What makes an Engineer an Engineer?

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ABSTRACT

When someone asks, "What makes an engineer an engineer?" it is no different from an engineer asking, "Who am I?" This question is fundamental to understanding not only who we are, but also how we can grow as individuals. The easiest way to approach this question is to understand how and why we choose this as a profession. What made us think that engineering might be what we want to do? What makes an engineer unique? What we find are character traits that are common to most engineers. We are partly mathematicians and scientists, as one would expect, but we are also creative artists and inventors. We tend to be visual thinkers, who are attentive and self-reflective. Engineers are also confident risk takers temped by worry, who value intuition, logic, and living meaningful lives. We are in constant search for the know-how to be able to actively participate in creating a better built world.

INTRODUCTION

This paper does not attempt to answer the question, “What do engineers do exactly?” The answer to that question is that engineers do engineering. If I attempted to answer that question, I would be describing engineering, the act of designing, not what makes an engineer an engineer. In addition, this paper does not attempt to provide legal definitions, such as "How does one become an engineer?" Not only is this question uninteresting, it is pretty straightforward. It takes graduation from an accredited engineering school, four years of experience, and passing a discipline-specific technical examination.

The question, "What makes an engineer an engineer?" is no different from the question asked by an engineer, "Who am I and why did I choose this profession?" (For those who don't fully accept free will, the question can be rephrased, "How am I and why did this profession take me?"). This paper will discuss how we are unique and what differentiates us from others. The first trait that most engineers share is that we are very curious and really good at making and fixing stuff.

ENGINEERS MAKE STUFF AND FIX STUFF

In order to answer, "What makes me an Engineer?" allow me to start with my childhood and reflect on key moments that led to my decision to go into engineering. I will later generalize to the type of person that typically enters this profession.

When I was about three years old, my parents were concerned that I might be autistic because I did not talk. I struggled in social situations and preferred being on my own with building blocks or trucks. Anything with wheels or toys for building were the most appealing. I learned much later that I was considered a "non-verbal" thinker (more on that later). I did not do well in kindergarten or first grade and flunked second grade. I specifically remember my mom telling me that I was going to stay in second grade and my twin brother was going to advance to third grade. I was given speech therapy and slowly caught up to others my age, but it really was not until high school that I felt comfortable reading and comprehending words. What I lacked in social skills, writing, or reading was offset by considerable skill in making stuff. I built pretty amazing castles and boats out of wood blocks and LEGO bricks. While upbringing specifics will obviously vary from Engineer to Engineer, I have yet to meet one who wasn't master of LEGOS.

The first time that I heard about engineering was when I was about ten. My mother told me that I would be a good one after I had fixed the back door of our AstroVan. It had two doors that opened like a refrigerator. There was a nylon strap that got disconnected from a steel bar that prevented the door from swinging too far. After fixing this and hearing from my mom, I thought to myself that engineering must be an easy profession. I was also a sort of family mechanic, setting up the new VCR, fixing the phone, taking apart the sewing machine and putting it back together. Being mechanical takes curiosity to understand how something works, along with the trial-and-error method. It is not only curiosity, it is the will to do something without help. My Mom would read the manual on how to connect the VCR and then she would worry. I didn't read the instructions, I just tried different plugs. It was actually very simple.

As a sophomore in high school, I received an assignment to write and present on what I wanted to be when I grew up. I heard from others the typical white-collar professions such as doctors, lawyers, businessmen, politicians, etc. Surprising my teacher but not my family, I wanted to be a car mechanic. I wanted to understand the car engine. Being a car mechanic made sense and was exciting. I loved cars as a kid and still do; what could be more exciting than understanding the car engine and developing the skills to be able to fix it? I was always good at math and physics, but I did not want to do math and physics; I wanted to design and build real things. Math was like a fun puzzle similar to Sudoku, but it was not something that felt real or tangible.

In college, I continued to excel at math and physics, but I did not really enjoy sitting and solving homework problems. I was a math major but I expressed concern with my advisor after finishing a test on Abstract and Discrete Mathematics. "How does the idea of Infinity or Set Theory relate to real things of this world? Just refuting the non-existence of infinity, does not make infinity real? It is all in the mind. What is it exactly and where is it constructed in material reality?" He asked me what interested me and realized something more concrete and obviously pertaining to this world would be a better fit, specifically mentioning three options: architecture, structural engineering, and mechanical engineering. I changed schools and chose structural engineering.

My early path in life described above may or may not be similar to that of other engineers, but there are likely similarities in abilities. We all choose a profession that is grounded in material reality and has obvious meaning and importance to humanity. We are also good at building or making stuff, fixing things, and taking things apart and understanding them; but why is this?

ENGINEERS ARE VISUAL THINKERS

We engineers are good at math, not necessarily because we are smart, but because we learned math differently others. Most of the population are verbal thinkers, but we are predominately visual. Visual thinkers can skip the reading in a physics textbook, focus on the figures and images, and then better understand the mathematical manipulations. Engineers do not memorize formulas, they internalize them and play with them by altering one variable in their heads. We can see a pendulum in our head while changing the length of the string. Then we can recognize that the period of a pendulum is independent of the mass and solely dependent on the length. We can see the formula and the swinging at the same time. This is very different from another student who might need to memorize the formula and be able to follow a procedure to solve a particular problem. Visual thinkers can have full intuitive understanding, which has obvious advantages over the verbal thinker in fields such as engineering.

I suspect that some people do mathematic only by following procedures, while others really understand it by taking the concepts further beyond just following established procedures. When math becomes procedural, it becomes boring and uncreative. Those who claim that they are bad a math say so because they have trouble visualizing the representation of it. Engineers are able to visualize equations as physical representations within the mind.

Engineers are visual or non-verbal thinkers in general. Not only do we represent physics in our minds, we are also able rotate static objects to understand them better. Our engineering designs live in our minds a spatial objects and we can enter our projects whenever we demand. We certainly are not talking to ourselves, we are seeing the thing in our mind. In Eugene Ferguson's book, Engineering and the Mind's Eye (Ferguson 1992), he quotes Richard Feyman (1988) when he discovered the difference between a visual thinker from a verbal one:

> I said, "Thinking is nothing more than talking to yourself."
> "Oh yeah", Bennie said, "Do you know the crazy shape of a crankshaft in a car?"
> "Yeah, what of it?"
> "Good. Now tell me: how did you describe it when you were talking to yourself?
> So I learned from Bennie that thoughts can be visual as well as verbal.

Research by child development theorist Linda Kreger Silverman indicates that less than 30% of the population strongly uses visual/spatial thinking (Silverman 2001). According to Silverman (2001), "Visual/Spatial learning is the common phenomenon of thinking through visual processing using the part of the brain that is emotional and creative to organize information in an intuitive and simultaneous way." It is the ability to mentally manipulate two and dimensional figures in the brain. Engineers tend to be good at this.

ENGINEERS ARE SELF-REFLECTIVE

Most engineers at a young age are unusually self-reflective. This is a necessary trait to be able to solve puzzles, build towers from blocks, or fix things. The curiosity to start a problem needs to be maintained by self-reflection and patience, and to complete the task takes a strong will.

In Zen and the Art of Motorcycle Maintenance, Robert Pirsig complained about a motorcycle mechanic who was not worthy of the name "mechanic" because he lacked both self reflection and patience. He dropped off his bike at a shop after the engine had seized up, which caused the rear wheel to lock up. When walking into the shop, a radio was going full blast, and the mechanics were clowning around and talking and did not seem to notice him. When one of them finally did, they immediately misdiagnosed the problem, which caused three overhauls. Pirsig (1974) describes the mechanic's next move: "He brought a hammer and cold chisel and started to pound something loose. The chisel punched through the aluminum cover and I could see he was pounding the chisel right into the engine head. On the next blow he missed the chisel completely and struck the engine with the hammer, breaking of a portion of two of the cooling fins." Pirsig later writes, "Why did they butcher it so? They sat down to do a job and they performed like chimpanzees. Nothing personal in it . . . they were good natured, friendly, easygoing – and uninvolved. They were like spectators. You had the feeling they had just wandered in there themselves and somebody had handed them a wrench. There was no identification with the job. No saying 'I am a mechanic.'"

What Pirsig is suggesting is that this person was not a mechanic and should not call himself one. He was a spectator who followed procedures, a non-thinker. By contrast, engineers are not spectators; we have to diagnose the problem and self-reflect to create ideas to help find the solution. We actively engage projects to reveal solutions to problems or yield new ideas. Matthew Crawford, in the terrific book Shop Class is Soulcraft, describes the difference between an expert mechanic and a procedural thinker: "The forensic perceptual expertise of the engine builder is active in the sense that he knows what he is looking for. But with the idiot we see the result of a premature conceit of knowledge" (Crawford 2009).

Thus knowledge itself is not what separates an engineer, or a mechanic, from an idiot. The most important difference is the humility to recognize one's own ignorance, combined with a good amount of skill acquisition through experience. An engineer, like a master mechanic, is self-reflective and constantly aware of the possibility of making a mistake. Before taking a hammer to the problem, the engineer (or master mechanic) reflects and asks questions regarding the solution such as, "Is this the best solution of all the possibilities?" or "Is this the right material choice?" or "Am I correct in assuming that this can be treated in this simplified fashion?" Being skeptical of our own thoughts and that of others is another common characteristic. We are proud of ourselves when we see our own ingenuity and analytic skills improve something or shape something properly or solve a forensic problem. Mistakes will still reveal themselves in projects, but engineering is not about that past, it is about taking action now and bringing the project to a lower state of imperfection. Experience is necessary to be able to see a few good potential solutions to a problem within an infinite amount of options. Our intuition is strengthened every year of our careers. Since problems in engineering are rarely simple or straightforward, it takes a high level of self-reflection and intuition to tackle them.

ENGINEERS ARE RIGOROUSLY LOGICAL CREATIVE ARTISTS

The most important trait is curiosity about the built world, the will to tackle difficult problems, and self-reflective methodology. The will is strengthened by confidence in using logic as a method to solve problems. Engineers are rigorously logical and independent thinkers. We do not just want to understand the system, but also to improve it. We want to know how and why things work, and how we can get them to work better. That is why we also invent new things, we are in a constant surprise at how much the built world could be improved. It is not uncommon for an engineer to think "Why in the world is this the way this thing is? It could be so much better if I just change this and add that." We are rational problem solvers who like to analyze things to understand how they work and how they can work better.

Engineering design is more of an art than a science; not in the sense that it is uncertain, but because it is true art, like the art of a sculptor or poet. Gordon Glegg’s wonderful little book, The Design of Design, begins: "An engineer has almost limitless possibilities. He can, and frequently does, create dozens of original designs and has the satisfaction of seeing them become working realities. He is a creative artist in a sense never known by the pure scientist. An engineer can make something. He creates by arranging in patterns the discoveries of science past and present, patterns designed to fit the evermore intricate world of industry. His material is profuse, his problems fascinating, and everything hinges on his personal ability. His successes and failures become incarnate in metal. They grow up and confront him, sometimes with surprising results. A scientist can discover a new star but he cannot make one. He would have to ask an engineer to do it for him.” (Glegg 1969)

How do structural engineers design beautiful works of “structural art”? Nervi (1956) states the importance of structural honesty or correctness: "Every improvement in the functionality and the technical efficiency of a product brings out an improvement in its aesthetic quality . . . there is no doubt that any product of high efficiency is always aesthetically satisfying. In the field of architecture, in which functional, statical, and economic needs are intimately mixed, truthfulness is an indispensable condition of good aesthetic results." So one answer, among many, is the fact that structural honesty is a necessary to beauty. Not that anything that is efficient is beautiful, but that for something structural to be beautiful it needs to be honest (efficient, economic, or elegant). In addition, it is the engineer's personal ability that contributes to great works of structural art. The engineer that seeks personal excellence will see that transcend themselves and into the built world.

I remember visiting a project where I designed all the connections for a large box truss that supported four stories of concrete and spanned 100 feet. The erector and welder was proud to show me his work and described the installation, welds and details as a master craftsman would. He was not being self-serving—he was describing the work itself. He and I both knew that the architect was going to cover it all up for no one else to see. He was still deeply satisfied, as was I. I realized much later that the satisfaction was not really about the truss or even the workmanship (craft). What he was really showing me was a manifestation of himself in the steel connection. The weld was beautiful and well-crafted, of course, and that was satisfying, too; but that is not really what he was feeling. He was really showing me that he was a good human being; that he is quality just like the connection. The inanimate object was a reflection of him and it was beautiful. We can learn a great deal about how the outcome of our work is conceived in our minds the same way. While we are not particularly goal oriented, we do see our work as a actively progressing towards "Quality" with a capital Q. Just like the erector, we are not spectators. We like private concentration, working autonomously or in teams, and delivering quality work (not ourselves) to others. The work is us, but that is our secret.

ENGINEERS ACT INTUITIVELY

Engineers are comfortable with mathematical abstraction and physical laws, but find them secondary to the primary feel and intuition of structures. Intuition is strengthened by experience and forms our strong subconscious reasoning process. Pier Luigi Nervi, one of the greatest structural engineers of all time, describes how our schools have failed the profession on this front in his seminal work Structures: "The pre-eminence given to mathematics in our schools of engineering, the purely analytical basis of the theory of elasticity, and its intrinsic difficulties persuade the young student that there is limitless potency in theoretical calculations, and give him blind faith in their results. Under these conditions neither the students nor teachers try to understand and to feel intuitively the physical reality of a structure, how it moves under load, and how the various elements of a statically indeterminate structure react among themselves. Today everything is done by theoretical calculations. That student is rated best who best knows how to set up and solve mathematical equations . . . the mastering of structural knowledge is not knowledge of those mathematical developments which today constitute the theory of structures. It is a result of a physical understanding of the complex behavior of a building, coupled with an intuitive interpretation of theoretical calculations." (Nervi 1956)

Engineers in practice know that the way we think and feel about structures is more important than the abstract mathematical models or analytical techniques that we use when solving problems. Hardy Cross, the brilliant developer of the moment distribution method, once said, "Design involves sound judgment as well as stress analysis; and judgment is more important." (cited in Addis 1990)

In Engineering and the Mind's Eye, Ferguson (1992) concludes, "Necessary as the analytical tools of science and mathematics most certainly are, more important is the development in student and neophyte engineers of sound judgment an intuitive sense of fitness and adequacy. No matter how vigorously a "science" of design may be pushed, the successful design of real things in a contingent world will always be based more on art than on science. Unqualifiable judgments and choices are the elements that determine the way a design comes together. Engineering design is simply that kind of process. It always has been; it always will be."

A New York Times article on “The Genius of Steve Jobs,” by Walter Issacson, repeats the importance of intuition: "Steve Jobs’ success dramatizes an interesting distinction between intelligence and genius. His imaginative leaps were instinctive, unexpected, and at times magical. They were sparked by intuition, not analytic rigor... he didn’t study data or crunch numbers but like a pathfinder, he could sniff the winds and sense what lay ahead... when he wandered around India after dropping out of college, (Jobs said) ‘The people of the Indian countryside do not use their intellect like we do, they use their intuition instead. Intuition is a very powerful thing, more powerful than intellect.’ ” (Issacson 2011) Engineers understand this and we work to develop our intuition thorough experience, whether it is moving away from past failures or moving towards our successes.

ENGINEERS WORRY AND ARE CONFIDENT

Engineers have to be risk-takers. We have to get it right, because there are enormous consequences of getting it wrong. Functioning with this knowledge requires a certain personality, someone who is confident in his or her abilities. This confidence is tempered by worry. Worrying about design makes us better. We are better able to prioritize which part of the project needs more attention. James Gordon writes, "When you have got as far as working drawings, if the structure you propose to have made is an important one, the next thing to do, and a very right and proper thing, is to worry about it like blazes . . . it is confidence that causes accidents and worry that prevents them.” (Gordon 2003)

In Henry Petroski’s book, Remaking the World, he states, "so many engineers seem to have spent so many sleepless nights while their designs were progressing from the back of an envelope through increasingly complex and detailed calculations and drawings to the realization in an artifact upon whose safety the lives of so many depend. If engineers do sleep, it is often with a pad and pencil nearby. They are there to record not dreams but nightmares, nightmares about collapses and explosions to be checked upon waking against the realty of a design. And it is a good thing, for otherwise there might be more tragedies than we can imagine.” (Petroski 1997)

There are engineering decisions that are made without the best understanding of how the part or system will perform. This is why engineering is a profession. Part of the anxiety of a structural engineer is that we are solving problems that never existed before and inventing something new.

Physics does not change, but that is about the only thing that does not. Every building has traits that no other building in the world has, and have we verified everything? Of course not. But have we verified everything we know how to verify? Probably. After all the calculations are applied, we still have to make a decision about whether it should be built a particular way or be changed. Eventually we have to say, “no exceptions taken,” and live with it the rest of our lives. Incredible structures get built and amazing engineers are the creative force behind all of them. Because engineering requires ingenuity, it requires risk.

CONCLUSION

I think for the most part Engineers are pragmatists and want to work to provide value for humanity. Engineering itself has obvious meaning. The final construction of the building, highway, or treatment plant is useful and therefore meaningful. Since the built thing has meaning, we have meaning. There are many professions that lack this, but we choose this profession partly because of this. Living a meaningful life is critical to one’s well-being.

Engineers, at a minimum, are visual thinkers, artists, scientists, risk takers, worriers, and self-reflective professionals who value intuition, logic, and living meaningful lives. We are in constant search for the knowledge to be able to do things (know-how) not necessarily knowledge itself (know-that). We want to actively participate in creating a better built world. These are some of the common traits that make us who we are.

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