Thinking like an engineer

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This article is the result of a question posed by the author on the Research Gate, How to think like an engineer? (https://www.researchgate.net/post/How_to_think_like_an_engineer?view=59b648be3d7f4b3231730249), which was a question not a recipe. Many scholar chose to answer this question. In this article I have freely drawn from this answers as well as from other sources.

Thinking like an engineer

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"Thinking is skilled work. It is not true that we are naturally endowed with the ability to think clearly and logically — without learning how, or without practicing…. People with untrained minds should no more expect to think clearly and logically than people who have never learned and never practiced can expect to find themselves good carpenters, golfers, bridge-players, or pianists." - Alfred Manner.

Abstract

Does a lawyer, a scientist, or a doctor, think like an engineer? All are trained to think logically; work for society's benefit; take their responsibilities seriously and observe the ethics of their profession, but all use different methods of problem solving, as they have been trained differently. Their training and experience influences the way they think. Business leaders are advised to think like engineers, implying there is a value in it. How do engineers acquire the mind-set they have? How can it be nurtured and best of all transferred to other professions? Engineers are success oriented, but how is success measured? Success for some is an idea becoming reality; or idea becoming a successful business, and for some an idea which provides a pathway straight to the bank. The intention of this paper is to share the author's vision of what it may mean to "think" like an engineer, hoping to reach a conclusion that all engineering educators can subscribe to.

Figure 1: A look into the cuckoo's nest

Introduction

There is no shortage of advice on how engineers should learn, behave, perceive and what ethics to subscribe to. There are also various theories on how to shape engineering curricula to make engineers more of a thinker than a technician. In this paper the author poses the question "how does an engineer think?" and if it is different from the way other professionals think. Naturally, in this examination one cannot ignore the teaching theories and their influences, as we are the product of our training and experiences.

Figure 1: What goes on in the mind of an engineer?

According to ABET (Accreditation Board for Engineering and Technology, USA - http://www.abet.org/) the core competencies of what is expected from an engineering education are:

a. Ability to apply mathematics, science and engineering principles.
b. Ability to design and conduct experiments, analyse and interpret data.
c. Ability to design a system, component, or process to meet desired needs.
d. Ability to function on multidisciplinary teams.
e. Ability to identify, formulate and solve engineering problems.
f. Understanding of professional and ethical responsibility.
g. Ability to communicate effectively.
h. The broad education necessary to understand the impact of engineering solutions in a global and societal context.
i. Recognition of the need for and an ability to engage in life-long learning.
j. Knowledge of contemporary issues.
k. Ability to use the techniques, skills and modern engineering tools necessary for engineering practice.

Undoubtedly these are important attributes, but, is a thorough knowledge of them sufficient to make you think like an engineer? It is not difficult to find very competent engineers who cannot positively respond to all the items in this checklist. Thinking like an engineer is more than understanding science and maths, since they are only tools, it is the way that engineers see the world, and solve problems that matters. Why might we want to think like engineers? What makes the engineering profession different from other professions?

Ever had to solve a problem in collaboration with engineers and found that they think in a completely different way? Engineers use their skills and knowledge to improve existing processes or find a solution to a problem. All professions share the feel they are duty bound to contribute to their society's benefit, hence being socially responsible is not a differentiating factor. Law school and engineering education are both nominally concerned with delivering a corpus of knowledge, but they also foster specific ways of thinking.

Management consultants have discovered the advantages of thinking like an engineer and advise entrepreneurs to "think like an engineer". Sasha Gurke, senior vice-president and co-founder of Knovel, In ***Bloomberg Businessweek*****,**
(http://www.businessweek.com/smallbiz/content/jan2011/sb20110114_396482.htm) offered his views **on how to think like an engineer.** Recently a few popular books on how to think like engineer has appeared on book shelves. Authors of popular books thinking like a salesman, not engineer.. These authors begin with anecdotes, and then determine what general conclusions can logically be derived from those anecdotes. In other words, they decide what theory or theories could explain the anecdotes. This is a reasonable hypothesis given the data. However, induction does not prove that the theory is correct. There are often alternative theories that are also supported by the data. Such books may have an entertaining value, but no one becomes a thinker by reading them.

Politicians make their decisions from an ideological standpoint, and if the evidence fits well (or can be 'made' to fit) that's nice, otherwise they explain it away, and over time the political system declines. In contrast engineers follow evidence based decision making by following the physical laws of nature. Engineers don't solve a problem by appealing to doctrine. However, the way we live is shaped by engineers.

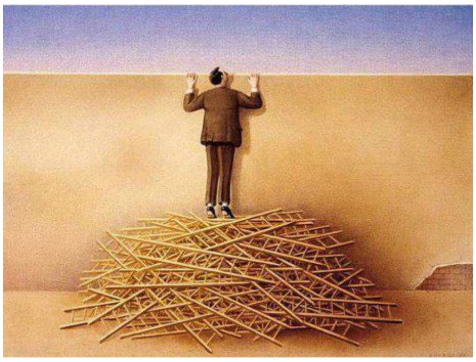

Figure 3: A little help to see

Paraphrasing Percy Bysshe Shelley (http://www.bartleby.com/27/23.html), Engineers are the unacknowledged legislators of the world. By designing and constructing new structures, processes, and products, they are shaping the world we live in, and their influence is much stronger that any laws enacted by the legislators of any country. The impact of innovations doesn't stop at the border, while law enacted in one country rarely influences another country.

Many entrepreneurs believe in "The greater the risk, the greater the reward", but engineers see it differently. You can still have a great reward with calculated risks. Engineers take in all the information, analyse all the data, identify hazards, eliminate them if they can, then mitigate and control the remaining hazards, before making decisions. Understanding what is at risk, makes the reward that much greater. Engineers have inquiring minds, and are curious about things around them and how they work. The need for understanding never leaves an engineer. Engineers think there is always a solution for every problem; some require finding a solution, others just require a new perspective to what is needed to succeed; one is never out of resources, just out of resourcefulness.

CDIO movement

The world movement toward market liberalization, and transition to a knowledge-based economy, combined with the desire for increased integration into the global economy has placed greater demand on education as a critical driving force for growth. It remains a challenge for universities, both in developed and developing countries, further advance teaching and learning methodologies to enable students to acquire the necessary understanding of information and skills, while also providing the feedback to determine the quality of teaching and continuously improve the learning process. An initiative called Conceive-Design-Implement-Operate (CDIO) is hailed to be an effective framework to create the right mind-set for the engineering profession.

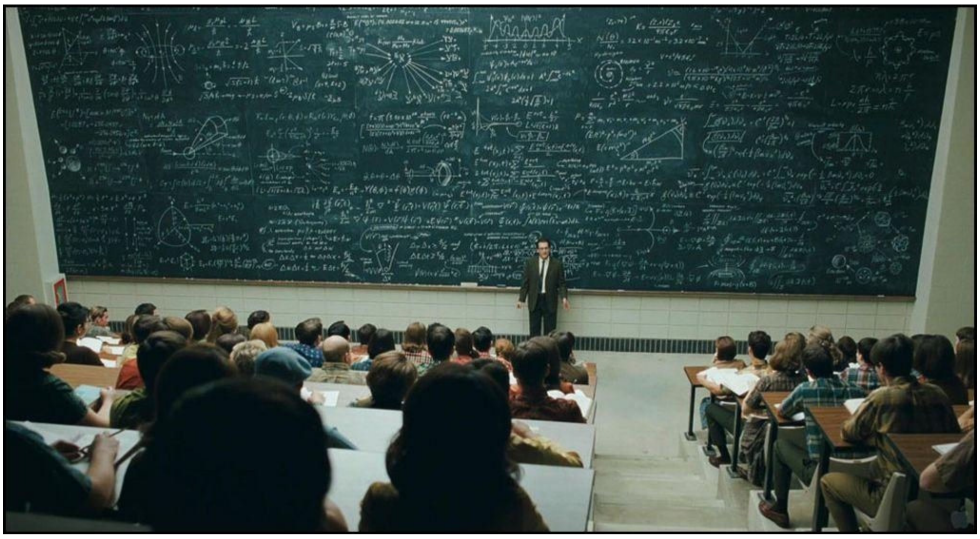

Figure 4: who knows what is going on?

Since the CDIO framework is promoted for instilling the ability to think like engineers, it is worth understanding how it supposed to work. The CDIO initiative is now a global movement as a framework for designing curricula. The http://www.CDIO.org site states, "*The CDIO™ INITIATIVE is an innovative educational framework for producing the next generation of engineers. Throughout the world, CDIO Initiative Collaborators have adopted CDIO as the framework of their curricular planning and outcome-based assessment*"

CDIO is a framework only, not a set of rules. One implementation of CDIO is the project based learning (PBL) in a workshop setting. In PBL, the learning process is not based on passive-note taking and reciting taught materials in written exams. To the author's knowledge most engineering universities in Iran have incorporated PBL in the senior years of undergraduate curricula. In fact this method of teaching goes back to the days of the founding fathers of the older universities.

If you think of anything that is manmade, whether it is a book, a car, a house or refrigerator, you will notice that its life cycle goes through 4 main stages. At the very beginning, someone has to have the initial concept; this is the process of **Conceiving** the idea of a product or service and is indeed the very first step. Many ideas remain just that, ideas, but to take the idea one step further, engineers need to **Design** and decide how the intended system, product or service will look like. The Design can be a sketch on a piece of paper or detailed drawing on a computer. After a product is designed, the next step will be to go ahead and make it, build it and bring it to life. Crawley et al calls this the "**Implement**" stage. Now that we have a tangible product, we need to "**Operate"** it safely and efficiently. So in a nutshell, a system, a product or a service will always go through this process of Conceive, Design, Implement, Operate, or CDIO. No argument here, but how does an engineer think at each stage. In fact engineers do nothing but CDIO, and it is part of their makeup. Every subject in the senior years revolves around a CDIO framework.

There is a need for a tool, a process or procedure to help engineers in making rational and relevant decisions. Thinking like an engineer is about how an engineer sees the world, analyses it, make sense of it and interacts with it. A saying which is attributable to Einstein states "make thing as simple as possible, but not simpler" aptly defines how an engineer approaches a problem. The first step to thinking like an Engineer is to simplify problems to the point of being manageable, but not beyond it. Getting to the root of the problem is the key. An engineer tries not to make things more complicated than they need to be. Any elegant system is just a collection of simple ideas brought together to deliver a function.

Similar to a product, we humans are also evolving prototypes. However, the evolutionary processes of nature aren't goal oriented, whereas the value of engineering is determined by its outcomes. There's hardly a scenario where the engineering mind-set doesn't add value or fresh new perspectives, and there are vital benefits to be gained through the engineering mode of thinking. Engineers are faced with design challenges and problems every day. They will be presented with a set of supplies, a set of tools and a particular aim, and then they will be left to try and create a satisfactory solution using those resources. As such, engineers will not stop when they hit a wall; they will try to find a way around it. The engineering mind-set sees structure where others see none, and is adept at working under constraints, and making calculated trade-offs in the scheme of what's available, what's possible, what's desirable and what the limits are.

Engineering education has traditionally been very focused on conveying a set of content and skills, with very little consideration given to how the pedagogies used to affect the learner's way of thinking, or the approach to questions that they foster. Engineering education typically excludes problems that involve people, and trains young engineers to be most comfortable with questions that have a single correct answer. But the types of problems we expect engineering graduates to be able to address involve complex interactions of technology, systems, and society. How do we help our graduates develop the ways of thinking they'll need in order to address these types of problems?

Figure 5: I can't see your point of view

How other professionals think?

Education is a process of learning how to think but not what to think. Different disciplines have different methods and modes of interpreting, thinking, and doing. Engineering education has often been viewed as imparting a powerful method of thinking that communities benefited through ages, but what it means to be an engineer continues to evolve.

Artists exhibit many creative traits such as exploration, novelty and adaptability. In an increasingly connected and dynamic world these types of creative skills have grown in importance for professionals; medical profession, scientist and engineers seeking innovation. Cubism never existed before Picasso invented it. In the 1950's abstract expressionism, dominated the art scene. Jasper Johns revolutionized art by painting simple icons, such as flags and maps, forcing us to see things in a new way. Artists and engineers work in response to different demands, and the product of their creativities serve different purposes as they tap into a different parts of their brain.

Engineers are firmly tied to reality, testability, reliability, and purpose, just to name a few, while an artist does not recognise any of such ties. The two groups are working from different premises. Creativity for an engineer is not for its own sake, as it must serve a purpose. The most important difference between artists and engineers is that artists do not use scientific methods. This means that artists can work from untestable hypotheses. They are not bound to physical realities or limited by their observations, and can instead choose to work from conceptual foundations which are imagined, abstract, or even irrational. This way of working is unsustainable for engineering an airplane, exploring the cosmos, or designing a city's sewer system. However, the artistic frame of mind also helps to push things forward; unfettered imagination is crucial for *inventing airplane*, *imagining* how the cosmos might be explored, and *inspiring* man to question the universe.

https://pams-doyle.wikispaces.com/

Figure 6: Different profession think differently

A Scientist looks at a problem in the abstract and uses testable hypotheses to isolate all the component parts of a problem and solve them (individually, if possible). Breaking down the problem into its component parts can determine the independent root causes. Solving problems in this way is more resource and time-intensive than the physicians' approach, but if the right hypotheses are posed, this system can handle a broader range of problems and generate new data that are applicable to other problems.

A scientist starts from scratch, simplifies reality to a bare minimum and tries to understand and make an attempt in generlisation. When he/she reaches this point the job is done. Alexander Fleming discovered penicillin but it was an engineer, Margaret Hutchinson, who utilised her knowledge of fermentation and petrochemical engineering to mass-produce the contents of Fleming's tiny petri dish.

The story of theory of turbulence illustrates two differing world vies. Stokes, as in Naivier-Stoke theory of turbulence, was one of the giants of fluid dynamics in his time. Stokes proposed a set of six equations to solve the turbulent flow. But he couldn't solve them. About this time Osborn Reynolds wrote a paper and described a method which is now known as "Reynolds time averaged bulk of turbulence flow" and suggested an approximate way out, but his paper was initially rejected by Stokes as not being accurate. Reynolds was looking for a "good enough" solution to put into practice, instead of sitting on it until the exact solution is found. Reynold approach is 100 years old, but it is still the main work horse of the industry. Even with supper computers the Navier-stokes equations can be solved only for very simple cases. This tell us a lot how the mind of scientists and engineers work. If less than an exact solution is not acceptable, then we still be waiting for somebody to come up with an idea better than Reynolds.

Physicians are trained in medical schools to think about differentials and categories. A physician uses a pattern seeking approach known as differential diagnostics. It consists of four steps. First, the doctor collects the patient's medical history, and makes a list of the patient's symptoms. Next, the doctor makes a list of possible diseases or conditions that might cause each of these symptoms. Third, the doctor organizes this list by priority. The ranking must take into account the likelihood, as well as the potential severity, of each possible condition. Finally, the doctor begins testing for each of these conditions, starting with the top of the list and working down. If the test results rule out a possible condition, the doctor moves on to the next one on the list. Sometimes, test results may prompt the doctor to reprioritize the items on the list. This mode of thinking is used by engineers to find fault in a system.

Physicians, scientists and engineers are all work from a testable hypothesis, and their world is constantly evolving, expanding and improving. How does a lawyer's way of thinking compare to these groups of professionals? Lawyers also have precision of thought, analytical capability, logic, abstraction, and assertiveness (http://dsgazette.blogspot.co.uk/2006/10/thinking-like-lawyer-vs-thinking-like.html). How does the precise thinking of a lawyer differ from the precise thinking of an engineer? In law, it's more important to keep the peace than it is to reach an ultimately just result, while in engineering it's more important to reach a "good enough" result than it is to get there the "correct" way. Everything else follows from that difference.

Law is based on the principal of predictably. You can't have the Rule of Law unless people know what the law is, and you can't know what the law is if it changes every time a new court looks at it. So we are willing to accept results that might not be perfectly equitable in a particular case so as to keep the peace in general.

If law is more about keeping the peace than about justice, what does that mean for legal reasoning? It means legal reasoning is not a search for the truth, it's a form of persuasion designed to convince the audience that a particular result is the proper one. Lawyers for both sides look at essentially the same facts and cases and write "tightly reasoned" legal briefs coming to completely opposite conclusions in order to convince the judge their conclusion is the right one. Similarly, judges write opinions designed to convince other judges, and ultimately the public, that their conclusions are correct. How does legal reasoning work to convince people? Every argument is laid out in many steps. Each step is joined to the next, and between the steps, there's some room to play. The more joints (i.e. more steps), the more room you have to play, and by adding just a little bit of “adjustment”, to your desired direction, at each joint, or by adding or removing a joint here or there, you can shift where the argument ends up. In general, law is very process oriented.

Thinking like an engineer is different from how a lawyer thinks. Engineers also care about reaching the ultimate result. Does the bridge carry the design load? Does the software run quickly enough? Their goal is to meet the design criteria for a problem –e.g. the wing must lift an X pound airplane while weighing no more than Y pounds itself, with a predefined safety margin. It's much less important how you get there. Like a lawyer, an engineer must deconstruct a problem into smaller and smaller pieces until the individual pieces are simple enough to solve. The difference is the focus: the engineer lets the goal drive the decomposition, while for the lawyer the decomposition itself must persuade the audience that the end result is the correct one.

The following four cases describe how different professions may approach the same problem (taken from Dan Buckland How Physicians, Engineers, and Scientists Approach Problems Differently http://www.medgadget.com/2012/08/how-physicians-engineers-and-scientists-approach-problems-differently.html)

Case 1: Patient A started coughing this morning, what should she do about it?

Physician: What are the top 5 reasons people cough? Has she been treated successfully for a cough in the past? For this patient’s age and medical history, which of those 5 causes are most likely? Would any test results change the treatment plan? Treatment will be based on what has historically worked best for the most likely diagnosis.
Scientist: What would cause this patient’s particular cough? What is the root cause of her lung or throat irritation? If it is infectious, what is causing the infection? If we find what is causing the infection, do we know how it is causing the cough or irritation?
Engineer: What is different now compared to when she wasn’t coughing? What was she doing this morning when the cough started? If she tries one treatment and gets a little better, then she should use more of it to get a greater effect.

In this case, the Physician probably has the fastest and most efficient route to diagnosis and treatment plan if there is a common cause for the cough. The Scientist’s method, when it eventually gets to a treatment, will have produced a lot of information, but it will take a longer time and be very resource intensive. However, if there is an uncommon cause for the cough, the Scientist method will be more likely to find it. The Engineer’s method could work as well, but it doesn’t use the shortcuts of the Physician or the robust strategy of the Scientist.

A lawyer would instantly think about responsibilities for action. A lawyer is likely to look for rules as to how to behave in this situation. As a start, a lawyer would recognize the danger of advising Patient A as to what she should do without being properly qualified to do so. Are there workplace policies at Patient A’s workplace which guide whether she should or shouldn’t come to work? And how do the consequences of breaching these actions compare to Patient A’s preferences to go to work or stay at home? Perhaps there is a precedent, by which lawyers mean known previous outcomes, which suggest answers. If Patient A visited the physician last time she had a cough and was told, “you did well to come and see me because as an asthmatic you are susceptible to complications”, then seeing a physician is indicated by precedent. Lastly, a legal analysis would look for desired outcomes. Does Patient A want to find a way to stay at home, in which case finding a friendly physician to excuse her from work becomes the priority? Or does Patient A want to work so she gets paid, perhaps in spite of company policy which says she should stay home, in which case finding a cough suppressant is more important.

Patients B, C, D, E, and F all have a form of slow growing cancer no one has seen before. They are all related, but the inheritance pattern is not one that has been observed in other cancers. What should be done?

Physician: Of all the cancer types known, which one is the closest to this one? How is that cancer treated? If that doesn't work, what is the next closest match? How is that one treated?
Scientist: How does this cancer work? What is the cell type involved? What makes the cancerous versions of that cell type different than the non-cancerous versions? Is that difference something that can be detected in this patient? Can that information be used to determine how to kill just the rapidly growing version of that cell type and leave the rest alone?
Engineer: What makes this cancer different than the closest match that has been treated in the past? Can we use that difference to modify the treatment plan?

In this case the Scientist's method is probably the best approach to take, since the problem itself has very little known about it. The Physician method will get to a treatment quicker, but is likely a shot in the dark and may cause more pain and discomfort with less overall benefit if the closest guess has a very different root cause. The Engineer method looks at these differences to try to get to a solution.

A lawyer would look for the cause of the cancer, and can someone be sued because of it? On the face of the matter this is an attractive way of thinking for the patients, because the financial windfall may cover the patients' cost of treatment. A good lawyer looks beyond the allocation of blame to a broader idea of 'equitable society'. Arrangements from health insurance to the obligations of their employers are affected by their illness. In parallel with the treatment process, these aspects of the patients' lives may make the difference between a recovery, to a life very like the one they had previously, and a recovery beset by worries of debt and eventual poverty.

The legal analysis does not touch the patient's treatment, which is a matter of science. The lawyer knows that this is not his/her place. The lawyer immediately thinks of the social context of the patient's illness, and about whether benefits, under the rules that govern the interaction between the person and society, have been triggered as a result of the illness.

Patient G had her gallbladder removed by Dr. H. She performs the procedure laparoscopically, but the tools she uses do not work the way she wants them to, and she feels that she spends too much time struggling with the equipment rather than doing the procedure. Other surgeons say they have the same problem too. What should be done?

Physician: What have other surgeons done to compensate for the unwieldy tools? Do any of those methods fix the problem of taking too much time struggling with equipment?
Scientist: How would we design a brand new laparoscopic system that doesn't have those problems?
Engineer: What exactly does the surgeon like and dislike about the system. How could we modify the current system to keep the benefits and lose the difficulties?
For this issue the Engineer probably has the best approach. Rather than starting from scratch like the Scientist, or treating the problem as fixed like the Physician, the Engineer's approach looks for the simplest

A lawyer can approach this problem from two angles. From the perspective of Dr. H and her colleagues, who want equipment, which works better. What did the manufacturer promise to deliver? Under those agreed rules ('contract'), can the manufacturer be made to improve the product? If the machine is faulty, then the manufacturer could be forced to replace it. A lawyer can also negotiate a win-win solution whereby Dr H. helps to improve the machine and have access to the latest prototype.

The second angle is the perspective of Patient G. Did they get the standard of care they were reasonably entitled to? If not, was Dr H at fault for performing the procedure with tools she knew were below par? Or is the manufacturer at fault? Is the patient prepared to endure the stress of litigation for the potential pay-out of a successful lawsuit?

These cases demonstrate that Law is fundamentally different to engineering, science and medicine in one important way. Law is completely a manmade concept. In engineering, science and medicine, the laws of physics rule; Bridges fall down, chemicals react, and people become sick according to physical processes irrespective of human preferences, agreements or desires. In law, human perspective is everything. People make laws, interpret laws and enforce laws, and if there is total agreement to act contrary to a law, then the text of the law is irrelevant. Laws are different from state to state and country to country. Physics is invariant.

This difference means that lawyers put a premium on being convincing (as opposed to being right). The engineer, on the other hand, puts being right ahead of being convincing. Is it any wonder then that both lawyers and engineers can't believe the other "doesn't understand the real world"? In a way, both are right.

What goes on in the mind of an engineer?

We know that engineers see the world differently from say that of an architect or a lawyer? But how different is it? The Royal Academy of Engineering sets out to answer this question in their recent study "*Thinking like an engineer"*. The report identifies six engineering habits of mind which, taken together, describe the ways engineers think and act.
Here are the six habits defined: (http://www.raeng.org.uk/policy/education-policy/learning-and-teaching)

1. **Systems thinking**: Seeing whole systems and parts and how they connect, recognizing interdependencies.
2. **Problem-finding**: Clarifying needs, checking existing solutions, investigating contexts and verifying.
3. **Visualizing**: Being able to move from the abstract to the concrete.
4. **Improving**: Relentlessly trying to make things better by experimenting, designing and conjecturing.
5. **Creative problem-solving**: Applying techniques from different traditions and generating ideas and solutions.
6. **Adapting**: Testing, analysing, reflecting and rethinking.

The authors of the royal society of engineers report call Engineers ways of thinking as 'habits of mind'. The question is how to harness these habits of mind in our education systems, in order to benefit from the 'engineering way of thinking'.

These habits are what enable engineers accomplish their highest goal: to make things work better.
This report offers fresh insights into the ways engineers think. It suggests ways in which the education system might be redesigned to develop engineers more effectively and makes suggestions as to how the wider public might become engaged with these issues. Universities need to redesign their education system so that these habits become the target outcomes of an engineering education.

In a previous paper the author analysed the first item on this list. In this paper the author outlines a systematic method for problem solving and the continuous improvement of the decision making process. There are different philosophies of problem solving as different thinking styles lead to different problem-solving strategies. Engineers use questions to understand the problem and search for the information needed to resolve it. Such questions are driven by engineers' intellectual curiosity and need for information. The manner in which these questions are articulated is a key to the successful outcome. Questions need to be posed specifically enough to guide the search for information. They should not be posed if the answers do not result in constructive actions. This framework enables practitioners to incorporate latest research findings into their daily decision making.

Engineers' decisions are based on the best available information, which is consistently and systematically identified, evaluated and selected. The decision process broadly follows the following five steps.

Step 1: What is the question?
Asking the right questions to understand the problem, the boundaries and the environment that the "outcome" should exist. The outcome is generally a system whose elements, the relationship between them and their iterations within and with the outside world must be understood.

Step 2: Identifying the Evidence
Engineers may search the literature for information to supplement what they know, hence searches could be limited to the information they deem important.

Step 3: Selecting the Best Available Evidence

Each piece of information is assessed for its relevance and each relevant information is further assessed for validity and applicability. Determining relevance is the first consideration in systematically selecting the best available information from that identified. The relevance of information may be different for every engineer, based on their range of experience and interests.

Step 4: Synthesizing information from multiple sources
Deciding on the best course of action requires synthesizing multiple sets of data from multiple sources. When multiple data are present on the same topic, preference for inclusion and organization must be based on the quality of methodology, depth of investigation, adherence to reality.

Step 5: Basing Conclusions on the collected data
Conclusions and recommendations from the evidence synthesis required for decision making. The overall conclusions provide a way forward (a solution).

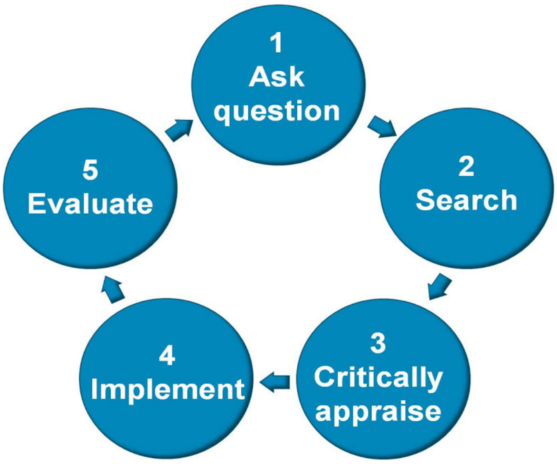

Figure 7: The never ending circle of inquiry and improvement

The above methodology is of several problem solving approaches that is applicable to all forms of practice, but is particularly useful for the engineering profession feeding their inquiring mind.

The spirit of inquiry is the curiosity to know, and questioning if one's past judgments can be improved. Questions like "Am I making the right decision?" help to find the deficiencies in one's knowledge. Engineers are required to have a predisposition to inquiry, as well as the impetus to pose searching questions. By searching equally hard for contradictory evidence as well as for evidence that confirms a notion, and by objectively applying critical appraisal of evidence specific to each problem, engineers are able to achieve consensus among their peers.

Generally, the tendency is to emphasise what worked in the past rather than why it worked. It is better to concentrate on what went wrong rather than what worked, as what worked embodies a set of unknowable assumptions either by design or by chance. This requirement emphasises engineering expertise, reasoning and the integration of this expertise with the best available evidence. Having access to the latest research in itself does not constitute good practice. It is the appropriate use of this information in the context of problem solving that marks the transition from evidence being simply information to being best practice. There is a danger of becoming a slave to evidence. This happens when the caveats behind the evidence are either ignored, or applied without using professional reasoning skills to consider whether an approach is applicable or appropriate to the situation.

The task as a whole may be complex but by asking questions similar to those listed below, a clear image might emerge:
1. Can the problem be simplified without losing substance?
2. What are we trying to achieve?

3. What are the major contributing factors?
4. How to proceed (Strategy)?
5. Where to look for evidence?
6. How do we collect evidence?
7. What should we do if there is no evidence or it is ambiguous?
8. How to make sense of the situation?

Reliance on intuitive modes of decision-making comes with a commensurate reliance on cognitive shortcuts or heuristics for managing the amount of knowledge needed for decision-making. This introduces systematic biases into decisions and deviations from the normative rules of 'good' decision-making. Fostering the culture of inquiry is essential if the prospect of delivering safe and reliable engineering systems is to be reached. While critical appraisal and the use of research are integral to this process, the process itself is much greater and more delivery centred than research alone.

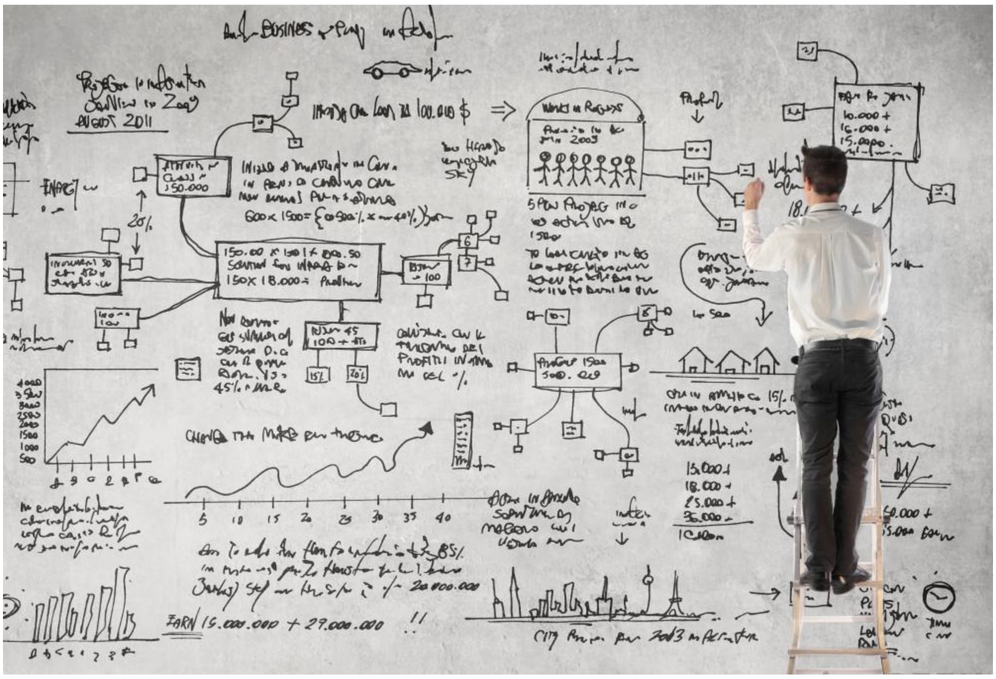

Figure 8: The answer is here

Discussion and Concluding Remarks

Engineers were asked what they think of themselves, and what they think others think of them. According to this survey Engineers see themselves as risk takers, humble, ambitious, and have a wide range of interests, while they think other non-engineers view them as risk adverse, borderline arrogant, not so ambitious, with a very narrow range of interests.

Engineers think differently from the rest of the world, and society needs their problem-solving ability, systems-thinking and their mind-set which is continually seeking to improve. Engineering is not about putting two and two together; it is a way of thinking. Engineers are behind many of the worlds greatest advancements including computers, the Internet, smartphones, medical tools and cars, just to name a few, which have had a great impact on the quality of life. These inventions have enriched our lives and enabled us to have a vivid experience of life. If you are not convinced, do a thought experiment and remove anything in your life for which an engineer is responsible; what is left?.

Who are these engineers that are responsible for these technological marvels? What inspires and enlightens them? What challenges them? And how can we learn to emulate them? We are urged to think like an engineer, but how does an engineer think?

Engineers are trained to take a known solution as a starting point to visualise ways of improvement, rather than starting from scratch like scientists do, or treating the problem as fixed (until it is proved otherwise) like physicians. Engineers look for the simplest novel solution using the current context; for them progress is one step at a time. The way different professionals think has a lot of similarity and one major difference. An engineer's way thinking is open ended, it may have a beginning but not an ending. An engineer's job doesn't end at the understanding phase, it even doesn't even finish when the first generation of the product is in use.

The CDOI and Royal Institute models for training future engineers has been discussed here. Every idea has its limits and potential, depending on the time of its promotion it may have something to offer, but one should seriously doubt that if any model is the universal answer. One should seek the most useful model, which has most to offer and be open to new ideas as they come along. The author has described an implementation of the Royal Institute Model.

Engineering educators have historically focused on the content and skills, and certainly no one wants to lose that. But it's time to start giving some thought to not just what engineering students should think about, but also how they think. Open-ended problem solving, in general, allows students to get comfortable with the idea that in engineering practice, as in life, there is rarely one right answer. In addition, engineers need to consider explicitly the social, political, or historical context of their work.

Creativity and imagination are not the prerogative of engineers, they play important roles in getting started with literature, architecture, arts, and science. Curiosity is also a shared trait. The difference is where curiosity leads each group, where they start and end, and which road they take.

An engineer has to be a 'systems thinker'—embrace the entire context of the problem. This involves understanding hidden feedback loops and processes, the nature of interactions between components in the system, etc. What really differentiates engineers is their insistence on building a prototype or detailed simulation or tests, to see if the system works. All successful man-made processes involve this kind of engineering thinking. Engineering is a lifelong learning. It is evolving from an occupation that provides clients with competent technical advice to a profession that serves the community in a socially responsible manner.

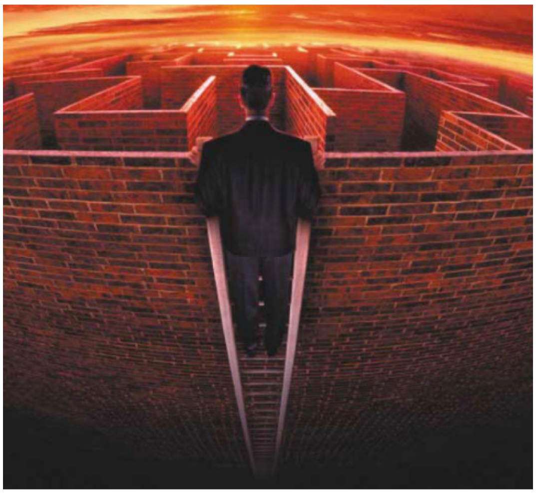

Figure 10: Now you can see

The author has also highlighted the very different ways each group of professionals was trained to solve problems and even how each group formulates problems themselves, which influences their problem solving approach and how they behave. What goes through one's head as he or she transitions from being an engineer to being a lawyer? Taking a sound egg, cracking it, and throwing it into a frying pan... it just isn't the same afterwards. Is this what happens, when one transition from one profession to another with a different mind-set? Are these professions using the same lines of reasoning but with two different rule sets?

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