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What makes a Great Scientist?

The topic of this essay is one that has already been written about in copious detail by many able people. So it was not without some hesitation that I decided to accept the invitation of my good friend, philosopher and guide (Mr. Gabriel), to present my own personal take on the subject. While making the draft, I initially felt that I ought to make the article's tone as objective as possible. But then it soon dawned on me that such an approach would only end up as a veil of disguise for my own beliefs - ones that I cherish very close to the heart. So in the spirit of intellectual transparency, I unashamedly confess right here at the start, that this essay contains the collected views of a man who has dedicated a substantial portion of his not so long life, to the study of the Natural Sciences and the History of Science. If my disclaimer has by any chance evoked a strong sense of disinterest in my gentle reader, I humbly apologize for the same and more humbly still ask that you nonetheless tarry on. Perhaps, you might find a gemstone or two in this tiny puddle that might not prove false or vain. As far as I can tell, there is no magic formula or sacred Ten Commandments that would aid in the making of a great scientist. Just a few opinions that can act as a guide and light to doing quality research in a dark and increasingly competitive world.

In order to keep this essay brief and to the point, I chose to list the qualities that I feel form the quintessence of a great scientist in serial fashion. One word of caution, though: it is advised not to think of any single quality as having a greater or lesser importance than any other quality. Try to think of them all on an equal footing, and resist the natural urge to attribute different weights to each.

1. **Faith in one's own abilities**

   It is precisely this quality of character that forms the hallmark of a scientist extraordinaire. Faith in one's own abilities to tackle a scientific problem, is the key step to finding its solution. In fact, the solution to a problem more often than not, arrives at one's consciousness sometime after faith has made its dwelling place there first. This *fact* regarding the process of scientific discovery may be lacking in objective evidence, but a simple survey of any 'n' number of scientists for whom creative problem solving is a day and night pre-occupation, will reveal that faith does indeed have an undeniable role to play on the road to discovery. The reason for this is simple. There is absolutely nothing mysterious about it. For it is by faith in your abilities, that you even come to realize that you have any ability at all. You cannot know what you are capable of unless you first try. The journey of self-discovery begins with faith as a first step. William James, the great American Psychologist and Philosopher, put it this way "Faith acts as a Working Hypothesis".

   The very progress of science itself depends on men and women who are willing and daring enough to invest faith in their own abilities. Take for instance, Prof. Andrew Wiles who proved Fermat's Last Theorem – a famous conjecture in Number Theory that was lacking a formal proof for more than three and half centuries. He first encountered the statement of the conjecture in a book borrowed from a local library, when he was just 10 years old. It just amazed his young mind that

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such a simply phrased statement which even a 10 year old could understand, defied all attempts at proving. This set his mind dreaming of being the one to achieve that grand goal. It was faith that finally got him there, at the age of 42.

Albert Einstein was well known for his confidence. So much so, that one could even misinterpret his confidence as bordering on arrogance, particularly when it came to judging the correctness of his Theory of Relativity. What experiment had to say, didn't really bother him. He was convinced of the theory's validity simply by its elegance. To him the theory was just too beautiful to not be true. And the pathway that led him directly to it was paved with faith. Eventually, experiment did catch up and Relativity's fundamental claims were verified to be true, beyond reasonable doubt. Such is the power of faith.

Richard Feynman, the witty physicist who co-formulated the theory of Quantum Electrodynamics, said that he always kept an open mind when considering new ideas in science. But when it came to making a hypothesis and going forth to prove it using some particular methodology, he would become so prejudiced about its correctness that he would shut out every other possible alternative. This too is another manifestation of faith in action.

Heinrich Hertz was the man who proved the existence of electromagnetic waves, which was first theorized by James Clerk Maxwell. This remarkable feat was again achieved by exercising faith in the assumption that electromagnetic waves do indeed exist in Nature. It was just a question of finding the right experimental methodology to reveal them. This pursuit obsessed Hertz's mind, and made him doggedly determined to not leave his laboratory till he was a step closer to baring Nature of her secrets.

2. Persistence - the Pain Phase, "Aha!" - the Gain Phase

Nothing of merit in this world has ever been achieved without the element of persistence. Every scientific invention or discovery has a story of persistence behind it; one of sweat, tears and pain. The quirkiest thing is that, these unpleasant internal experiences are soon followed by a tremendous rush and thrill once the mind has hit upon a breakthrough solution. This kick is so pleasurable to the scientist that all the sweat, tears and pain are forgotten in a fraction of a second. In fact the pleasure so enjoyed compensates for all the pain endured. Scientists live for these ecstatic moments and crave for them to happen as often and as intensely as possible.

Persistence plays sentinel to these "Aha!" moments. In other words, once you shake the hands of Persistence, you will sooner or later find yourself introduced to "Aha!" There are many instances in the History of Science, where persistence was rewarded by the Aha feeling. Some of these stories are even ridiculously funny. But some are so deeply emotional and intensely personal, that the scientist is drawn to tears if asked to recall his internal experiences just moments prior to and after the particular insight came to him.

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Einstein described his discovery of the Equivalence Principle as the happiest thought in his life. He hit upon the insight after interviewing an artist who had fallen from the upper floor of a building. Archimedes ran through the streets naked shouting with joy "Eureka!" upon discovering an important sub-part of the Laws of Floatation, while taking a bath. Stephen Hawking made his mark by proposing a revolutionary new idea at the time, that blackholes actually radiate energy. This idea came to him while he was struggling to get himself into bed at night (his Multiple Sclerosis condition makes this a slow process). That was one of his "Aha" or happiest moments.

3. Exploit the power of Sleep and Dreaming

This may seem a strange point to include in my list. But from personal experience, I can in all honesty confess that this indeed is a very powerful method for arriving at what one is seeking. The human mind has an unexplainable capacity to tap into hidden knowledge from some mysterious source that acts as a Universal Compendium of all Useful Information. The portal of access to this source is the dreaming process. As mystical as this may sound, it really does work. Many of the greatest ideas that had a lasting impact on our world, have come to men and women who have simply learnt to exploit the latent power of dreams. These include not just scientists, but even writers and artists. For instance, Nikola Tesla came up with many of his most important inventions, like the rotating magnetic field motor, from one of his dreams. Mary Shelly got the plot for her book – Frankenstein - from a nightmare. And so did Robert Louis Stevenson who wrote the famous Dr. Jekyll and Mr. Hyde novel. August Kekule finally realized after a prolonged period of study, that the Benzene molecule had a ring structure to it. His inspiration came from a vision of a snake seizing its own tail. The famous mathematician Poincare made an important mathematical discovery regarding Fuchsian functions while boarding a bus; the solution just flashed before him when he wasn't even consciously thinking anything mathematical prior to boarding.

It appears that the creative mind, when faced with a problematic task to tackle, goes into a stage of incubation, wherein ideas are cooked under high pressure. During this stage, which is entirely subconscious, (i.e. they happen below the level of conscious awareness), unrelated ideas begin colliding with each other at random and with increasing frequency, until suddenly the right two ideas stick together, forming an inseparable bond between them. This newly formed idea, then leaps from the subconscious mind into the conscious mind. It is precisely this sudden, uninvited but nonetheless welcome and explosive entry that is experienced as the "Aha!" moment. The people who have learnt to exploit this incredible power, at will, end up as the Creative Geniuses that grace the pages of History.

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4. Be not afraid of making mistakes, but acknowledge them as quickly as you make them

Making mistakes is a very important step on the road that leads to discovery or invention. But equally so is acknowledging those mistakes the moment you realize the error in your judgment. Samuel Smiles put it this way "He who has never made a mistake, has never made a discovery". Einstein said "He who has never made a mistake, has never tried anything new". For Edison, "my most important discoveries were suggested to me by my failures".

Science owes more to the unknown mistakes and accidents committed along the way, than the celebrated successes at the end of the journey. Our mistakes are therefore, undoubtedly our greatest teachers and the fear of making them is precisely what holds people back from success. It happens very often in science that mistakes can act as the Pandora's Box of new possibilities. For instance, Einstein referred to the famous Cosmological constant that he first introduced into the Field equations, as his greatest blunder. But today it forms a hotbed of research in Modern Cosmology, spreading its tentacles in unexpected directions.

Golgi and Cajal are considered pioneers in the area of neurophysiology. They had totally differing views on the structure of the nervous system. Golgi believed in the Reticular theory, where the entire brain and spinal cord is considered a single interconnected network, while Cajal stood for the Neuron doctrine, according to which the nervous system is composed of discrete, individual cell units. Both men interestingly received the Nobel Prize in Medicine/Physiology the same year (1906) for their respective contributions. This despite the fact that by then, Cajal was already proven right and Golgi wrong by experiment. However, during the prize ceremony speech, Golgi failed to acknowledge his erroneous position and chose instead to denounce Cajal's theory as the wrong one. Ironically, ever since the discovery of gap junctions in the 1950s, some aspects of Golgi's debunked theory have been resurrected in mainstream neuroscience, and is currently an area of active research.

Isaac Newton first forwarded the Corpuscular theory of Light (i.e. light is made up of particles) which was contested by Christian Huygens' Wave theory of Light (i.e. light consists of wave propagations). Owing to Newton's higher regard in the scientific community, the Wave Theory suffered much unpopularity until Thomas Young came along years later and actually devised an experiment (called the Two-Slit Experiment) to measure the wavelength of light. This experiment along with the theoretical works of James Clerk Maxwell, pretty much established the wave nature of light and the corpuscular theory got buried six feet under. The great Newton was proven wrong and Huygens right. But only for a short while. In comes Einstein, who resurrects the dead and buried Newtonian Corpuscular theory in his explanation for the Photoelectric effect, by considering light to consist of tiny packets of electromagnetic energy called light quanta (or photons). Experiments ended up proving Einstein's theory true and thus, a final stalemate was reached. Light is now said to possess both wave and particle natures. Under certain prescribed

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circumstances, it behaves as a wave and under certain other circumstances, light behaves as a particle. But never both at the same time (a.k.a. Bohr's Complementarity Principle).

From the above examples, one can fairly infer, that in the context of the evolution of scientific ideas, mistakes are only a temporary phase. In the long run, they may turn out to be the spring board necessary to reach a deeper understanding of reality. So don't be afraid of making mistakes! The Great ones made them aplenty!

5. Question all that is established

"Oh, but all the books say this!" or "Oh, but all the papers say that!" These exclamations come from the mouth of one who has *mindlessly* or rather *uncritically* submitted his or her soul to the authority of the establishment. The progress of Science suffers terribly during such phases in history. To overlook the tremendous potential lurking in questioning what is known, before venturing into the unknown, is folly. The paradigms of the present times must always be looked upon with suspicion as possible prejudices that shackle progress. There is just no other way to be explosively creative as a scientist. Employ "out of the box reasoning" or lateral thinking as it is often referred to, to arrive at new solutions to old problems. By doing so, you would have effectively re-evaluated the older existing solutions, with all its flaws. Always ask yourself both questions "why?" and "why not?" simultaneously. This way you will end up understanding a lot more about a current problem and develop your own unique methodology to render that problem tractable.

For close to two millennia, Aristotle's physics held unquestioned dominance till Newton came along and overturned it completely. For close to three centuries after that, Newton's physics held unquestioned dominance till Einstein came along and overturned it completely.

Euclid's geometry was thought to be the only kind of geometry there was, till the Fifth Postulate (a.k.a. The Parallel Postulate) in his book - the Elements - was brought into question. That act of questioning gave birth to what are now known as the Non-Euclidean Geometries. They had a critical role to play in the formulation of the General Theory of Relativity.

6. Keep updated with the latest literature on a subject

In order to be able to make a significant contribution in any field of science, it is of the highest importance that the researcher keeps himself abreast of all the latest developments and available literature on the subject of his interest. Considering the current style of academic writing in journals - so dull, dry and indifferently toned - it is no easy or joyful task to get through this step. It should be thought of as a necessary evil – a rite of passage in order to move towards greener pastures of increasing understanding. You need put up with the sludge only till you finally hit a breakthrough idea yourself. From that point onwards, you can pursue your own independent line of reasoning.

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7. Maintain a Hunger for Knowledge, a Thirst for Understanding and a Heart full of Enthusiasm

No person better embodies all these three qualities than Leonardo da Vinci. How else can one explain his versatility and sheer genius? He was everything, from a painter, sculptor, architect, musician, mathematician, engineer, inventor, anatomist, geologist, cartographer, botanist and writer. He was described as a man of unquenchable curiosity and feverishly inventive imagination. To me, he was a *Complete Man.*

It would be silly to suggest that every scientist ought to rise up to the standards set by old Leo. But the qualities of character and habits of thought that made da Vinci the man that he was, are worth investigating for the purpose of gaining inspiration. Such efforts are bound to be rewarded by higher levels of creative expression in one's own research. Because the best way of increasing one's own creative capacity, is by studying the lives of creative people themselves.

8. Strive towards increasing concentration and focus of mind onto a single goal

The importance of keeping goals cannot be over-emphasized. It forms the crux of achieving anything of worth. Your goal may be to solve some particular problem. First break it down into smaller sub-goals that would be more easily manageable. Then work on the problem piece by piece, and finally put all the parts back together again and see if a coherent whole results. If not, don't be dismayed. Just start all over by breaking the sub-goals down still further and make any necessary changes to your plan of attack. Also don't forget to give your subconscious time to process all the sensory data that you present it with. Trust your subconscious to solve the problem for you. It will, if you give it the necessary and sufficient time. Described below is the sort of concentration and *"goal-mindedness"* that's often associated with high impact researchers.

Newton was famous for his power of concentration. When working on a problem, he would sit quietly for hours at a stretch. The environment around him would pale into a state of non-existence. Only the thoughts bouncing around in his head mattered. He lived his philosophy day in and day out, that "truth is the offspring of silence". It is no great wonder that such a mind gave us the Principles of Calculus, the Binomial Theorem, the Laws of Motion, the Laws of Gravity, the Laws of Optics and several novel devices including a reflecting telescope.

There is a story of Einstein visiting Bohr at a Copenhagen train station. They boarded a tram together to go to Bohr's home. They got so involved in their conversation on quantum mechanics that they missed their stop, and had to get down at a different station. From there, they boarded another tram going the opposite way. And as expected, they missed their stop again. Finally at the third attempt they reached their destination.

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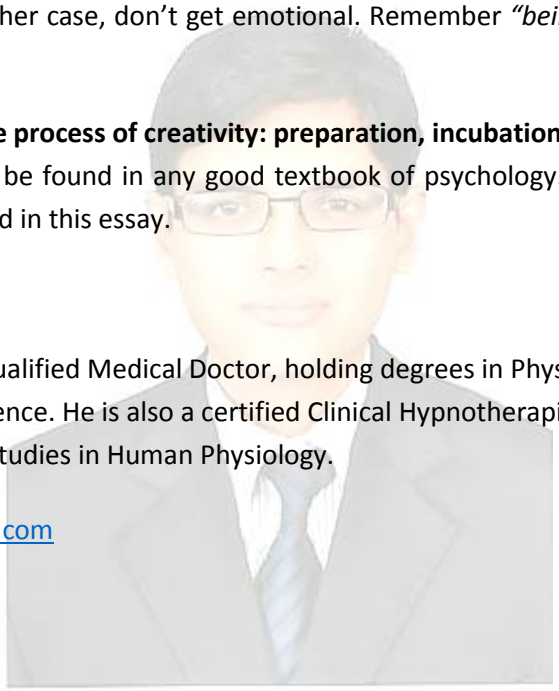
9. **Take criticism constructively even if it may be packaged with destructive force and intent**

   This is no easy task. More often than not, people criticize just because they haven't fully understood something. Demolition, after all is always more satisfying to the animalistic instincts of man than seeing to the fruition of a particular theory. So keep this fact in mind while deciding how to respond to your critics. But there are those rare breed of *good* and *kindly* people, who do criticize with the sole intent of seeing your work improve. It is their opinion you ought to seek and value above all else.

   It is also of the utmost importance to divorce emotions from the positive or negative feedback that will inevitably come your way, if your work has had an impact on the scientific community. In fact the degree and ferocity of attacks is directly proportional to the square of the impact of your work. If you receive positive feedback, be thankful and if you receive negative feedback, get thoughtful. But in either case, don't get emotional. Remember *"being criticized is always better than being ignored."*

10. **Exploit the four stage process of creativity: preparation, incubation, illumination, verification**
    More about this can be found in any good textbook of psychology. The first three stages have been amply illustrated in this essay.

About the Author



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Acknowledgements

Gloria in excelsis Deo

Manuscript completed on 1 October 2014