WHAT IS ENGINEERING

by

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INTRODUCTION

The title engineer is often used to describe a specialty. For example, at WPI we use the titles chemical engineers, mechanical engineers, civil engineers, and electrical engineers. These seemingly independent disciplines may even be further sub-categorized with titles such as aeronautical engineers, environmental engineers and manufacturing engineers. A substantial list of engineering titles could be made by referring to various engineering schools catalogues or professional society publications. One may naturally conclude from such a listing that these specialties are unique because their problems are different (build a bridge, design a chemical reactor, design a car ... etc). They are, however, very similar in their methods and objectives.

This paper reflects on a recent lecture that I presented to a group of undergraduate students who were being asked to undertake a rather complex environmental engineering project. Because they were asking a very basic question, "How do we conduct an environmental impact study" I felt I should respond with a basic answer, "What is Engineering". The intent of this paper is to give those unfamiliar with the engineering profession a sense of how engineers in the United States view themselves and how they function. Because the layman very often seems to misunderstand the engineering profession by confusing an engineer with a scientist, a comparison of engineers and scientists is given. To help further answer the question "What is Engineering", fundamental tools and techniques used by engineers to solve problems are outlined. This paper asks three questions:

Section I - What is an Engineer's Role ?
Section II - How Do Engineers and Scientists Differ ?
Section III - How Do Engineers Arrive at a Solution ?

WHAT IS AN ENGINEER'S ROLE ?

The question - HOW DO I CONDUCT AN ENVIRONMENTAL IMPACT STUDY was presented to me by a group of engineering students and faculty advisors who were planning a seven week study at a remote ski resort in the Italian Alps. They were asked by Italian developers and local villagers to determine how the environment would be impacted if the present ski resort area was to be expanded. Apparently the villagers had no idea what to ask, but feared that some type of environmental disaster might result if they blindly went ahead with an expansion.

Based on some casual conversations with some of these students beforehand, I knew they were feeling overwhelmed with the enormity of their impending task. My suspicion was that they were trying to place themselves into roles of scientists (i.e. biologists, botanists, chemists, geologists, etc) - and felt uncomfortable with those roles, as WPI was not training them to be scientists. In other words, they thought they were being asked to conduct scientific studies - such as determine what specific plants or animals might be threatened if an increased number of skiers were to visit that region of the Alps. This is what Environmental Engineers must do - they thought. We just haven't studied that material yet. The simple truth, however, is that they never would study that type of material unless they became involved in specific research work that goes beyond applied engineering activities. Although they may not totally appreciate it yet, their many engineering courses were collectively preparing them for the engineering profession.

Having been asked this type of question before by other students and faculty advisors who were facing similar problems, I took this to be an excellent opportunity for me to define the role of an engineer. I began by asking them to participate in a class exercise, which began with a discussion of a dramatic engineering failure.

Many of you may remember the tragic accident that occurred about ten years ago at the Hyatt Regency Hotel in Kansas City. A suspended walkway overlooking a dance floor came crashing down on people - killing and injuring many. I asked the students to form small groups and within five minutes report to the class what they thought the probably cause of this engineering failure was. They answered:

- Improper materials were used on the walkways (inferior steel or concrete).
- An improper factor of safety was used in the design.
- Too high of a loading was on the walkways (too many fat people).
- People on the walkways dancing or moving to the music caused a vibration which amplified the overall loading.

These answers, which all sound feasible, are similar because they attempt to explain the cause of failure from a technical point of view. The cause of this failure, however, was not so much of a technical problem, but was more of a communications breakdown. The walkway design specified for one piece steel support rods suspended from the ceiling to pass through an upper walkway and then connect to the walkway below. Although this design did not totally conform to standards, the eventual failure was due to a basic operational breakdown (1). Possibly due to construction difficulties, a field decision was made to use two shorter rods which were secured by bolts at the upper walkway floor. As should have been evident through visual observation - this configuration would be much weaker than a single rod approach as the lower walkway was only being held by a bolted connection to the upper walkway floor and would easily pull through. A faulty decision was made. The cause for failure could not really be based on a lack of scientific knowledge (although certain field personnel may have been lacking in that area), but was due to a management breakdown. The responsible structural engineer was not properly consulted about the decision not to follow the approved shop drawings.

A principal role of engineering, therefore, is to manage. One answer to their question -WHAT IS AN ENGINEER'S ROLE, therefore, could be - TO ACT AS A MANAGER. In fact, a definition of the verb "TO ENGINEER" as given in the Oxford Dictionary is "TO MANAGE SUCCESSFULLY".

Perhaps the Italian Alp's project itself warns of a potential engineering failure because the project objective has not yet been clearly identified. This is a management problem. Obviously, an engineer must have a very clear understanding of what is being asked to successfully produce a product. Another management breakdown that can lead to engineering difficulties is a failure to understand the entire picture. Again, using the Italian Alp's project as an example, suggested solutions for avoiding environmental impacts would only be successful if the relationship of these suggested changes on other factors (including social and political factors) were known. Proper management, therefore, is closely linked with engineering. It is needed:

1. At the initial planning stage (what is the project objective - or what is being asked),
2. To assure that the proposed solution is practical, and
3. During the implementation of that solution.

There is, in fact, a sub-discipline of civil engineering called engineering management, which has arisen from the need to coordinate (or manage) the increasing number of sub-disciplines involved with engineering projects (such as this environmental impact study). But there must be other factors that define engineering. In other words: If to engineer means to manage, what is the difference between an engineer and any other manager (let's say the manager of a McDonald's Restaurant). Both are concerned with planning, personnel management, scheduling, material purchases, delivery, and of course a successful final product.

Clearly, a major difference between a manager and an engineer who manages, is the engineer's reliance on scientific principals. This leads us to another basic question. How are these professions (the engineering profession and a scientist) different ?

HOW DO ENGINEERING AND SCIENCE DIFFER ?

The role of a scientist and an engineer is often confused by the layman. The statement "If scientist can place a man on the moon, why can't they .... " is a typical example of that confusion. Scientific advancements made it possible to enter space and land someone on the moon, but it was accomplished by engineers. In the same manner, an environmental impact study can be accomplished because various sciences are able to predict cause and effect, but the over-all study is an engineering project. There is a distinction between scientific studies and engineering projects.

From the previous section, we might conclude that the role of an engineer is different from that of a scientist simply because the engineer is responsible for the management of his or her solution. An even more significant difference between these two professions, however, is their inherently different objectives.

To help characterize objectives of an engineer, I asked the students to list what they thought scientist and also what engineers would do in their environmental impact study. They answered:

The Scientists could:

- study the impact of artificial snow making on weather conditions and air quality,
- determine how tree removal would affect indigenous plant and animal life,
- predict water quality of planned impoundments (future water supplies), and
- identify what fish and animal life would be most suitable for these impoundments.

The Engineers could:

- identify and prioritize areas of environmental concern.
- determine development needs (buildings, roads, etc),
- determine how much water would be needed and how much waste would be generated,
- design roads, dams, reservoirs, buildings, water and wastewater treatment facilities, etc., and
- predict costs and benefits for these activities.

As can be seen, both professions are concerned with gathering information that will help them understand something. In this example it is a small ski resort village in the Italian Alps, but it could be anything. A closer examination of these answers, however, point out a significant difference between the objectives of engineering and scientific studies. In addition to focusing on planning or management issues, the engineer is also concerned with information needed to solve an immediate problem. The scientist, however, is mainly concerned with information that will help him or her further understand the system - and possibly to study more. The engineer must focus on an end result - such as a design, while the scientist is free of that constraint. The engineer is even further constrained because he or she must arrive at that solution within barriers defined by present understanding and available resources. Perhaps this focus on a specific end-point forces the engineer to take short-cuts, or to make assumptions that can't be fully supported by science.

Another answer to the question: WHAT IS THE ROLE OF ENGINEERS ?, therefore, is - TO PROVIDE A SOLUTION THAT CAN BE IMMEDIATELY IMPLEMENTED. Although this solution may normally be a design, different end products such as recommendations from a study may also be a resulting product of an engineering project.

HOW DO ENGINEERS ARRIVE AT A SOLUTION ?

Bill Koen (2) defines THE ENGINEERING METHOD as: " the strategy for causing the best change in a poorly understood or uncertain situation within the available resources by reason". He explains his use of the word "change" to represent a design (such as a design of an automobile or a dam), while "available resources" partly refers to such limitations as costs and materials, and when combined with the term "poorly understood" to mean that engineers must find practical solutions for problems that are beyond the knowledge of science. The term "reason" represents an engineer's need to distinguish between true and false.

Using this definition and referring to the Italian Alps environmental impact study as an example; "change" would be recommendations (or results of those recommendations) resulting from that study, and "poorly understood or uncertain situation" would refer to today's level of understanding regarding the environment. Perhaps if the students took this point of view, they may not have felt they were facing an almost unsurmountable task. Unfortunately, they were assuming that the role of an engineer (in this case an environmental engineer) was the same as a scientists (or in this case a host of scientists). The task they were giving themselves, therefore, was indeed unsurmountable.

But HOW DO ENGINEERS ARRIVE AT A SOLUTION if they are not scientists or if science can only provide a poor understanding of the problem. In other words, can engineering come before science? Consider the ancient Egyptian, Greek, and Roman engineers. Even more recently, consider the great Cathedrals that were built during the Middle Ages. These engineering designs were accomplished when science was either very primitive or was in its infancy. One must conclude, therefore, that engineering can come before science. What about the other way around ? Can science also come before engineering. Although Newton's principles were published in the late 1600's, a simple truss analysis was not accomplished until the middle 1800's (nearly a 200 year gap). History therefore tells us that engineering achievements can come either before or after scientific advancements.

Apparently, one must conclude that there is a distinction between scientific principles and the development of engineering tools that use those principles. What are these tools ? The remainder of my lecture to the Italian Alp's project students addressed these tools and their significance.

Past Observations (Precedence)

Consider the space shuttle disaster. As you may recall, the cause for this failure was a faulty O-ring on the booster rocket. Apparently, the O-ring material did not perform satisfactorily when exposed to below freezing conditions - which possibly was not anticipated for a Florida launch site. The important thing to note from this failure and the subsequent investigation, however, is that most of the attention was directed to the availability of performance data regarding these O-rings. Was data available for the engineers to show how the O-ring material would respond to cold temperatures ? The emphasis was on availability of data, not on a scientific understanding of the O-ring material that would make it possible to anticipate what would happen at low temperatures.

But isn't available data and our understanding of a material the same thing ? Possibly not - data, by its very nature, is restricted to its own boundaries. In other words, if data is available to show how the O-ring material would respond to 28 deg. F, how could we say without a doubt what would happen at 27 deg. F ? What is the degree of belief ? An emphasis on data is different than having a complete understanding of something.

This emphasis on data availability tells us something about how the engineering profession functions. The focus is on the availability of data (or observation) - not on an absolute understanding. The scientific community relies on data too, but not for the same reason. Again, the difference may be attributed to each profession's respective objective. The engineer must design, while the scientist uses data to further understand. For example, if the environmental impact study was to recommend the need for a wastewater treatment facility, that design would be largely based on past observations of similar facilities. Having a complete understanding of what biological reactions were occurring in that treatment facility would not be as important to the engineer as knowing how similar facilities functioned. The scientist, however, might be more interested in knowing exactly what types of bacteria were cultivated. Perhaps this knowledge could lead to a new and improved bio-culture.

In a sense, the engineering profession works very much like the legal profession. It bases its decisions on precedence. The difference is that the final judge for the engineering profession is data, which may be generated from laboratory experiments, field observations, physical and conceptual models or (unhappily) tragic failures, while the final judge in the legal profession is the supreme court (of course you know I'm only guessing here).

Empirical Relationships

Although today's engineers are using more sophisticated tools (mathematical models, new and precise measurements, computer simulations, etc) to arrive at their solutions, they are ultimately, still basing their decisions on observations. The engineering profession relies on EMPIRICAL RELATIONSHIPS, and supports these relationships with performance.

A commonly used empirical formula used by hydraulic engineers is the Hazen-Williams equation. This equation is used to calculate energy losses as water travels through a pipeline. The need to know how to transport water or wastewater would certainly be needed if expansion of the Italian Alp's ski resort was to be accomplished with minimal environmental impact. In the early 1900's, engineers reasoned that friction would be influenced by:

a. Pipeline Roughness,

b. Total pipeline length,

c. Pipeline Diameter, and

d. Water Velocity.

The Hazen-Williams equation was developed by mathematically fitting these parameters to measured friction losses. This equation became very popular because, friction loss coefficients were published for various types of pipe materials and shapes. The Hazen-Williams equation is still used today, and is found in popular hydraulic network computer models. The lasting acceptance of this equation is based on it's proven ability to predict energy losses in pipe systems. Therefore, not only was the development of this equation based on an empirical relationship, but it's continued popularity is based on observations.

Rational Methods

Modern engineers, and most certainly young engineering scientists and academicians, are often reluctant to admit to empirical approaches. This may be partly true because the term EMPIRICAL implies that engineers are simply randomly trying different combinations until something finally works. Such an approach would not only be inefficient and unprofessional, but would also result in a very large number of failures. Today's capabilities (measurement capabilities, mathematical methods, simulations, understood sciences, etc) allow engineers to function at a higher level of sophistication than in the past. The term empirical may very well be inappropriate if it is interpreted as being based solely on data or observations. There are many gray areas where one may question whether an engineering solution was obtained through empirical methods or through more rational means. For example, other methods of solving hydraulic problems have since been developed using methods of dimensional analysis and boundary layer theory. It should not be surprising to note that the acceptance of these methods is mainly based on their ability to derive older empirical equations such as the Hazen-Williams equations and to be verified with observations.

Engineering Judgement

The meaning of "engineering judgement" may seem rather obscure - particularly for those outside of the engineering profession (3). To some it may seem to be a catch-all phrase used when engineers are simply guessing, or using a mysterious set of rules that no one else could possibly comprehend. So far we have identified management, past observations, empirical equations, and rational methods as tools used by the engineering profession. Either one of these tools used alone, however, could quite possibly either produce a wrong answer - or only a partial answer.

For example, simply basing decisions on calculations (theoretical or empirical) or past performances, would reduce engineering to a "cook-book" mentality. Identifying when this situation has occurred is sometimes obvious because it is based on a failure to sense the reality of calculated solutions. For example, students often blindly follow equations - "plug-and-chug" - without thinking of what they are calculating. The result is often a ridiculous solution that would be obvious if a feel for the problem were present.

In addition, failing to properly manage the implementation of an engineering design or to propose a design solution that is unmanageable would be a breakdown in the engineering process. Engineering judgement results from a combination of these tools. Dr. Koen's definition of the engineering method uses the term reason (meaning the ability to distinguish between true or false) to refer to engineering judgement.

CONCLUDING THOUGHTS

Because the engineering profession has evolved to its present level of sophistication, it has become increasingly difficult to recognize when satisfactory observations have been made. For example, past observations relating to the space shuttle tragedy do not necessarily refer to past booster rocket explosions - but could have included experimental or field data, or even conceptual models that indicated how the O-ring material would be affected by cold temperatures. Recognizing the significance of that type of data, therefore, is an important variable when evaluating the existence of precedence.

The engineer's arsenal of resources has also advanced to a very high level. Very often it is difficult to recognize when rational methods leave off and when empirical relationships take over. The engineering profession's ability to combine enormous volumes of very accurate observations (sometimes at the microscopic level) with rationally based mathematics and high speed computer computational methods may often give the impression that an absolute solution has been found. Again, it is important to note that the engineering profession is constantly referring to past performances (observations) when demonstrating the validity of their methods. In fact, failure to recognize past performance is a principal indicator of engineering error.

Apparently, with all of our advances, we are still confronted with the same dilemma - What is our degree of belief ? The engineering profession, therefore, with it's many technical sophistications, still heavily relies on a practical understanding of the situation for making decisions. This reliance on engineering judgement, therefore, defines more than anything else what it means to be an engineer. Even with today's amazingly rapid technological advancements, the engineering profession will continue to rely on skills that have been developed over many years.

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