Preface

This is an expanded version of the talk I gave on October 17, 2015 as a part of the Hobbs Observatory Astronomical Series talks for the general public. In this version, I have included more material than it would have been feasible to use in a 50 minute talk. I hope that you will find it interesting. A note on the style of writing: I often write out my talks in some detail. This is a practice that I started in my days teaching people who didn't want to learn calculus based physics. In those days, I would even include the jokes that I would tell at the half-way point of the lecture in order to wake the audience up. I did not chose to continue that practice here at this time --Allan Moose

Einstein's Creativity

Part 1 Early Influences

Good evening. I'm delighted to see you here this evening. One hundred years ago next month, Albert Einstein completed a seven year struggle to develop a theory of gravity that was compatible with his Special Theory of Relativity. We can actually pin down the time of his completion of the General Theory of Relativity to the weeks of November 11 to November 25, 1915 because in the previous October, Einstein had scheduled weekly talks starting Thursday, November 4 and running through the 25th. The publication of what was covered in these talks gives us a week by week summary of his thinking. Because of the Einstein Collected Papers Project it is possible for us to now trace his steps in that eventful month as he cleaned up conceptual and mathematical errors that had haunted him since the summer and fall of 1911.

One of the three predictions of Einstein's theory was that the path of light from distant stars would be bent as it passed our sun. Four years after publication, on November 6, 1919, the British astronomer Arthur Stanley Eddington announced, before a joint meeting of The Royal Society of London and The Royal Astronomical Society, the results of an expedition to the West African island of Principe to photograph and measure the deflection of starlight during a total solar eclipse the previous May. Eddington's measurements showed very close agreement with Einstein's predictions. In an unusual move for the staid Royal Society, the press had been invited to the meeting with a promise of the announcement of startling new scientific results. The next morning the London Times featured the story on its front page:

Within two days the New York Times had picked up the story and published front page articles about Einstein's theory on two consecutive days. As a portent of things to come, the NY Times, published a total of sixteen articles on relativity that November. In what can best be described as a 'Phenomenon', a term I borrowed from Oprah Winfrey to describe sudden and unexpected celebrity status, the press catapulted Einstein into mega-superstar celebrity status, a position that has lasted until this day.

I will not dwell on Einstein's celebrity status beyond mentioning a few things that substantiate its unique nature. They include: the celebration of significant “Einstein Anniversaries” such as the 100th anniversary of his birth; the 100th anniversary of the “miracle year”, 1905, in which he published several ground breaking papers; and this year's 100 year anniversary of General Relativity. Then there was the naming of Einstein as Time Magazine's *Man of the Century.* Finally, a couple years ago, the editor in chief of the Einstein Collected Papers Project wrote that, as of her writing, 1700 books on Einstein had been published. That estimate is out of date as this one hundredth year anniversary has been the occasion of at least a dozen books, probably more, devoted to Einstein. One tends to think that we are running out of Einstein anniversaries, but I can think of at least one more coming up and that will occur in 2035 on the 100th anniversary of the publication of a paper by Einstein, Podolosky, and Rosen on the theory of Quantum Mechanics but that's a topic for another talk which I would be delighted to give on that anniversary if the opportunity presents itself.

Tonight, I will speak about Einstein the man. Next month, on November 21, I will tell you about Einstein's path to The Theory of General Relativity. In that talk I will, among other things, tell the story of his work leading up to the eventful stress-filled months of October and November when Einstein was in a race with one of the world's greatest mathematicians to obtain the proper equations to describe the gravitational field.

In broad terms, in my talk tonight I will describe life influences that helped shape Einstein into one of the greatest physicists of all time. A strong sub-theme in both talks will be what traits led Einstein to be such a creative thinker. While this might seem presumptuous on my part, I will be

drawing the substance of my remarks from Einstein's own writings as well as out of the way papers written by colleagues and historians of science. Thus, I will be offering you information that often is not in Einstein biographies. This is not to put down Einstein biographies in general as there are some very good ones out there, particularly those published recently. However, when I was growing up, there was a considerable mythology about Einstein floating around that originated in the 1920s and lasted through the 1970s. That mythology pretty much painted a caricature of the man and has been somewhat demolished since the start of publication of Einstein's papers in 1985. That ongoing project has produced 14 volumes so far and is projected to produce 30 volumes devoted to his writings and correspondence, and that's not including the countless number of books that will be published analyzing the content of his published work. To substantiate that projection, I need only mention that Einstein's notebook from the fall of 1912 alone has already generated four volumes of analysis.

Conceptually, I have broken my talk into five sections. The first deals with events influencing the young Einstein between the ages of 10-1/2 to 15. In the second, I will speak briefly about his college years. The third will deal with his time working in the patent office, which is interesting in several ways. In the fourth section, I will talk about Einstein's friendships. In the last section I will point out some of the things that influenced the way Einstein thought.

The Youthful Einstein.

It is generally accepted that the preteen through the teen years can be an important time in a person's development. Starting in 1889, when Einstein was 10-1/2, and lasting until he was 15, a young medical student named Max Talmey was a regular dinner guest in the Einstein home. Years later, in 1932, Talmey published a book titled *The Relativity Theory Simplified And the Formative Period of its Inventor.* It turns out that Max Talmey had an important influence on the young Einstein in several ways.

First, some background. The Einstein family were non-practicing Jews. At age 6, or so, young Albert was sent to a local Catholic school. Undoubtedly that school had instruction in the Catholic religion. In order to acquaint their son with his Jewish heritage, his parent arranged for him to receive instruction in the Jewish faith. As a result, and according to Einstein's own recollections, he went through a period of intense religiosity. Now, Talmey recollected that when he became a regular dinner guest, he and the boy became friends, and young Albert would discuss physical phenomena with him.

As a result, Talmey gave him a set of books, titled *Popular Books on Physical Science.* It's interesting that Einstein recalled these books 55 years later in his autobiography and remarked on the effect they had on him, though his recollection of the title differs slightly from Talmey's. In Einstein's own words:

> Through the reading of popular scientific books I soon reached the conviction that much in the stories of the Bible could not be true. The consequence was a positively fanatic orgy of free thinking coupled with the impression that youth are intentionally being deceived by the state through lies; it was a crushing impression. Suspicion against every kind of authority grew out of this experience.

Einstein goes on to say that the suspicion of authority never left him. We can surmise that the end result of this loss of traditional religious feeling was, for Einstein, a transference of that sort of reverence to the study of nature. This is implied by two things he said later in life:

> In every true searcher of Nature there is a kind of reverence, for he finds it impossible to imagine that he is the first to have thought out the exceedingly delicate threads that connect his perceptions
>
> My comprehension of God comes from the deeply felt conviction of a superior intelligence that reveals itself in the knowable world.

Talmey's influence on the young Einstein was not limited to just bringing him a set of books on natural science. A year or two earlier, Albert's uncle had introduced him to some basic ideas in algebra and geometry, in particular the Pythagorean theorem. Einstein recalled that he had, after much effort, 'proved' (his quotes) the theorem. The boy must have asked Talmey questions about geometry, because Talmey brought him a textbook of geometry. This book made a lasting impression on Einstein because as he put it,

> Here were assertions, as for example, the intersection of three altitudes of a triangle in one point, which --though by no means evident-- could nevertheless be proved with such certainty that any doubt appeared to be out of the question.

Talmey helped the boy work his way through the geometry book and in a few months he had made his way to the end. That success motivated him to continue further and Talmey recommended a set of books on higher mathematics. In his autobiography, Einstein said that by the time he was 16 he had learned differential and integral calculus, analytical geometry, and infinite series. I would like to

point out that this pretty much demolishes the myth that Einstein flunked mathematics. Talmey reports that when young Albert's mastery of mathematics went beyond his own, their conversations switched over to philosophy such as Kant's *Critique of Pure Reason.* This was the start of Einstein's lifelong interest in philosophy, which as we will see in next month's talk had a strong influence in his approach to physics.

Einstein's precocity in mathematics during his youth, is interesting in and of itself, but there is another experience that is worth noting. Again, let me give you some background. Remember we are talking about life in the mid 1890s. That as you may, or may not, recall, was before TV took over most people's evenings. Therefore, families had the problem of how to entertain themselves in the evening. It was not uncommon for middle class people to have musical training as children and later in life get together to play music in the evening, usually what we now call classical music. My own parents, though not of Einstein's generation, met this way. My mother played the piano, my father the violin. In Einstein's case, his mother was an accomplished pianist. She started him on violin lessons when he was six. He later said that he "had no luck" with his teachers for whom instruction was mechanical practicing. However at age 13 he heard some well played Mozart violin sonatas and something clicked:

> My wish to reproduce them in their artistic content and their unique gracefulness forced me to improve my technique; this I acquired without practicing systematically. I believe that love is a better teacher than a sense of duty –at least for me.

It was "love at first listen". Within a year, the lessons were discontinued and he was practicing Mozart on his own. Just as with mathematics, he was once again teaching himself.

College Years

When Einstein entered the Zurich Polytechnic in 1896, he entered a program that would train him to be a high school mathematics and physics teacher. However, in the back of his mind his goal was to prepare himself to become a professor of theoretical physics at the university level though at that time the designation "theoretical physicist" was just starting to become recognized. In the 1890s, the Zurich Polytechnic was primarily a technical college and a teachers' college. Just as in his teenage years, we can see in these college years some influences on his attitudes and development. First, I want to single out something that is, with one exception, never alluded to by his biographers. There was, in

Europe, in the late 1890s and early 20th century a subculture of musicians, artists, and authors who eschewed material things, practiced an unconventional lifestyle, and often practiced frugality out of necessity. Their intention was to concentrate their intellectual and emotional energies on their artistic endeavors. They were called bohemians from the mistaken idea that the movement originated in Bohemia. This subculture often congregated in cafes and enjoyed musical soirees. We know from accounts by people who were acquainted with Einstein in his college years that he was a “cafe goer” and a participant in evening and Saturday afternoon musical get-togethers. From Einstein's letters to his first wife in the years before their marriage we know that he identified with people of the bohemian subculture and it was suggested by one biographer that Einstein's unconventional dress and hairstyle in his later years may have had its origin in these college years. His self-identification with the people who separated themselves from the mainstream, was echoed in later writings and reflects Einstein's oft stated desire to stand apart from the lifestyle of those around him.

During one particular musical evening, Einstein met one of two extremely influential lifelong friends. He was Michele Besso, a fellow violinist and an engineer who had graduated from Zurich Polytechnic the year before. We will meet Michele Besso twice in next month's talk. The other influential lifelong friend was a fellow classmate, the mathematics major Marcel Grossman. It turns out that four times Grossman stepped in to, in a sense, “rescue” Einstein or direct him in the right direction. The first two rescues will turn up in a few minutes.

Einstein's primary physics professor at Zurich Polytechnic was Heinrich Weber who was an experimentalist. Shortly before Einstein enrolled, Weber had obtained money from Werner von Siemans, founder of the large electrical manufacturing company to build an up to date physics laboratory. The resulting physics lab was the envy of physicists at many of the European colleges and universities. At first, Weber's lectures pleased Einstein immensely and his relationship with Weber was cordial. However, as Einstein became an older teenager, his self assurance grew and he began to assert his independence. As a consequence, this meant that his lack of respect for authority became more apparent. At this time in Europe, college and university professors were revered by the populace at large and often were autocrats in their domain. The differences in temperament between Einstein and Weber were bound to eventually lead to, if not outright conflict, then estrangement. Contributing to this was Einstein's disappointment that Weber's courses contained a great deal about the historical development of physics and little to nothing about recently developing fields. In particular, the important new topic of Maxwell's theory of electricity and magnetism was not covered at all. Having

taught himself calculus, Einstein, was well capable of studying electromagnetism on his own, which he did. The lack of “modern” topics in Weber's lectures frustrated Einstein so much that he gradually didn't bother to hide his feelings. These came out by addressing him “Herr Weber” rather than the customary “Herr Professor Weber”. By the end of Einstein's time at Zurich Polytechnic, the two were antagonists. Weber is probably most remembered for his saying to Einstein, “You're a very clever fellow Einstein. But you have one great fault, you'll never let yourself be told anything.”

Although Einstein had found mathematics enjoyable and something he could readily master, he made a mistake in his college years that he later came to regret. At this point in his life, he believed that in physics all he needed to know was comparatively elementary mathematics. Some of you here will be amused when I say that in this case “elementary” means at the level of calculus and differential equations. As a result of this mistaken attitude, Einstein's attendance in the more advanced mathematical courses he was registered for was sporadic. As he said in his autobiography,

> There I had excellent teachers (for example Hurwitz, Minkowski), so that I really could have gotten a sound mathematical education. However, I worked most of the time in the physical laboratory, fascinated by the direct contact with experience. The balance of the time I used in the main in order to study at home the works of Kirchhoff, Helmholtz, Hertz, etc.

I believe that it is important to note that Einstein spent considerable time in the physics laboratory. This continued a practice he had in his last year of preparatory school at the Swiss Canton school in Aarau where he spent extra time in the physics lab. This extra time spent in direct contact with physical phenomena would become helpful both in his later work at the patent office and in his theoretical work. The works by Helmholtz and Hertz that Einstein refers to are their writings on those parts of the more recent physics that he felt Weber was ignoring such as electromagnetic theory, kinetic gas theory and statistical mechanics.

One additional interesting fact about Zurich Polytechnic is that students at this time were required to attend at least one class each year outside of their major field. It turns out that to satisfy this requirement, Einstein attended more than the required number of courses in the “General Studies and Economic Department.” In particular, two of the lecture series that Einstein enrolled for were “Banking and Stock Exchange Dealing” and “Statistics and Life Insurance.” The reason that I mention this is that while Einstein is noted for his two relativity theories, and work on quantum theory, he was

very good at probabilistic and statistical reasoning throughout his physics career. Several of his important papers used probabilistic reasoning and it's tempting to conjecture that his interest in probability and statistics started with what he heard in these lectures and what he learned in kinetic gas theory in his readings at home. I have in my collection of papers a little known paper from an engineering journal in which the author shows that as early as 1904, Einstein knew the substance of the famous Wiener-Khinchin theorem which has application to the study of time series. Einstein published the substance of that theorem in a short paper in 1914 that may be found in volume 4 of his collected works.

As I mentioned, Einstein's comparative neglect of mathematics led to his erratic attendance in those classes. This gave rise to another famous quote, in this case by Hermann Minkowski: "You're a lazy dog, Einstein". However, it actually gave rise to a much more serious problem than that of being called a lazy dog. In order to obtain his degree, Einstein had to pass a set of comprehensive examinations for which he was ill-prepared due to spending his time working on things he felt were more important than math lectures. Fortunately his friend, Marcel Grossman attended class regularly and took notes which he carefully rewrote. Grossman allowed Einstein to use his notes to prepare for the final exams which he subsequently passed. This is the first instance of Grossman coming to Einstein's rescue.

The Patent Office

Upon graduating from the Zurich Polytechnic, Einstein hoped to obtain an entry level position at the college or university level. However, this is when the conflict with Weber came back to haunt him. Weber himself had two open positions, but those were awarded to two other graduates. That can probably be explained by the fact that Weber was an experimentalist while Einstein's self professed main interest was in theory. However, it is highly likely that any of the people who Einstein applied to at other universities would have contacted Weber for his opinion of the applicant, and, in all probability, given the history of the two men, Weber's opinion would have been unfavorable. Also at this point in Einstein's life, his self confidence outstripped his tact. An example of this can be seen in the following: Although out of work, he kept up with what was going on in physics and, in particular, he read a paper by Paul Drude, who at the time, was the director of the Physical Institute of the University of Giessen and the editor of *Annalen der Physik*, the foremost physics journal of that era. Writing to Drude, Einstein identified what in his opinion were two errors in Drude's paper on electron

theory, and in the same letter included an application for any open position that he might have. Unsurprisingly, he never heard back from Drude.

In the end, Einstein was reduced to eking out a living as a substitute teacher and advertising his services as a tutor. This last effort to earn money led Einstein to meet another life long friend, Maurice Solovine. The rapport and mutual interests between the two men was such that after one meeting, tutoring was soon forgotten and they started to meet to read and discuss philosophy. They were soon joined by an acquaintance from Einstein's college days, Conrad Habicht. For the next few years the three met regularly to discuss joint philosophical readings. Their reading list reads like a Who's Who of classical authors, e.g. Immanual Kant, John Stuart Mill, and David Hume in philosophy, and Ernst Mach, and Henri Poincare in physics. In literature they read Sophocles, Dickens, and Cervantes. Their meetings lasted from the spring of 1902 until November of 1906 when Habicht and Solovine moved on to earn their livings elsewhere.

Marcel Grossman's father was a friend of the director of the Swiss patent office in Bern, Switzerland and in the spring of 1901 Marcel passed on to Einstein the information that there would probably be an opening soon at the patent office and suggested that he should apply for the position. He also indicated that his father would recommend him to the director. This was the second instance when Grossman rescued his friend. Einstein quickly applied for the potential opening, however the wheels of government sometime move slowly and after a year delay, Einstein started work in Bern in June of 1902.

Many of the early biographers of Einstein have bemoaned the fact that he spent the next seven years working as a civil servant in the patent office, seemingly feeling that it was a waste of time. Actually, one can make a pretty good argument that there were positive benefits to his work there. Einstein himself seems to have had mixed opinions about the matter. In a letter to Max Laue, in an explanation as to why he couldn't write a book on relativity, Einstein described his job at the patent office as eight hours of strenuous work a day. However, in later years he referred to the patent office as “a worldly cloister where I hatched my most beautiful ideas”.

Whatever his actual opinion about his employment at the patent office, one can deduce several beneficial results of Einstein's stay there. Frederich Haller, the director was something of a stickler when it came to the presentation of the examiners' work in the evaluation of patents and insisted that reports should be clearly written and to the point. When reading Einstein's later papers one is often

struck by the clarity of Einstein's writing in contrast to some of our contemporary authors. I recall that when I was preparing to start the research that became my thesis, I labored for several weeks over a paper on five-dimensional relativity finding it nearly unintelligible, but when I was finally able to obtain a copy of Einstein's paper on the same topic everything became clear almost at once. That Einstein absorbed this approach to his writing at the patent office is attested to in a letter Einstein wrote in 1917 to a friend who had asked him to express an opinion on a text the friend was writing on medicine, law, and causality. After taking the friend to task over some "unnecessarily opaque" passages, Einstein commented,

> Nevertheless, I understood everything; it may well be possible that my perpetual ride on my own hobbyhorse and the conventions at the Patent Office have driven my standards to exaggerated heights in this regard.

Another of Haller's maxims was for the patent examiners not to trust a word that the applicant says but to examine the claims in detail. As Einstein put it,

> Working on the final formulation of technological patents was a veritable blessing for me. It enforced many-sided thinking and also provided important stimuli to physical thought.

I have often come across review papers written by other physicists where they remark on Einstein's uncanny physical intuition. Earlier I remarked about the importance of Einstein's extra work in the physics laboratory It is my opinion his physical intuition was honed by his work in the laboratory followed by his time in the patent office where it would have been necessary to examine patent descriptions to ensure their compliance with the known laws of physics. It is interesting to note that when the distinguished physicist Henri Poincare wrote a letter in support of Einstein for a university position, he commented on Einstein's ability to look at all sides of a problem.

Finally, one might wonder whether Einstein's work in the patent office influenced any of his ideas in the thinking that led to his research. As a teaser for next month's talk, I would like to point out that in the late 1800s and the early 1900s one of the big problems in the countries of Europe and in the United States, as well, was the establishment of consistent time keeping systems from country to country in Europe, and from state to state in the U. S. The importance of accurate time keeping was brought to the fore in the U. S. by several horrific passenger train crashes that were directly traceable to

errors in time keeping leading to two trains on the same track simultaneously. Thus, the problem of synchronizing clocks within a city, a country, or from country to country, became an important focal point for research and development. In 1901 there were eight patent applications at the Swiss patent office for patents on electrically controlled clock systems. In 1902, the year Einstein started work there were ten applications, in 1903 there were six, and in 1904, a year in which Einstein was mulling over what would become his Special Theory of Relativity, there were fourteen patents granted on electrically controlled clock systems. This idea of synchronizing clocks was central to Einstein's development of Special Relativity.

Friends and Collaborators

We have already met four of the men that Einstein made friends with during his college years and shortly thereafter. One of the myths perpetuated by the media in the storm that developed after the eclipse verification of General Relativity was that Einstein worked alone. That myth was partially perpetuated by Einstein himself by occasional references to his aloneness. Those sorts of remarks were more prevalent in the 1930s when the mainstream of physics diverged from the areas that Einstein was interested in. In actuality, according to Abraham Pais, who wrote one of the best Einstein biographies, throughout his career Einstein had a total of 30 collaborators. I want to talk briefly about the four people I mentioned earlier. Of the four, only Besso and Grossman were at some point collaborators, but all four of the people were influential in some respect. As I mentioned, Einstein and Michele Besso met in one evening in 1896 at a musical event at the home of Mrs. Selina Caprotti. Both Einstein and Besso were violinists and presumably the event of the evening was one where they participated in playing their violins. Their friendship lasted until their deaths just a few months apart in 1955. It is well known that Einstein and Besso worked together for a few years in the patent office starting in 1904. What is less well known is that they met together during summers from 1899 to 1901. The way this came about is as follows. In 1894, Einstein's father and uncle moved their business to Milan, Italy where they had business contacts and prospects seemed more favorable than in Munich, Germany. Besso had family in Milan and moved there himself in 1899. Einstein returned home to his parents during his summer vacations and he and Besso met almost daily in the evenings to discuss various scientific topics, particularly among them electrodynamics and molecular theory, the first of these is the central topic of his paper on Special Relativity, the second is the central feature of several of Einstein's first scientific papers including his papers on Brownian motion. Biographers of Einstein often write

about his miraculous year of 1905 when he wrote four seminal papers in less than six months. What is often not remarked upon is the fact that Einstein had been thinking about the phenomena behind those papers for the previous eight years at least. Throughout the lives of both men, Besso was a constant sounding board both when they had the opportunity to meet in person and by mail when they didn't. A book of their correspondence running some 550 pages was published in 1972. Unfortunately it is written in German with French translations. Since I took French in high school a little longer ago than I wish to admit, and got thrown out of German in college, it might take me a while to read them. Besso will turn up again at a crucial time in the development of General Relativity.

Earlier I told you that Marcel Grossman helped Einstein out by lending him his notes, particularly those on mathematics, before the required final exams and telling Einstein of the opening st the patent office. It turns out that Grossman was interested in, and did his doctorate work in, the geometry of curved surfaces and curved spaces. It is precisely this geometry that Einstein needed to complete the General Theory of Relativity. I shall discuss this in detail next month.

Underlying much of Einstein's work was his interest in philosophical issues such as epistemology. Epistemology is the theory of knowledge, in particular how do we know what we think we know. As he wrote in 1949,

> Epistemology without contact with science becomes an empty scheme. Science without epistemology is –insofar as it is thinkable at all-- primitive and muddled.

One of the philosophers that Einstein, Solovine, and Habicht read and discussed was the Scottish philosopher, David Hume. Hume wrote a number of books, but the one that is most relevant is his *An Enquiry Concerning Human Understanding.* Hume subscribed to the principle of empiricism which essentially is the idea that all knowledge of the world cones from, and is based on experience. In his autobiography, Einstein noted that the type of critical thinking necessary for the development of the special theory of relativity was stimulated by reading David Hume's writings.

In addition to Hume's book , Einstein, Solovine and Habicht read some of Henri Poincare's writings. In particular, Solovine wrote that “Poincare's *Science and Hypothesis* kept us spellbound for several weeks”. It's interesting that *Science and Hypothesis* is still in print, a testament to its lasting value. The book is a collection of essays about fundamental mathematical and physical concepts with a strong overlay of “how do we know this”, that is, epistemology. A reading of the titles of the chapters

in the book seems like a listing of topics that later came up in Einstein's work:

Chapter 3: Non-Euclidean Geometries
Chapter 4: Space and Geometry
Chapter 5: Experiment and Geometry
Chapter 7: Relative and Absolute Motion
Chapter 8: Energy and Thermodynamics
Chapter 13: Electro-Dynamics

Just to mention a few.

It's hard to escape the conclusion that between Einstein's discussions of philosophical issues with Solovine and Habicht, his discussion of physics issues with Besso, and his work at the patent office, he was thoroughly primed for the so-called miraculous year of 1905 in which he published five seminal papers.

Einstein's Creativity

Up to this point I have presented to you a few of the influences that I believe helped to make Albert Einstein one of the most creative physicists of all time. I want to take a few minutes to add a few more ideas in this vein.

At some point after Einstein became famous his sister, Maja Wintler-Einstein, wrote a brief biographical sketch about her brother, an excerpt of which is included in Volume One of the collected papers. In it she makes a suggestive comment about their father, Hermann Einstein,

> Hermann Einstein had a particularly pronounced way of trying to get to the bottom of something, by examining it from every side, before he could reach a decision.

Think back to Einstein's experience at the patent office. It is evident that from an early age, Einstein was exposed to the idea that problems should be examined from various points of view. This as we've seen was a feature of his thinking that Poincare mentioned in a letter of support for a university position. During the 1920s through the 1940s, Einstein had a series of assistants, primarily mathematically inclined physicists or mathematicians, who worked with him. In 1979, the 100th anniversary of Einstein's birth, there were several conferences worldwide devoted to his life and work. Many of these former assistants gave talks recalling what it was like to work with the great man. One of the common themes was his tremendous creativity. For example, if they became stuck in a

calculation and had to put further work off until the next day, Einstein would usually come to work the next morning with several ideas of new approaches. In my opinion this ability is a reflection of his penchant for looking at a problem from many different directions.

Another thing mentioned by Maja Wintler-Einstein was that as a child her brother showed a dogged determination when he became engaged in a task. This is a trait that he showed throughout his life, particularly in his later years when he worked on a unified theory of gravity and electromagnetism for 30 years without much success. Einstein's son, Hans Albert, once told a biographer “I am the only project my father gave up on. I was too stubborn.” I credit patience and doggedness at an early age for Einstein's success in teaching himself a great deal of mathematics and physics and in learning to play the violin well. He also taught himself to play the piano, although he primarily used it as an instrument for improvisation.

Let's now return to his childhood experiences with geometry and music, recall that they occurred roughly at the same age. I would like to suggest that these two events: Einstein's success with mathematics well beyond grade school, followed by his subsequent mastery of the violin are connected. That there is, for some people, a deep connection between mathematics and music is commonly observed. During the 1940s when the federal government was setting up the Los Alamos atomic bomb laboratory, one of the logistical problems they had was the transport of the pianos of several of the atomic physicists from Europe who joined the Manhattan Project. We know that music was extremely important to Einstein from his comments in various interviews and the fact that he took his violin with him when he traveled abroad. In preparing for this talk, I noted that Einstein's favorite composers were Bach and Mozart, while he criticized Wagner's music as “having no structure”. Being pretty much a listener and not a player of music, I wondered what he meant by that remark. Then by chance a friend of mine who is a mathematics professor and a classically trained violinist, posted the following link on her Facebook page:

http://www.itsokaytobesmart.com/post/42869472186/the-genius-of-js-bachs-crab-canon-visualized

The video shows that Bach's Crab Canon is the musical version of the Moebius Strip, a twisted plane surface with only one side. That video was a revelation to me and I pursued the connection between mathematics and music further. A Google search led me to this website:

https://www.youtube.com/watch?v=V5tUM5aLHPA

where there is a beautiful discussion of music and mathematical symmetry. It's well worth a look. J.S. Bach in particular loved to play with symmetries in his music. "A mathematician, like a painter or a poet, is a maker of patterns." wrote the famous pure mathematician G. H. Hardy in his essay *A Mathematician's Apology.* Music is constructed in patterns: patterns of sounds occurring in pitch, amplitude, tempo and timing. There's a close connection between mathematics and music. UWEC's math professor, James Walker has recently coauthored a book on mathematics and music. These observations prompt the question, "Are mathematical ability and musical ability connected in some way? There has been extensive research on the cognitive effects of musical training in school aged children. A recent review of the research literature on this that I read pointed out that when it comes to learning there are sensitive, and even critical, periods for different types of learning. I suspect that it is no accident that geometry and music made such an impression on the young Einstein nearly simultaneously. The review of research into the relationship of music to learning was very circumspect about evidence for the possibility that mathematical and musical ability are coupled. The researchers were more inclined to link music training with increasing verbal memory and executive functioning. Be that as it may, I think we can surmise some of the role music played in Einstein's life.

Considering the fact that on his world-wide travels his violin was Einstein's constant companion, what besides enjoyment might have been the role of music in Einstein's work? I think that can be best answered by a story told by a well known applied mathematician, Cornelius Lanczos, who worked with Einstein for a year, or so, in the late 1920s. The arrangement was that Lanczos and Einstein would meet once a week for an hour for a discussion and then Lanczos would go home to do calculations and return the following week and report on his progress. Their work started off with Einstein giving Lanczos an equation, call it E, and saying that he needed a solution with properties a, b, and c. After a week's struggle, Lanczos found a solution to the equation and found that it had the desired properties a, b, c. When he took his work to Einstein and showed it to him, Einstein's face lit up and he said, "Yes, yes, it has the properties a, b, and c." Then Einstein frowned and said, "But didn't you see I gave you the wrong equation?" The two stood there for a bit staring at the equation, and then Einstein turned and went for his violin, while Lanczos sat down at the piano. The two played Bach for the rest of the hour. Another some-time collaborator of Einstein, Wolfgang Pauli, who was not noted for his calm and pleasant personality, recalled that, to him, the most amazing thing about Einstein was

how completely unaffected he was when a piece of research didn't work out, whereas, he Pauli, said he would be depressed for a month afterwards. I see music as Einstein's escape into an activity that provided him stability and rejuvenation.

I want to isolate some of the characteristics that made Einstein the thinker what he was..

First he started out life with a patient determination which he applied to whatever task he chose to work on, and although I didn't mention it, he was quite particular about what he chose to devote his time to.

Second, let's not forget his questioning of authority of all kinds. This fed into his approach to physics, particularly when coupled with his deep interest in the philosophy of knowledge. This will be made explicit next month when I discuss his path to General Relativity.

Third, Einstein's ability to look at situations from different directions had two effects. It gave him the ability to come up with different ideas as to how to approach a problem, and, when you couple it with his skepticism of authority, it implies that he would not get "locked in" to the prevailing thinking of the time. His ability to look at received wisdom in different ways was behind two of his 1905 papers.

Fourth, throughout his life, Einstein kept up a steady correspondence with Besso, Solovine, and other physicists about his scientific and political issues. This is completely contradicts the myth that he worked alone. In some cases, such as in the early work on bringing gravity into compliance with special relativity, this correspondence enabled Einstein to get a feeling for what the actual issues were.

Let's see what Einstein had to say about his own thinking. In the 1940s the mathematician Jacques Hadamard published a little book titled *The Psychology of Mathematics in the Mathematical Field.* In the preparation of the book, Hadamard sent a letter to Einstein with several questions about his modes of thinking Here are portions of Einstein's answers:

> (A) The words or language, as they are written or spoken, do not seem to play any role in my mechanisms of thought. The psychial entities which seem to serve as elements of thought are certain signs and more or less clear images which can be "voluntarily" reproduced and combined.
>
> (B) The above mentioned elements are, in my case of visual and some of muscular type. Conventional words or other signs have to be sought for laboriously

only in a secondary stage…

I take Einstein's use of “other signs” to mean mathematical equations. Try as I might, I cannot figure out what Einstein means by “of muscular type”. In addition to the above comments, Einstein wrote one other thing that I want to pass on,

> For me it is not dubious that our thinking goes on for the most part without use of signs (words) and beyond that to a considerable degree unconsciously. For how, otherwise should it happen that we sometimes “wonder” quite spontaneously about some experience? This “wondering” seems to occur when an experience comes into conflict with a world of concepts which is already sufficiently fixed in us.

With Einstein it seems that his occasions of wonder were often directed towards the physical universe around him.

That concludes my talk for tonight. In next month's talk on Einstein's path to General Relativity I will give more examples of Einstein's approach to puzzling out this universe we live in.