “I am indebted to him for many a valuable suggestion.”

Another example: In a 1952 letter to Einstein, Besso says that he had been talking with Joseph Sauter, one of Einstein’s colleagues at the patent office:

“Lately he found again your papers on thermodynamics [1902b, 1903] . . . He remembers having discussed one of them at length at that time, and having to a certain extent saved what was essential in it, in spite of a mistake that he discovered, this in the face of a pessimistic attitude on your part . . .”

For his part, Einstein remembered these discussions with Sauter, although—after 50 years—he had no recollection of which specific points were at issue.⁴⁹

Thus any of these Einstein’s circle, Marić included, could conceivably have made central contributions during this period. But there is no solid evidence that any of them actually did so, nor did any of them ever claim to have made such contributions—again, Marić included.

By some accounts, Einstein did not even need his listeners to understand fully what he was discussing. Philipp Frank tells us in his biography that during the years Einstein was in Berlin,

There was yet another factor that brought Einstein into closer contact with his students. This was his need to clarify his ideas for himself by expressing them aloud and explaining them to others. Thus he often conversed with students about scientific problems and told them his new ideas. But Einstein did not really care whether the listener actually understood what was being explained or not; all that was necessary was that he should not appear too stupid or uninterested.

Einstein once had an assistant who helped him with his administrative duties while at the same time completing his own studies in physics. Every day Einstein explained his new ideas to him, and it was generally said that if this young man had had only a slight talent, he could have become a very great physicist—very few students had ever received such good instruction. But while the student was an intelligent and industrious man and an ardent admirer of Einstein, he did not become a great physicist. The influence of the teacher is not so great as some people believe.⁵⁰

And with this quotation I return to my original theme, the education of Albert Einstein. It is not hard to see why Einstein spoke so critically not only of his own education, but of educators generally. As we have seen, Einstein learned physics pretty much on his own. He did not, it appears, learn a great deal from his teachers, who in turn, saw in him little promise. In the crucial years he worked entirely apart from the community of European physicists. It is a hard lesson for a teacher to come up against.

But it gets worse. Suppose Einstein had been more malleable, more open to guidance from the ETH faculty. Or suppose he had won his assistantship and had come under the influence of a mentor, someone like Lorentz in Holland or Boltzmann in

Vienna. Perhaps such a teacher, skilled at guiding and encouraging students, could have molded Einstein's thinking, brought him into the mainstream, and directed him to the problems that the leaders of 19th c physics thought important. Einstein would surely have become a successful physicist; but would he have become the original, revolutionary shaper of 20th c physics? Perhaps he was better off at the fringes.⁵¹ It is, for a teacher, a distressing case history—I'm not sure which alternative is the worst: to think we are not after all very good at recognizing promising students; to think we don't have as much effect on our students as we often suppose; or to think that such influence as we do have serves to sidetrack their creative energies and mold them into intellectual clones of ourselves.

Now of course Einstein was an exception. Then too, these things happened long ago, and doubtless people were different then. But the nagging fear remains: Is there, as Einstein suggested, "too much education altogether, especially in American schools"?

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