Thinking Like an Engineer

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Table of Contents

Introduction

There is an old saying that an engineer can do for $1.00 what any other person can do for $2.00. That saying isn't true in two ways. First, when considering the Total Cost of Ownership, an engineered solution typically costs far less than half the cost of a non-engineered solution. Second, there is no assurance that a non-engineer can even accomplish the things an engineer can do, no matter what the cost.

I use that old saying as a way of introducing the concepts this course intends to address. The reason why engineers can do things for $1.00 that others can only do for $2.00 or more is held in the words structure, discipline and then, a little bit of magic.

The structure is in the way an engineer does things in an orderly manner. Structure includes both the sequence in which things are accomplished and the way the steps of each sequence are assembled and planned in detail.

The discipline has to do with the engineer's dedication to strict adherence to the structure that has been established as being optimum or being required by his or her employer.

The little bit of magic has to do with all the science and analytics that our predecessors have left behind for us to use whenever they are needed. By saying a little magic, I am not suggesting that the techniques we apply are by any way small or insignificant. They are very large and significant, but we use only a small portion of what is available during each of the tasks we perform.

But, in addition to the ability to do for $1.00 what others can only do for $2.00 or more, there are two other important aspects of how an engineer performs work and of the results he or she produces.

The first has to do with the physical integrity of his or her products. Possibly the most apparent examples of products that depend upon the characteristic of physical integrity are skyscrapers and bridges. For those examples, the lives and well-being of hundreds or thousands of people are dependent. There are specific requirements for design calculations, safety factors, material selection and so on. The engineer is responsible for the proper application of each to produce a product that will assure absolute physical integrity.
While skyscrapers and bridges may be the most apparent examples of assets that require physical integrity, they are not the only ones. The design of aircraft, vehicles, homes, and the systems they contain, machinery, equipment, processing, and production facilities and on and on all depend upon the same kind of focus on physical integrity to assure the safety and long-term usefulness of the assets.

While the work done by registered professional engineers can be characterized by specific steps and processes leading to the physical integrity of the assets they produce, they are not the only kind of engineers that must produce assets with certainty of physical integrity. Engineers working in plants, manufacturing facilities and many other kinds of engineering jobs work to achieve similar results involving safety and survivability.

The last of the elements important to engineering are those of honesty and integrity having to do with the way in which they behave and deal with others. In simple words, engineers have to be honest. They need to tell the truth. They need to do what they say they will do. They need to do the work that is expected of them. They always need to act with integrity in their words and actions.

While this third of the characteristics of engineers might seem to be expectations for everyone, we see too many situations in which it is impossible to take honesty and ethical behavior for granted. Even a single engineer who acts with the absence of integrity creates an illusion of mistrust and uncertainty that all other engineers must then confront.

The three results expected from engineers are:

- $2.00 in value for $1.00 in cost.
- Physical integrity of products
- Functional integrity in thoughts, words, and deeds.

Those results depend, in a large way, on the ways in which engineers think and the tools they use when performing their jobs.

When I began to think about this subject in a very general way and with an open mind, I decided to ask an AI program the question, "What is special about the way an engineer thinks?" The program responded by saying that the thought pattern of engineers have a number of special characteristics, including:

- It is Analytical.
- It is Creative.
- It is Systems-based.
- It is Structured in an organized manner.
- It intends to deal with Restraints in a considerate manner.
- It is Optimistic.

A few weeks later, I asked the same question again and received a slightly different answer:

- It applies structured problem-solving methods.
- It is innovative and creative.
- It depends on applying scientific principles.

- It includes optimization of results.
- It pays attention to details.
- It depends on interdisciplinary collaboration.
- It accounts for ethical considerations.
- It is adaptable.

Each of the two lists provide several items that somewhat overlap with the other list, but they also provide some characteristics that are distinct. That distinction being produced at different times while using the same program and asking the same question says something about AI and something about the nature of time. AI’s response depends upon sources of information that are continually changing. That fact provided another important characteristic that was contained in either of the lists: Engineering thinking depends upon remaining current and up to date.

The differences in the lists are consistent with human intelligence. A truly intelligent person makes recommendations based on the best information available, but the information changes over time and so should the recommendations or responses that are provided.

At any rate, for purposes of this discussion, I will use the following list of twelve characteristics to describe “engineering thinking.” I will leave it to the student to check back on frequent occasions to determine if any new of different items have been made to the final list:

1. It is analytic.
2. It includes problem solving as an important element.
3. It is based upon scientific principals.
4. It requires attention to all the details.
5. It frequently requires a multi-disciplinary effort to properly include various kinds of expertise.
6. It is system-based as a way to add focus.
7. It uses a structured and repeatable process.
8. It frequently is creative and innovative.
9. It is adaptable to other needs.
10. It considers known restraints when identifying solutions.
11. It is both optimistic and optimized.
12. It considers ethical issues.

While this list may or may not adequately cover all the characteristics of engineering thinking, it provides a useful starting point.

Keeping that in mind, we have two objectives for this discussion.

First, we hope to engage you in a detailed discussion of the kinds of thinking and accomplishments you hope to achieve while working as or while representing the image of an engineer.

Second, we hope to help you always remain engaged as the same kind of useful and productive person as you progress through all phases of your career. While you might not always have the title "engineer," it is the characteristics of an engineer that always remain important to the things you do.

When those two objectives are achieved, both you and your employer should have a long and successful relationship working together.

Organization of this Course

When looking at the list of twelve characteristics, an engineer might identify several of the characteristics as being "mandatory" for achieving his or her own personal expectations. The remainder of the list are characteristics that any employer would have a "right-to-expect."

I divide the characteristics in this manner because there may be some expectations that are reasonable only after specific forms of training or years of experience, but other characters, like honesty and personal integrity, should always be present.

The first characteristic is everything having to do with personal honesty and integrity. You might say that personal honesty and integrity is a characteristic expected of everyone. But engineers frequently find themselves in special situations that most others do not. For instance, when a registered engineer stamps and signs drawings and specifications for a structure, that act is meant to assure the owners and users of that asset that it has been engineered to conform to the required engineering standards. It assures physical integrity in a way that is different from that assured by anyone other than an engineer. For instance, when a car mechanic says your car with 100,000 miles on the odometer is "good as new", his or her assurance is not the same as the assurance provided by an engineer that is safe to support specific loads.

In addition to the integrity of designs, engineers are often assigned responsibility for managing large sums of money, large quantities of resources and other elements like time and performance. When an engineer is assigned to perform a job that contains those kinds of responsibilities, in accepting the trust of his or her employer, the engineer must show that he or she is worthy of that trust.

The second kind of characteristic has to do with those things that the employer of an engineer has a "right-to-expect." Say you are performing a piece of work that is not going to be stamped and signed by you. Then what level of performance is expected from you? In this case, it is not the absolute degree of certainty and performance that would be expected as would a mandatory characteristic. Instead, it might be better described by saying it would be the "best possible job" that can be done in the limited amount of time or with the limited number of resources available.

In this case, if the level of absolute assurance cannot be achieved, the engineer should be expected to describe the "inherent limitations" under which he or she is working. For instance, if some portion of the work must be completed by the end of the day, the engineer might do his or her best but deliver the work with a caveat describing the limitations of the results. For instance, the engineer might add the words, "Having more time, I would have looked into the following issues, or I might have performed calculations in a more accurate or complete manner." In that case, the employer would know the limitations of the product and have an opportunity to assess their impact and choose to continue on the current path to delivery or to stop and spend more time performing the engineering dependent tasks.

For example, when working in a plant as a plant engineer or a maintenance manager, there is frequently more work than can be completed in a typical workday. Despite that fact, the plant has to keep operating and do so in a safe, reliable manner. In this situation, it is important for everyone to understand both the expectations of performance and the implied limitations.

Here it is important to say that registered engineers and engineers in general perform a wide variety of roles. It would be impossible to describe all those roles, but it is possible to say that most engineers, registered or not, intend to perform their roles with a high degree of integrity and responsibility. The point being made here is that all transactions should be as transparent as possible. If an asset is “good as new” say so. But instead, if it has had operability restored but it is only “good as old,” instead you should say that.

In this course, we are discussing characteristics and standards that should apply to everyone who is performing engineering and using the term “engineer” as an entree into specific jobs and specific kinds of work. If you are doing work that the public depends upon in any manner whatsoever, the standards for thinking and analysis described herein should apply to you and the work you perform.

So, the first way this course will be organized is by separating thinking processes leading to behaviors that are viewed as “mandatory” from those for which an employer has a “right-to-expect.”

The mandatory areas are the kinds of things we typically believe should be provided by all employees but occasionally are not. When it comes to the kind of work being done by engineers, if a mandatory characteristic is not delivered, it can produce much more severe results. Say, for instance if we are discussing the requirements for ethical behavior, an unethical worker may cheat his or her employer out of a few hours of work each day. On the other hand, if unethical a project engineer for a multi-million-dollar project can find ways to cheat his or her employer out of much larger sums of money.

During my career, I had several experiences with regulatory agencies in which honesty was by far the best policy. By openly admitting to the presence of some kind of violation and describing all the details, the regulators received two benefits. They learned the kind of situations that might lead to violations, and they learned what must be done to avoid similar violations in the future. As a result, they typically viewed complete honesty as a reason sufficient to forgive any possible penalties associated with the current violation.

If for no other reason than self-improvement and organizational improvement, ethics must be an absolute characteristic for individuals representing themselves as engineers and performing engineering work.

The second category of characteristics are those for which an employer has a "right-to-expect." For instance, when an engineer is assigned to solve some kind of problem, an employer has the right to expect that an engineer will employ a knowledge of scientific analysis and understanding in forming a solution. If the engineer represented himself or herself as possessing those skills when hired, the employer has a "right to expect" the individual to perform the associated work immediately upon being hired. If the future employee never said that he or she had the requisite capabilities, the employer must plan to provide the employe with an opportunity to learn those skills before having that expectation.

As mentioned, we will begin by dividing the various thinking skills into those that are mandatory and those for which the employer has a right to expect.

Then, in a general way, we hope to describe how each thinking method can be applied both when the engineer might be using it as a part of his or her specific engineering discipline and then, later, when filling some role that may come later in his or her career but no longer have the focus of an engineer dedicated to a single discipline. Examples of applying engineering thinking later in one's career might happen in more senior roles like that of an engineering manager, a regional engineer or the manager of a functions that depends on various engineering disciplines but do not personally provide them.

Imbedded in the context of this course is the belief that engineers continue to have a lot to offer at their place of work, in their communities and in their homes. By using all their tools and, like the army ads say, "being everything they can be," the profession of engineering can make its presence felt by continuing to contribute by adding professionalism, expertise and ethical approach to everything they touch throughout their lives.

Mandatory Characteristics

1. Attention to Detail

An engineer's attention to detail is one of his or her most important traits. Many, if not most, engineers occasionally have roles that are best described as project engineering or project management. It is during the execution of those roles that attention to even the most minute detail remains critical. In those roles, the three key elements are scope, schedule, and budget.

The scope describes all the details of every element that is part of any project. If missing from the scope, the element will be excluded from the schedule and the budget and will be completed only by running the schedule over on time and the budget over on costs.

The schedule describes both the amount of time an overall project of any kind will take and the point in time each element must be accomplished. Failing to do first things frequently results in do-overs and failing to determine the overall duration of a project results in other parts of an organization failing to achieve the commitments they have made.

The budget is the basis for financial commitments made by organizations. When an organization spends money, it does not have it becomes bankrupt. Most often bankruptcy is avoided by finding other sources of funding, but that alternative is never a certainty. At the opposite extreme is when a budget overstates the need for money. In this case, the amount that has been overstated could have otherwise been committed to other attractive investments but was not. As a result of both situations, it is critical that budgets be accurate.

Every component and every task use time and costs money. If the complete scope does not include each element, it will lead to overruns in schedule or budget or both. Details can be small, or they can be very large. I recall one instance in which new owners of a refinery had laid off all the experienced engineers shortly before a major turnaround. When the remaining personnel assembled the scope, they completely forgot scaffolding. They focused only on the physical elements that would be a permanent part of the resulting asset. Almost immediately, the job fell behind schedule and, when unplanned scaffold builders and materials were added back, the budget immediately ran over. The new owners immediately stopped the work, left the refinery out of operation, and began to cast aspersion on the integrity of everyone involved. That was a very significant example of a lack of attention to detail.

Another example was a situation in which it was expected that a project team would save time once a week by conducting an update over lunch. In this case, when everyone showed up for the lunchtime meeting, it was discovered that no one had ordered lunch for the group.

As a result, rather than saving time, additional time was lost, and an unexpected expense had to be added to the budget.

Attention to detail doesn't have to be an instantaneous trait. By that I mean you do not have to recognize all the details immediately. Instead, it is important to have a habit of keeping a notepad close and using it over several days until all the details are remembered, listed on the notepad, and cared for using the required methodology.

Frequently, engineers are described using the compliment, "He (or she) never forgets anything!" A more appropriate comment is, "What the mind forgets, the pencil remembers."

2. Multi-Disciplinary Involvement

A second mandatory characteristic involves the use of true experts when needed. On numerous occasions, I have seen situations in which a single engineer tries to perform all the aspects of a project. This is even on those occasions when engineers with greater and more applicable skills are readily available. They like the feeling of having done all the work themselves.

It is important to recognize when the best available capabilities should be applied. This is particularly true in situations where the results can be disastrous. For instance, structural engineering, electrical engineering of high voltage circuits, pressure vessel engineering for high pressure or corrosive applications, metallurgical or corrosion engineering for special applications are examples in which the generalist can and should act as the organizer, but not the overall expert.

It is important for engineers to be experts in their own fields, to develop those skills and to maintain those skills at a state-of-the-art level for the entire period over which they are viewed as the specialist or expert. But it is equally important for those engineers to recognize their own limitations and to apply to other experts when needed. They should recognize that no one is an expert at everything.

But also, like the results coming from an AI program described at the beginning of this document, things change quickly, and true experts need to stay up to date on current issues. For instance, during my early years working in the process industry, it was found that many counterfeit fasteners had found their way into the general supply of materials across the United States. Some of those fasteners were used in aircraft. Others were used in assembling pressure vessels in the process industry. Ultimately, the Congress of the United States passed a bill regulating fasteners. This all had to do with simple nuts and bolts.

The point here is that the true experts needed to both pay attention to details and to stay up to date with current situations. If those industries depended only on generalists, a lot more of the counterfeit fasteners would have found their way into critical applications and those that did would never have been found and removed.

3. Consideration of Restraints

It should go without saying that every task in life has its own restraints. If you go out to purchase a new car, the term "Money is of no concern." Is seldom, if ever, heard. You never use the words, "Take as much time as you like." when speaking to someone who is working under a cost-reimbursable or cost-plus contract.

On one occasion, the hot gas temperature was so great, and the gases were so corrosive in the plenum of a process heater that conventional structural shapes and readily available materials were totally inadequate. In this case, support beams were constructed as box beams that were connected to openings on each end and vented (so cooling air could flow through them) and the material was upgraded to 50% Chrome and 50% Nickel.

Here the point is that a solution that combines the two characteristics described above is one that is applied only when everything else has failed. An engineer of any kind must always be concerned with the details and three of those details are, as described above, scope of work, schedule for completion and the ultimate cost. In addition, those restraints must be dealt with in a manner that addresses the right amount of expertise to ensure everything is done properly and will achieve the stated objectives.

In the example described above there was one primary restraint and that was the need to prevent the convection section heater tubes from collapsing on one another, plugging the exhaust gases, and shutting down the distilling unit and all other refinery units that received feed from the distilling unit. In the refining business, it would be difficult to conceive of any restraint that would be more important.

4. Consideration of Ethical Issues

The last of the four mandatory issues involves the handling of everything in a completely ethical manner. So, when you look at yourself in the mirror, do you see a person who is ethical in everything he or she does? Or are there a few small instances you would prefer not having your family and friends know about you?

Answering that question may require you to answer some fairly difficult questions, including:

1. Do you ever exaggerate any of the responses you provide to any of your clients? (including your boss and coworkers)
2. Do you ever allow funds to be moved from the place they belong to where they do not belong? For instance, if one account is over budget and another is under, do you transfer finds from one account to the other so they both appear to be under budget?
3. Do you always treat everyone the same? For instance, are there individuals for whom you overlook the same transgressions, that for most people you view more harshly?

4. Do you make a practice of "putting lipstick on a pig"? In other words, when you deal with poor results (e.g., a project over-run), do you find ways to present it that are inconsistent with actual facts? For example, there is a way to present the schedule of a project that is running behind by saying, "We are well ahead of our most recent schedule."
5. Do you find yourself having to set time aside to modify your project status reports so they seem more successful than they are?

This list is just a start on describing the ways in which the ethical boundaries of tasks performed by engineers can be breached. You will need to review your own activities to determine where you may be acting in an unethical manner. One thing for certain, when people place their trust in an engineer, they expect that all aspects of that assignment to be done in an ethical manner.

On several occasions, I have found instances in which people have shifted funds from one sub-account to another. When discovered, they say that if the total remains the same, everything is OK. In the ways that things are now measured in detail, the sub-account totals are frequently used to measure performance in sub-categories. When money is shifted from one sub-account to another, a category that was particularly well managed might be overlooked while one that was poorly managed might be ignored.

It is easy for practices that seem only to be convenient to quickly turn into ethical breaches when accepted.

Characteristics that Others have a Right-to-Expect

Unlike the mandatory items described above, the characteristics that others have a "right-to-expect" are not as "black and white." These items can be done to varying degrees but always should be done to the degree that is required. As an example, the first item on the list involves using an "analytical approach" to developing solutions and performing work.

I recall back when I was a young engineer serving in the Air Force in Alabama. There were several situations in which the head of the engineering group felt they should have been done in a more thoughtful manner. When he assembled the entire group of engineers and inspectors together to discuss his expectations, he made it clear that everyone was expected to perform their jobs in a thoughtful manner, possibly performing some form of analysis and then behaving in the manner that reflected the analytics they performed.

After the engineering leader finished describing his expectations, one of the older inspectors stood up and placing his flattened hand in front of his neck, he said, "You hired me from the neck down." The inspector was saying that he would work hard, but for the most part, he would follow procedures and the directions that had been given to him. But he should not be expected to act independently or be held responsible for correcting mistakes made by others particularly those in more senior positions than him.

While the methods used to fulfill the expectations described below are not specific, it is expected that, when an engineer is hired, he is hired from "the neck up" as well as from "the neck down." Engineering is always a role that involves some degree of thoughtfulness and response that is measured by the results of that thinking.

1. An Analytic Approach

When an engineer is hired to perform a job, it is expected that he or she does not limit their role to simply following written instructions or doing it the way it had been done in the past. In the back of an engineer's mind there should always be the concept of "continuous improvement" and "thought-based" efforts.

A useful approach is to begin by identifying the end results that he or she is planning to achieve. In the business of maintenance or construction, the result may be a semblance of either the current device (only maintained or renewed) or the physical manifestation of the drawings and specifications that were provided. In some instances, the analytical approach may not point to creating visible changes or improvements to the object. The analytical approach may simply result in better ways to achieve those results.

In other words, the engineer may focus his or her analysis on:

- Doing it faster
- Doing it for less money
- Doing it while using fewer resources
- Doing it safer
- Doing it in a manner that is viewed as being superior to previous methods

Using an analytical approach usually depends upon understanding several alternatives then selecting the best alternative. Obviously, the "tried and true" way it has always been done is one choice. But there may be faster ways that are more resource intensive. There are more economical ways that use fewer resources but take more time. There are safer ways that may both use more resources and take longer but result on less exposure to injuries.

The challenge here is identifying the alternatives and the characteristics of each alternative and that takes analysis and an analytical mindset. In addition, it is necessary to both identify and calculate the specific measures of success and the value of each measure. Generally, there are trade-offs and risks for each measure. When choosing which approach to use, it is important to advertise both the improvement that is expected and the risks that are being taken if the new approach is used.

For instance, it is possible to perform work faster using critical path planning and then performing the "critical path" of the project much faster. While this analytical approach is better, the return on investment is only achieved if the entire project finishes early. If it does not, and a surprise causes the project to consume the original schedule or even a greater amount of time, the additional resources spent on accelerating the critical path will have been wasted. I have known individuals who spent time and money making a show of using sophisticated critical path planning programs, then ignored what the program showed them should be emphasized with additional resources and attention.

If you have used your analysis to improve the schedule and you have communicated the risks involved, it your efforts fail because of a surprise, your efforts will be viewed as being positive and exactly what is expected from an analytical and aggressive engineer. If you did your best, all that can be said if there is a totally surprise is that things would have been worse had you not made your special effort.

On the other hand, if the surprise turns out to be something you could have identified with adequate analysis, your efforts and additional expenditure will be viewed as being wasteful and inadequate.

Focused on Solving the Problem

Engineers like to solve problems. They expect to encounter problems and enjoy solving them. While others may view problems as barriers, engineers view them as just a part of their job and part of the reason they became an engineer.

In recent years, problem solving techniques have become more structured and formalized. Those characteristics tend to fit better with an engineer's thinking processes than just hoping for the best. As the saying goes, Hope is not a plan!"

A typical problem-solving process starts with an accurate description of the real problem. Knowing the real problem can lead to finding the true root cause. If the root cause is never found and corrected, the problem will just keep happening. Once the true root cause is known, the failing element can be identified. When the failing element is known, it is possible to determine specifically why it is failing. Once you know why it is failing, it is possible to eliminate the specific failure mechanism, then the failure to the element can be halted.

The "apparent" problem may be that the engine of a car fails to operate. By applying more appropriate terms, it is possible to identify a failure mode. The failure mode describes a function that is no longer being performed and the specific behavior associated with that system performing that function. Since functions are directly associated with the specific systems that perform them, every lack of functionality points to a specific physical system. Knowing which physical system to investigate helps limit the space in which you must search for failed components.

By digging into the problem deeper within a specific system, it is possible to identify the specific component that has failed. Then, using the more specific term "failure mechanism," an engineer will identify the condition of the specific component that failed. For instance, if you find the products of corrosion on or around the component that has failed, you will know that the failure was caused by the failure mechanism, corrosion.
If you have been wise enough to have recorded past failures, you might also know which kinds of failures are chronic or happen most frequently. While more parts than just the specific one that failed are likely to need replacement, it is important to understand the specific part that is failing and, even more important, to understand why it is failing and what other parts are being adversely affected by the failure.

There are four basis mechanisms including: corrosion, erosion, fatigue, and overload. It is important to identify the specific failure mechanism that is present because they all are prevented using different techniques. They also all tend to produce varying downstream effects. For instance, it there is some form of corrosion in your lubrication system (say rust in a water-cooled heat exchanger), then the corrosion products can be carried along with the lubricant. If the lubricant contains particles of rust, it may be causing erosion instead of aiding smooth operation. In that case, the erosion due to abrasion by rust particles can cause accelerated wear of your bearings ultimately leading to a major engine overhaul.

This example is intended to describe the detailed but far-reaching kind of analytical thinking an engineer should perform. It helps the engineer justify maintenance including timely oil changes and uses the avoided costs of engine overhauls as a part of the justification for the costs.

Say, your car will not provide transportation because the engine doesn't run, to solve the problem, you need to determine why. The complete function of providing power to the car is provided by a single major system that can be broken into several smaller sub-systems, each producing a different function. The electrical starting system cranks the starter motor and turns the engine over until it starts. Other sub-systems include: the fuel system, the engine itself, the exhaust system, etc.

Say your engine will not crank when you turn the key to engage the starter, that narrows the problem down. If your lights also do not turn on, the battery is likely to be dead. It also might be that the connections to the battery terminals are loose. It might be that one of the battery cables has rusted through. All those things can be found by inspecting the subsystem or checking it with a volt-ohm meter.

Someone who does not understand the systems and subsystems and does not know the elements that are a part of each is unlikely to be able to diagnose and solve a problem. So, the thinking process used to solve problems is one that causes engineers to learn about systems, functions, failure modes, failure mechanisms and how to investigate them

But all the problem solving is highly analytical and structured which are other ways engineers like to think. So many things tend to tie together.

2. Based on Scientific Principals

Here we will discuss some of the scientific principles on which engineering thinking is based.

Let's begin with a simple one. The total force being exerted against a surface of some area (in pounds) is the differential pressure that is present (in pounds per square inch) times the area (in square inches) over which the pressure difference is present.

Say you have an air-tight door that you must push to open. So how much force must you apply? For convenience, let's say the door is 100 inches tall and 40 inches wide. That is 4000 square inches. Now let's assume that the air pressure on your side of the door is a little more than atmospheric pressure or 15 psi (pounds per square inch) and the pressure on the other side of the door is 25 psi. The pressure differential is 10 psi. Not much, is it?

Multiplying the pressure differential (10 psi) by the total area (4000 square inches) tells us it would take a force of 40,000 pounds to open the door. That is a lot.

So, if it is important for me to open the door, how will I produce sufficient force. To determine how to produce sufficient force to open the door, I decided to take a run at it and force it with my shoulder. So, the question is how to determine the force that will be produced when my body is instantaneously slowed from any specific velocity. Once I know that, I can determine if my body has sufficient mass and if I can reach the speed needed to impart the required impact when decelerating from that velocity nearly instantaneously.

When I describe the analysis in those terms, even without performing the exact analysis, I can come to an understanding that I will likely not survive that method for opening the door. So instead, a better approach may be to reduce the pressure differential between the pressure on the outside and that on the inside.

Again, we can simply consider the logic contained within that methodology. I would either need to increase the internal pressure to almost the same pressure on the outside or decrease the external pressure to the same as the pressure on the inside. Or I could do a little of each, raising the inside pressure near a midpoint and decreasing the outside pressure near a midpoint. Here, I need to look at the physical configuration of both the internal structure containing the pressure and the source of pressure on the outside. And I need to consider the restraints. One might be the physical limitations of the person passing from the inside to the outside. Another might be the source of pressure on the outside of the door.

While it may seem that this is an unrealistic example to use to describe scientific principles, real life examples include situations when a human being must leave a submerged enclosure to enter the water far below the surface of any body of water. It also happens, in reverse, when a person leaves the pressurized enclosure of an aircraft to enter the atmosphere high above the surface of the earth.

In the case of a diver entering the depths of the water from a submarine, he or she first enters an intermediate chamber that slowly adjusts the external pressure to the pressure of the surrounding water.

Here, the analysis begins with defining what is happening. Next, it is important to identify what is significant about that event. Third, it is important to identify the scientific principals involved in the event. Fourth is necessary to apply those principals to understand the true physical nature of the event. Then it is necessary to describe the steps between the initial condition and the ending conditions and create methods to manage those steps in a realistic and safe manner.

In the case of a diver leaving a submarine to enter the extreme pressure of deep water, the intermediate chamber is the solution. It provides a way to adjust the pressure to either that of the submarine or that of the deep water and to do it in a way and at a rate that the submariner can survive.

When attending engineering school, students are confronted with lots of these kinds of problems as a way for them to learn that it is possible to deal with complex situations if only, we take the time to think things through.

3. Systems-based Focus

In this section, we will discuss the "systems-based" thinking frequently used by engineers. Here it is useful to understand that a single system is synonymous with a single function. The function is the act we want the physical collection of components to perform. It is useful to keep in mind that a single system performs a single function because the loss of that function is a signal that some part of that system has failed.

When a single system is designed to perform more than one function, both functions frequently have to be sub-optimized so neither of the functions or none of the multiple functions are done as well as possible. When you tune the system to perform one of the functions as well as possible, you will typically find that the other function (or functions) is at the same time sub-tuned to provide much lower performance.

Part of systems-based thinking is identifying the components that are part of any system. The function being performed by the system will fail in a various number of ways depending on the component that fails and the way each component fails. Say, a component is important to the function and the function will no longer be possible if a specific component fails, then that component will be viewed as being a critical component.

On the other hand, if another component fails and the overall function is either not affected or affected in a less important manner, the component will be viewed as being non-critical.

It is important to distinguish between critical and non-critical components because they do not deserve the same amount of attention. For example, if you choose to identify an asset as a complete delivery service and view the overall asset as a system, then the delivery trucks would be subsystems. Two of the components of that subsystem (the truck) would be the engine and the radio. The engine would be a critical system because deliveries could not be accomplished if the engine doesn't operate. On the other hand, if the radio isn't working and the driver cannot listen to music, it is not critical to the desired function.

The distinction between critical and non-critical elements is important because you should be willing to spend more resources to purchase reliable critical components, to understand their condition, to maintain them and to correct problems as soon as they are noticed.
A significant part of systems-based thinking is the understanding of criticality, it's importance to functionality and its relationship with the ability to generate income and to support safe and secure existence.

4. Structured and Repeatable Processes

There is a system for organizing projects or other kinds of work called "Critical Path Method" planning (CPM). CPM starts by identifying all the activities that must be completed to construct or maintain an asset. Next, the tasks are grouped by identifying their effect on one another. In other words, does one have to be done before another or, just the opposite, can a certain activity only be accomplished after another event is complete. Or, equally important, are they totally unrelated to one another.

Next all the tasks that have an order or time relationship with each other are grouped together into a time-sequenced string of events. Ultimately, you will find that all the tasks in every job or project all link to a single event called the start and a single event called the finish. But after the start, the activities separate into several distinct "paths" that have different durations and accomplish different parts of the project or job.

The path with the longest duration is called the "critical path" and determines how long it will take for the overall project or job to be completed

While this description of Critical Path Method is more than a little vague in terms of how an actual project or job is planned, It is useful when thinking of doing things in a structured manner that is fully repeatable.

When the CPM plan for a project is complete, the project manager will know:

- How long will the project take.
- What will the peak amount of all kinds of resources be and when the maximum need will occur.
- The value of adding resources to shorten the job and where they should be added.
- The cost of adding resources compared to the value in terms of reduced down-time.
- The effects that congestion or nearness of work can have on the project.
- How resources will need to be managed (e.g., In cases when specific resources are limited and must be moved between work areas.)
- The impacts of work stoppages or weather-outs in terms of durations and added costs.
- The relationship between the budget and the schedule. (Once the budget is set, it is no longer possible to significantly adjust the schedule.)

Once a project or job is completed using a CPM plan, it is possible to perform a highly accurate assessment and to make significant improvement when performing similar projects in the future. The main things one can learn from experience are the things they thought they knew but didn't and the important things they simply ignored.

In addition to using CPM to accomplish important projects and other kinds of jobs, it is possible to use similar forms of structured analysis to optimize other kinds of business activities. For instance, business processes can be mapped in much the same way projects are mapped using CPM. Business process mapping can show where unnecessary steps are being taken and where physical arrangements of people and events can be changed to allow repeated business processes to be accomplished faster, more accurately, with fewer resources, and more easily understood and adjusted when anything goes wrong.

While not confined to "engineering thinking" this kind of an approach closely fits the way engineers like to think and to work.

5. Creative and Innovative

To be "creative or innovative" you can either be the first one to introduce a new approach across the entire earth or you can be the first one to introduce a new approach only at the place you are working. The personal benefit coming from this distinction is that the reward produced in either case is much the same. You are just as much a hero in either case.

By "copying" the way someone is doing things elsewhere, you are being creative by recognizing the fact that the better approach will work at the new place it is being applied. In addition, "copying" an approach is only an accurate description when all elements are the same. It is unlikely that any adaptation of a good idea at a different location will be the same as it was at the prior location. There will always be changes and those changes will require creativity and innovation be applied when installing the approach elsewhere.

Many CEO's and Senior Executives tend to support the "copying" of good ideas by saying that it is one of their personal goals to "steal at least one good idea every day."

Clearly there are places where you can be creative and innovative and places where you cannot. Places where you can be creative and innovative are situations in which you will achieve the exact same results using less time or fewer resources. Situations in which you should carefully assess the use of creativity or innovative approach are where the results are not the same but still fill the same requirements. Situations in which the requirements are not achieved should not be a place where creativity or innovativeness should be used without assuring that the change in meeting requirements are acceptable.

For instance, if two people are performing a job that can be done as well and as safely by one person, it would make sense to make the change. On the other hand, it the job being performed by two people requires a second person to act as an observer, to provide communications, to check surroundings or to do any needed service that the first person cannot do while engaged in performing the work, it would be best to find ways to accommodate those requirements before moving ahead.

A real-life example provides some valuable learning about making improvements. In one situation involving a bagging machine used to package a dry product that needed to remain dry until used, it was found that the product was getting wet before being used. In this case, even atmospheric moisture was unacceptable.

Here, nothing was thought to have changed, but the product was deteriorating due to moisture before the bags were opened and the product was used. For nearly six months, we searched for the cause of the problem without success. Finally, when we began to review the source of materials used to make the bags, we found that the adhesive on the bag openings had been changed. This was a question that had been asked repeatedly over the period of the investigation and the supplier repeatedly confirmed that nothing had changed.
When we finally found out the source of the problem was the adhesive and asked why the supplier didn't tell us about the change, they responded, "We didn't make a change. We made an

improvement." This was a good example in which creativity and innovation produced the wrong kind of results.

6. Adaptable to other needs

A question an engineer must ask himself or herself is exactly how specialized is the current task? Is the current activity one that will be done only once? Or is it something that is done regularly? Or maybe is it something in the middle? It is not done every day or week but happens fairly frequently.

Keep in mind that if you do something one way one time, then do it differently sometime later, your client has a right to ask why you do things differently. Say, there was an accident or an injury resulting from the later methodology, you might be asked to explain why you did not use the earlier technique.

Say, for instance, you routinely produce estimates, budgets, or bills-of-materials, or presentations, or reports, or any other tool for organizing and communicating your work, wouldn't it be best to take a little additional time to just once create the standard you will use for all instances going forward or at least until something of significance changes?
Standards can improve with time and experience, but they seldom lose the value of any important learning experience once saved by a little extra effort.

Once the wheel was created, it became possible to apply the functionality it provided to myriads of applications and each of them built upon the earlier learnings. It was the individuals who thought like engineers in the various societies who first saw a wheel and began to adapt it. There are lots of civilizations that people point to and say that they never had the wheel. But, in their art, in their pottery and in their shelters, they all had circles. Over millennia, it is likely that at some point a pot fell on its side and rolled away, but people choose to believe that in those cultures no one ever adapted rolling to movement. Or did they. Maybe it was that they never applied the common concept to more generalized usage. Maybe they just needed a few more people who thought like engineers.

7. Both Optimistic and Optimized

Think about the two words in the title of this section: Optimistic and Optimized. Both refer to the ability to go beyond what is commonly expected.

Being optimistic infers a way of viewing things that goes beyond what currently exists. A product being optimized suggests that a new version of something being done can be accomplished in a manner that is somehow better than the current version.

Being optimistic is the forward-looking point of view that makes betterment possible. Being optimized is the product of seeking out and producing that betterment. One is at the beginning of an effort and the other is at the conclusion. The second is never achieved without the first being present.

Had the Wright brothers never envisioned in their minds some kind of physical object travelling through the air, they would never have constructed the Wright flyer. At the time the Wright brothers were young men, if you were to think of the next great development to affect mankind, would you have thought it would come from their bicycle shop in Dayton, Ohio? In that bicycle shop, the two brothers were both enthusiastic about the same thing. They were both optimistic about their beliefs and that optimism allowed them to turn available materials into an optimized product. Their product had to be optimized because it had to behave as though it was lighter than air when many of the materials, they used to be much heavier than air and heavier than the materials used to do those things now.
Think of all the other attempts at building flying machines during that era. The people who built them were also optimistic, but they never constructed a product that was optimized in the same way as the one developed by the Wright brothers. The secret of heavier than air aircraft is that it carries with it only the loads necessary to produce the thrust needed to provide the lift and overcome the drag associated with the aircraft. Throughout the years, the Wright brothers remained optimistic that they could produce such an optimized product.

Objectives

Clearly, the objectives we hoped to achieve through this discussion is to introduce a variety of "engineer-like" thought examples and, by doing so, inspire the audience to think of those examples in the context of his or her own life and work.

It was your approach to thinking that probably sparked your interest in engineering. It was that interest in engineering that led you to be educated as an engineer. It was the resources and efforts you invested in your engineering education that caused you to pursue a job in engineering. And it was all those things that led some employers to hire you and trust that you will think and behave like an engineer when serving in your employers' behalf.

I understand that that the stream of events described above does not always happen in exactly that way. If after working ten years, you win the lottery, the stack of money you receive may result in your choosing to take a different path than the one that previously mapped out for your prior life. Along the way, you might find a different pursuit that seems to attract you more than continuing your path in engineering. There might be several reasons that you choose a different path, but it is unlikely that you will do anything in life that no longer requires that you think like an engineer. Once you learn how to think like an engineer and see the value in doing so, it is something you just cannot avoid doing almost automatically.

Here we hope to encourage your continued path in engineering but hope you do so while viewing things from a somewhat different perspective. For instance, like the discussion about the Wright brothers hoped to encourage, if you are intending to do anything or create any new product that is somehow optimized, you need to start by being optimistic. Any other mind-set or attitude will only result in sameness and not improvement or optimization.

Conclusion

Hopefully, you have had some thoughts and have made some notes along the way. It is hoped that you view this effort as a mechanic might view an overhaul to an old engine. If the engine had lots of miles on it, the rings and bearings might be worn. The seals might be leaking, and the timing chain or belt might need to be renewed. In fact, there are lots of parts that will simply go back to the same as they were when originally constructed.

On the other hand, depending on the age of the engine, there might be a few things that have improved since the engine was first assembled. Probably every elastomer used in the engine has been improved since it was first assembled. Gaskets may be the same but those too may be made from improved materials.

While many of the parts may be at their end-of-life conditions, others may just be at their mid-point or a little past. But many of those items are like the story about eating a turtle, "Once you open the shell, you should plan to eat everything." In a similar manner, once you disassemble an engine, you should make the available renewals and improvements that present themselves.
In a similar manner, once you begin working on how to energize your engineering thinking, try applying your new techniques everywhere they may fit. Engineering thinking is not something that should be confined only to your work or to specific tasks. It is something for which there is universal applicability.

Think of how much time and resources you might save if only you can do them with structure, discipline, and a little bit of magic.

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