21GNH101J- PHILOSOPHY OF ENGINEERING
UNIT-1

Definition:

"Engineering is the discipline and profession of applying technical and scientific knowledge and utilizing natural laws and physical resources in order to design and implement materials, structures, machines, devices, systems, and processes that safely realize a desired objective and meet specified criteria."

The American Engineers' Council for Professional Development (ECPD, the predecessor of ABET) has defined engineering as follows:

"The creative application of scientific principles to design or develop structures, machines, apparatus, or manufacturing processes, or works utilizing them singly or in combination; or to construct or operate the same with full cognizance of their design; or to forecast their behavior under specific operating conditions; all as respects an intended function, economics of operation and safety to life and property."

One who practices engineering is called an **engineer**, and those licensed to do so may have more formal designations such as European Engineer, Professional Engineer, Chartered Engineer, or Incorporated Engineer. The broad discipline of engineering encompasses a range of more specialized sub disciplines, each with a more specific emphasis on certain fields of application and particular areas of technology.

History

The *concept* of engineering has existed since ancient times as humans devised fundamental inventions such as the pulley, lever, and wheel. Each of these inventions is consistent with the modern definition of engineering, exploiting basic mechanical principles to develop useful tools and objects.

The term engineering itself has a much more recent etymology, deriving from the word engineer, which itself dates back to 1325, when an engine'er (literally, one who operates an engine) originally referred to a constructor of military engines.

The word "engine" itself is of even older origin, ultimately deriving from the Latin *ingenium* (c. 1250), meaning "innate quality, especially mental power, hence a clever invention."

Later, as the design of civilian structures such as bridges and buildings matured as a technical discipline, the term civil engineering entered the lexicon as a way to distinguish between those specializing in the construction of such non-military projects and those involved in the older discipline of military engineering.

Ancient Era

The Acropolis and the Parthenon in Greece, the Roman aqueducts, Via Appia and the Colosseum, the Hanging Gardens of Babylon, the Pharos of Alexandria, the pyramids in Egypt, Teotihuacán and the cities and pyramids of the Mayan, Inca and Aztec Empires, the Great Wall of China, among many others, stand as a testament to the ingenuity and skill of the ancient civil and military engineers.

The earliest civil engineer known by name is Imhotep. As one of the officials of the Pharaoh, Djosèr, he probably designed and supervised the construction of the Pyramid of Djoser (the Step Pyramid) at Saqqara in Egypt around 2630-2611 BC. He may also have been responsible for the first known use of columns in architecture.

Ancient Greece developed machines in both in the civilian and military domains. The Antikythera mechanism, the earliest known model of a mechanical computer in history, and the mechanical inventions of Archimedes are examples of early mechanical engineering. Some of Archimedes' inventions as well as the Antikythera mechanism required sophisticated knowledge of differential gearing or epicyclic gearing, two key principles in machine theory that helped design the gear trains of the Industrial revolution and are still widely used today in diverse fields such as robotics and automotive engineering.

Chinese and Roman armies employed complex military machines including the Ballista and catapult. In the Middle Ages, the Trebuchet was developed.

Middle Era

An Iraqi by the name of al-Jazari helped influence the design of today's modern machines when sometime in between 1174 and 1200 he built five machines to pump water for the kings of the Turkish Artuqid dynasty and their palaces. The double-acting reciprocating piston pump was instrumental in the later development of engineering in general because it was the first machine to incorporate both the connecting rod and the crankshaft, thus, converting rotational motion to reciprocating motion.

Renaissance Era

The first electrical engineer is considered to be William Gilbert, with his 1600 publication of De Magnete, who was the originator of the term "electricity".

The first steam engine was built in 1698 by mechanical engineer Thomas Savery. The development of this device gave rise to the industrial revolution in the coming decades, allowing for the beginnings of mass production.

With the rise of engineering as a profession in the eighteenth century, the term became more narrowly applied to fields in which mathematics and science were applied to these ends. Similarly, in addition to military and civil engineering the fields then known as the mechanic arts became incorporated into engineering.

Modern Era

Electrical Engineering can trace its origins in the experiments of Alessandro Volta in the 1800s, the experiments of Michael Faraday, Georg Ohm and others and the invention of the electric motor in 1872. The work of James Maxwell and Heinrich Hertz in the late 19th century gave rise to the field of Electronics. The later inventions of the vacuum tube and the transistor further accelerated the development of Electronics to such an extent that electrical and electronics engineers currently outnumber their colleagues of any other Engineering specialty.

The inventions of Thomas Savery and the Scottish engineer James Watt gave rise to modern Mechanical Engineering. The development of specialized machines and their maintenance tools during the industrial revolution led to the rapid growth of Mechanical Engineering both in its birthplace Britain and abroad.

Chemical Engineering, like its counterpart Mechanical Engineering, developed in the nineteenth century during the Industrial Revolution. Industrial scale manufacturing demanded new materials and new processes and by 1880 the need for large scale production of chemicals was such that a new industry was created, dedicated to the development and large scale manufacturing of chemicals in new industrial plants. The role of the chemical engineer was the design of these chemical plants and processes.

Aeronautical Engineering deals with aircraft design while Aerospace Engineering is a more modern term that expands the reach envelope of the discipline by including spacecraft design. Its origins can be traced back to the aviation pioneers around the turn of the century from the 19th century to the 20th although the work of Sir George Cayley has recently been dated as being from the last decade of the 18th century. Early knowledge of aeronautical engineering was largely empirical with some concepts and skills imported from other branches of engineering. Only a decade after the successful flights by the Wright brothers, the 1920s saw extensive development of aeronautical engineering through development of World War I military aircraft. Meanwhile, research to provide fundamental background science continued by combining theoretical physics with experiments.

Methodology

Engineers apply the sciences of physics and mathematics to find suitable solutions to problems or to make improvements to the status quo. More than ever, Engineers are now required to have knowledge of relevant sciences for their design projects, as a result, they keep on learning new material throughout their career. If multiple options exist, engineers weigh different design choices on their merits and choose the solution that best matches the requirements. The crucial and unique task of the engineer is to identify, understand, and interpret the constraints on a design in order to produce a successful result. It is usually not enough to build a technically successful product; it must also meet further requirements. Constraints may include available resources, physical, imaginative or technical limitations, flexibility for future modifications and additions, and other factors, such as requirements for cost, safety, marketability, productibility, and serviceability. By understanding the constraints, engineers derive specifications for the limits within which a viable object or system may be produced and operated.

Problem solving

Engineers use their knowledge of science, mathematics, and appropriate experience to find suitable solutions to a problem. Engineering is considered a branch of applied mathematics and science. Creating an appropriate mathematical model of a problem allows them to analyze it (sometimes definitively), and to test potential solutions. Usually multiple reasonable solutions exist, so engineers must evaluate the different design choices on their merits and choose the solution that best meets their requirements.

There exists an overlap between the sciences and engineering practice; in engineering, one applies science. Both areas of endeavor rely on accurate observation of materials and phenomena. Both use mathematics and classification criteria to analyze and communicate observations. Scientists are expected to interpret their observations and to make expert recommendations for practical action based on those interpretations.

Relation between Arts, Mathematics, Science, Technology and Engineering

Art:

Art is a wide range of human activities (or the products thereof) that involve creative imagination and an aim to express technical proficiency, beauty, emotional power, or conceptual ideas. The three classical branches of visual art are painting, sculpture, and architecture. The creative arts are often divided into more specific categories, typically along perceptually distinguishable categories such as media, genre, styles, and form.

Art form refers to the elements of art that are independent of its interpretation or significance. It covers the methods adopted by the artist and the physical composition of the artwork, primarily non-semantic aspects of the work such as color, contour, dimension, medium, melody, space, texture, and value. Form may also include visual design principles, such as arrangement, balance, contrast, emphasis, harmony, proportion, proximity, and rhythm. In general there are three schools of philosophy regarding art, focusing respectively on form, content, and context.

Art has had a great number of different functions throughout its history, making its purpose difficult to abstract or quantify to any single concept. This does not imply that the purpose of Art is "vague", but that it has had many unique, different reasons for being created. Some of these functions of Art are provided in the following outline. The different purposes of art may be grouped according to those that are non-motivated, and those that are motivated

Non-motivated functions

The non-motivated purposes of art are those that are integral to being human, transcend the individual, or do not fulfill a specific external purpose. In this sense, Art, as creativity, is something humans must do by their very nature (i.e., no other species creates art), and is therefore beyond utility.[67]

1. **Basic human instinct for harmony, balance, rhythm.** Art at this level is not an action or an object, but an internal appreciation of balance and harmony (beauty), and therefore an aspect of being human beyond utility.
2. **Experience of the mysterious.** Art provides a way to experience one's self in relation to the universe. This experience may often come unmotivated, as one appreciates art, music or poetry.
3. **Expression of the imagination.** Art provides a means to express the imagination in non-grammatic ways that are not tied to the formality of spoken or written language. Unlike words, which come in sequences and each of which have a definite meaning, art provides a range of forms, symbols and ideas with meanings that are malleable.
4. **Ritualistic and symbolic functions.** In many cultures, art is used in rituals, performances and dances as a decoration or symbol. While these often have no specific utilitarian (motivated) purpose, anthropologists know that they often serve a purpose at the level of meaning within a particular culture. This meaning is not furnished by any one individual, but is often the result of many generations of change, and of a cosmological relationship within the culture.

Motivated functions

Motivated purposes of art refer to intentional, conscious actions on the part of the artists or creator. These may be to bring about political change, to comment on an aspect of society, to convey a specific emotion or mood, to address personal psychology, to illustrate another discipline, to (with commercial arts) sell a product, or simply as a form of communication.[67][72]

1. **Communication.** Art, at its simplest, is a form of communication. As most forms of communication have an intent or goal directed toward another individual, this is a motivated purpose. Illustrative arts, such as scientific illustration, are a form of art as communication. Maps are another example. However, the content need not be scientific. Emotions, moods and feelings are also communicated through art.
2. **Art as entertainment**. Art may seek to bring about a particular emotion or mood, for the purpose of relaxing or entertaining the viewer. This is often the function of the art industries of Motion Pictures and Video Games.
3. **The Avant-Garde. Art for political change.** One of the defining functions of early 20th-century art has been to use visual images to bring about political change. Art movements that had this goal—Dadaism, Surrealism, Russian constructivism, and Abstract Expressionism, among others—are collectively referred to as the *avant-garde* arts.

4. **Art as a "free zone"**, removed from the action of the social censure. Unlike the avant-garde movements, which wanted to erase cultural differences in order to produce new universal values, contemporary art has enhanced its tolerance towards cultural differences as well as its critical and liberating functions (social inquiry, activism, subversion, deconstruction ...), becoming a more open place for research and experimentation.
5. **Art for social inquiry, subversion or anarchy.** While similar to art for political change, subversive or deconstructivist art may seek to question aspects of society without any specific political goal. In this case, the function of art may be simply to criticize some aspect of society.
6. **Art for social causes.** Art can be used to raise awareness for a large variety of causes. A number of art activities were aimed at raising awareness of autism, cancer, human trafficking, and a variety of other topics, such as ocean conservation, human rights in Darfur, murdered and missing Aboriginal women, elder abuse, and pollution. Trashion, using trash to make fashion, practiced by artists such as Marina DeBris is one example of using art to raise awareness about pollution.
7. **Art for psychological and healing purposes.** Art is also used by art therapists, psychotherapists and clinical psychologists as art therapy. The Diagnostic Drawing Series, for example, is used to determine the personality and emotional functioning of a patient. The end product is not the principal goal in this case, but rather a process of healing, through creative acts, is sought.
8. **Art for propaganda, or commercialism.** Art is often utilized as a form of propaganda, and thus can be used to subtly influence popular conceptions or mood. In a similar way, art that tries to sell a product also influences mood and emotion. In both cases, the purpose of art here is to subtly manipulate the viewer into a particular emotional or psychological response toward a particular idea or object.[91]
9. **Art as a fitness indicator.** It has been argued that the ability of the human brain by far exceeds what was needed for survival in the ancestral environment. One evolutionary psychology explanation for this is that the human brain and associated traits (such as artistic ability and creativity) are the human equivalent of the peacock's tail. The purpose of the male peacock's extravagant tail has been argued to be to attract females (see also Fisherian runaway and handicap principle). According to this theory superior execution of art was evolutionarily important because it attracted mates.

Mathematics:

Mathematics, the science of structure, order, and relation that has evolved from elemental practices of counting, measuring, and describing the shapes of objects. It deals with logical reasoning and quantitative calculation, and its development has involved an increasing degree of idealization and abstraction of its subject matter. Since the 17th century, mathematics has been an indispensable adjunct to the physical sciences and technology, and in more recent times it has assumed a similar role in the quantitative aspects of the life sciences.

In many cultures—under the stimulus of the needs of practical pursuits, such as commerce and agriculture—mathematics has developed far beyond basic counting. This growth has been greatest in societies complex enough to sustain these activities and to provide leisure for contemplation and the opportunity to build on the achievements of earlier mathematicians.

All mathematical systems (for example, Euclidean geometry) are combinations of sets of axioms and of theorems that can be logically deduced from the axioms. Inquiries into the logical and philosophical basis of mathematics reduce to questions of whether the axioms of a given system ensure its completeness and its consistency.

Science:

Science (from Latin *scientia* 'knowledge') is a systematic enterprise that builds and organizes knowledge in the form of testable explanations and predictions about the world.

The earliest roots of science can be traced to Ancient Egypt and Mesopotamia in around 3000 to 1200 BCE. Their contributions to mathematics, astronomy, and medicine entered and shaped Greek natural philosophy of classical antiquity, whereby formal attempts were made to provide explanations of events in the physical world based on natural causes. After the fall of the Western Roman Empire, knowledge of Greek conceptions of the world deteriorated in Western Europe during the early centuries (400 to 1000 CE) of the Middle Ages, but was preserved in the Muslim world during the Islamic Golden Age. The recovery and assimilation of Greek works and Islamic inquiries into Western Europe from the 10th to 13th century revived "natural philosophy", which was later transformed by the Scientific Revolution that began in the 16th century[10] as new ideas and discoveries departed from previous Greek conceptions and traditions. The scientific method soon played a greater role in knowledge creation and it was not until the 19th century that many of the institutional and professional features of science began to take shape; along with the changing of "natural philosophy" to "natural science."

Modern science is typically divided into three major branches[19] that consist of the natural sciences (e.g., biology, chemistry, and physics), which study nature in the broadest sense; the social sciences (e.g., economics, psychology, and sociology), which study individuals and societies; and the formal sciences (e.g., logic, mathematics, and theoretical computer science), which deal with symbols governed by rules. There is disagreement, however, on whether the formal sciences actually constitute a science as they do not rely on empirical evidence. Disciplines that use existing scientific knowledge for practical purposes, such as engineering and medicine, are described as applied sciences.

Technology:

The word "technology" can also be used to refer to a collection of techniques. In this context, it is the current state of humanity's knowledge of how to combine resources to produce desired products, to solve problems, fulfill needs, or satisfy wants; it includes technical methods, skills, processes, techniques, tools and raw materials. When combined with another term, such as "medical technology" or "space technology," it refers to the state of the respective field's knowledge and tools. "State-of-the-art technology" refers to the high technology available to humanity in any field.

Technology can be viewed as an activity that forms or changes culture.[14] Additionally, technology is the application of mathematics, science, and the arts for the benefit of life as it is known. A modern example is the rise of communication technology, which has lessened barriers to human interaction and as a result has helped spawn new subcultures; the rise of cyberculture has at its basis the development of the Internet and the computer. As a cultural activity, technology predates both science and engineering, each of which formalize some aspects of technological endeavor.

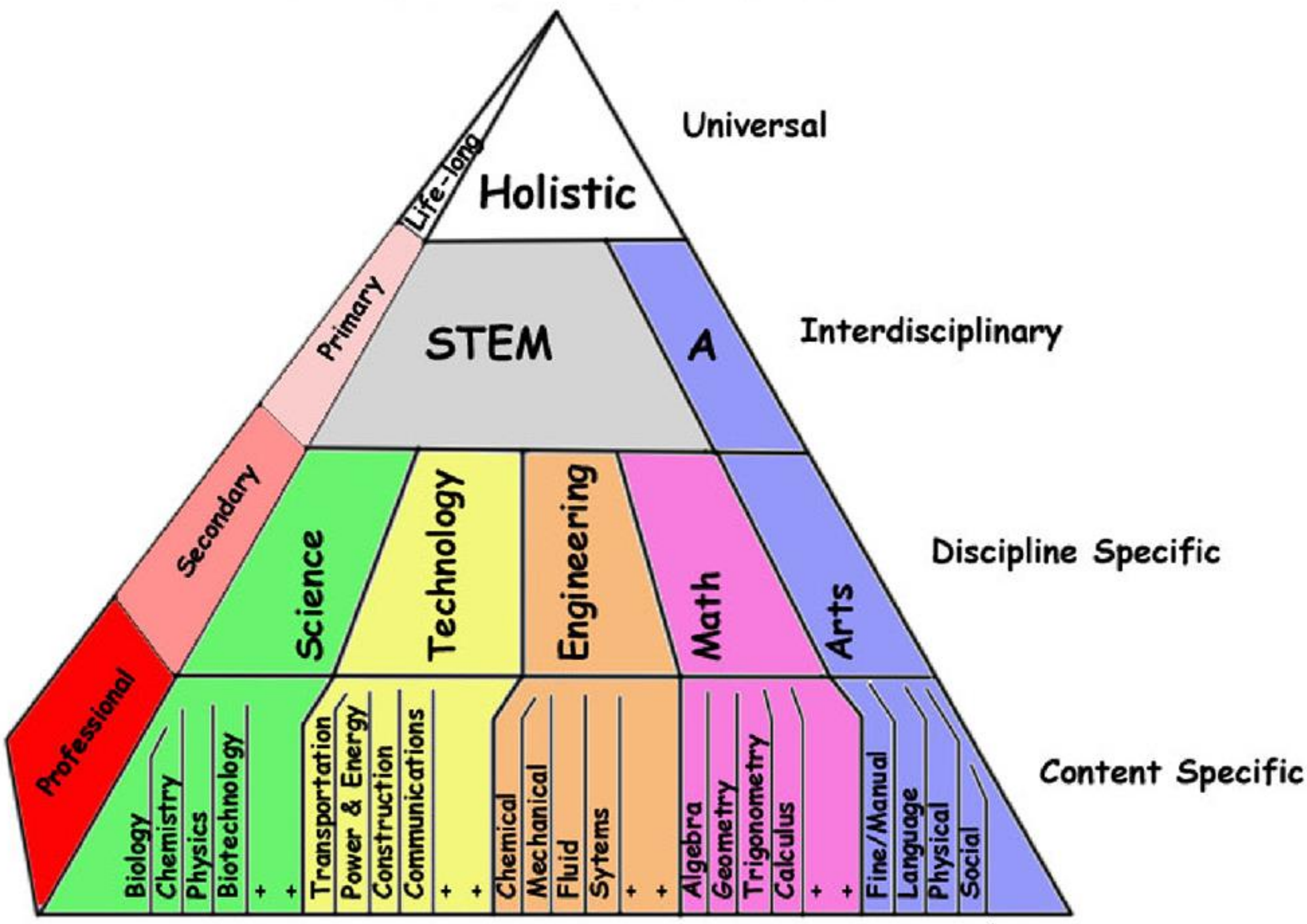
Science, engineering, and technology

The distinction between science, engineering, and technology is not always clear. Science is systematic knowledge of the physical or material world gained through observation and experimentation.[16] Technologies are not usually exclusively products of science, because they have to satisfy requirements such as utility, usability, and safety.

Engineering is the goal-oriented process of designing and making tools and systems to exploit natural phenomena for practical human means, often (but not always) using results and techniques from science. The development of technology may draw upon many fields of knowledge, including scientific, engineering, mathematical, linguistic, and historical knowledge, to achieve some practical result.

Technology is often a consequence of science and engineering, although technology as a human activity precedes the two fields. For example, science might study the flow of electrons in electrical conductors by using already-existing tools and knowledge. This new-found knowledge may then be used by engineers to create new tools and machines such as semiconductors, computers, and other forms of advanced technology. In this sense, scientists and engineers may both be considered technologists; the three fields are often considered as one for the purposes of research and reference.

STEAM Pyramid:



STEM education was introduced in order to improve competitiveness in Science and Technology in the United States in 2003. STEM teaches science, technology, engineering, mathematics in an integrated way. In 2007 George yakman has announced STEAM in addition art to the STEM. Yakman said by the STEAM education we can increase their relevance to real life and interests. Many education scholars into a unified art in STEM education, said be STEAM. Out from the dichotomous thinking such that science of conventional is logical and art is not logical, STEAM is to foster creative human resources by integrating STEM and art. Science provides a methodological tool in the art and art provides creative model in the development of science. Science uses imagination and emotion, thinking that the power of visualization principles of art and art uses scientific discoveries and principles of science.

The STEAM pyramid was built to help educators and students see the subjects involved in STEAM and the learning approaches practiced at each level. Understanding the framework is important for teachers to provide appropriate teaching plans and activities for their students. As for the students, they can clearly know the subject in each field. For example, the subject science fields involved are biology, chemistry, physics, biochemistry, geoscience and so on.

This knowledge allows students to know what fields they are interested in, the potential of each field and they can make plans for their future.

STEAM education is a complete educational model to be applied in teaching and learning in primary schools especially in first year science subjects. According to past studies, there are many benefits we derive from STEAM education. Among the benefits of STEAM education are:

STEAM can attract students in science subjects. STEAM education can increase students' interest in science subjects in primary schools. This is because STEAM approaches such as using experimental teaching methods, simulations, projects, technology and visits allow students to learn through experience.

The value of collaboration is the value of art that is the ability to collaborate and interact in groups. Therefore, STEAM is important in ensuring that creative students can be born and can solve problems while they work the class. These skills will be able to guarantee in an effort to provide a multi-skilled workforce in the 22nd century.

In STEAM education, one of the key features is to encourage collaborative teaching. Collaboration in the teaching and learning process can train students to be tolerant, cooperative, always respect others and the environment and understand the concept of socializing.

STEAM can help improve social relationships among students through active learning through questioning and discussion activities. Transdiscipline through STEAM can help solve problems in society. Various inventions such as technological and scientific innovations can ease the burden of society while doing work. For example, humans use robots to perform daily tasks such as sweeping, sending and picking up goods and discussing. These changes are a result of STEAM education.

STEAM with the arts can help strengthen the foundation of science. Pupils use a variety of ways to produce their products based on science concepts through art. From this opinion, the researchers found that the arts can help improve STEM achievement at the primary school level.

Art skills are directly related to science teaching skills especially of students in primary schools. The combination of arts and STEM has produced a more perfect teaching known as STEAM. Through STEAM students can learn science in a more interesting, fun and easy way to remember science facts

Desired Attributes of an Engineer:

Engineers are the inventors, designers, analysers and builders of our modern age. They create the machines, structures and systems we use on a daily basis. The constrains of physics, the confines of the manufacturing technology of the modern age, the limitations imposed by current material properties, requirements in terms of health and safety and cost: all of these are things that engineers must take into account when designing whatever it is they're working on. Luckily, engineers are trained to recognise and solve these problems; but in *order* to recognise and solve them, engineers have to have a very particular set of skills, skills acquired over a long career, skills that make engineers a nightmare for anything these problems might throw at them. But what are these skills?

1. Teamwork

2. Continuous learning

3. Creativity

4. Problem solving

5. Analytical ability

6. Communication skills

7. Logical thinking

8. Attention to detail

9. Mathematical ability

10. Leadership

1. Teamwork

Teamwork drives the successful completion of a project. No one can complete a project on their own; they need others to contribute. There are functions that can be performed individually, but more often than not, an engineer will be part of a bigger team, and must be able to work well therein.

Courtesy and tact goes a long way in building team trust. Project details are often presented to managers and customers, and these interactions may become confrontational. An engineer must understand everybody's position and should not feel attacked, keep team members informed, and always present facts accurately.

2. Continuous learning

Technology and methodologies are constantly changing, and nowhere is this truer than in engineering. A successful engineer is able to keep abreast of the latest technological updates and capable of delivering the best value and quality work.

Engineers are curious by nature. They are interested in understanding how things work. This gives them a natural aptitude for learning and allows them to continue building their knowledge. In modern times technology changes quickly, so it is critical to constantly learn and stay up to date. Successful engineers never assume they know everything.

3. Creativity

It may sound clichéd, but successful engineers have an innate ability to 'think outside the box'. The engineering industry runs on the ability to creatively solve problems. Engineers able to bring passion, creative solutions and big ideas to the table are more valuable as businesses depend on creativity to efficiently resolve problems or improve the efficiency of existing systems and processes. Simultaneously, a successful engineer needs to be attentive to practicality when proposing a creative solution - which entails being creative in itself.

4. Problem solving

Any project, no matter how big or small, will face problems. An engineer must be able to effectively address these as they arise. They must meticulously study the problem, fully understand the impact it has on the project, and then apply their analytical skills in a methodical and efficient way in order to identify the root cause.

To effectively solve problems an engineer must also have the ability to truly listen to the problem 'owner'. By attentively listening an engineer is able to fully comprehend what the problem consists of and provide solutions from a well-informed standpoint.

5. Analytical ability

The ability to effectively solve problems goes hand-in-hand with the ability to properly analyse problems. Engineers are required to think analytically in order to create solutions. Analysing a project scope or product specification ensures that an engineer fully understands the relevant requirements and efficiently applies resources to achieve the optimal outcome. Various methodologies may have to be tested before committing resources to guarantee a successful solution.

6. Communication skills

Communication is more than reading, writing, speaking or listening. For an engineer it means the ability to not only understand technical complexities, but the ability to succinctly and effectively translate technical jargon into layman's terms without patronising others.

Engineers communicate with people at many different levels, from unskilled workers to directors. The ability to communicate in a respectful, clear and concise manner is critical to ensure that the core message is effectively relayed.

7. Logical thinking

To fully comprehend complex systems an engineer must understand all aspects of the system. An engineer must know how the system works, what can go wrong and how to fix it. This requires an ability to think logically, and evaluate and understand each element that makes it up.

Successful engineers are naturally curious and always looking for ways to make things better. They have to be able to analyse an existing system to understand how the different pieces work individually and as a unit.

8. Attention to detail

Successful engineers pay meticulous attention to the smallest of details. They understand that the slightest error may cause a structure to fail, a system to malfunction or software to glitch. The smallest error can cost a significant amount of money or, in some cases, be fatal.

Complex projects may have a large number of steps to complete and having one tiny thing out of place may delay an entire project. Being detail orientated during the planning and development phases is pivotal for overall success. Successful engineers know that their success depends on their ability to control the details. Never assume something is too small or insignificant to care about.

9. Mathematical ability

Software has replaced almost all of the complex derivative equations engineers used to do manually. Even though engineers are no longer required to do these complex calculations themselves it doesn't mean that, to be successful, they don't have to possess excellent mathematical skills.

Engineers must be well-versed in trigonometry and calculus in order to use software packages and be able to interpret the results derived from them. They must be able to understand the type of calculations required to ensure the correct type of simulation is performed, and that models are correctly defined when performing simulations.

10. Leadership

Leadership ability encompasses many of the characteristics already mentioned on this list. But being a leader is far more than this. It also requires excellent interpersonal skills and an ability to inspire and motivate others to drive a team to achieve success.

Sure, an successful engineer needs to tick all the engineering hard skills boxes listed above, like maths knowledge and analytical ability - but they also need well-developed soft skills so they can smoothly perform non-technical duties. People who are charismatic, articulate and friendly are normally well-liked, and are able to easily garner support.

ABET EC 2000 Engineering Accreditation Criteria (Criterion 3) In 1996 ABET (formerly the Accreditation Board for Engineering and Technology), the influential engineering accreditation board, adopted a new set of standards for undergraduate engineering education, called Engineering Criteria 2000 (EC2000) (ABET, 2014a). EC2000 shifted the focus of undergraduate engineering accreditation from lists of required courses to eleven learning outcomes. These outcomes are summarized below in Table 1:

a. An ability to apply knowledge of mathematics, science, and engineering appropriate to discipline.
b. An ability to design and conduct experiments, as well as to analyze and interpret data
c. An ability to design a system, component, or process to meet desired needs
d. The ability to function on multi-disciplinary teams
e. An ability to identify, formulate, and solve engineering problems
f. An understanding of professional and ethical responsibility
g. An ability to communicate effectively
h. The broad education necessary to understand the impact of engineering

solutions in a global and societal context
i. A recognition of the need for and an ability to engage in life-long learning
j. A knowledge of contemporary issues
k. An ability to use the techniques, skills, and modern engineering tools necessary for engineering practice

Table 1: ABET Engineering Criteria EC2000.

In addition to topics long-associated with engineering practice such as mathematics, science, design, experimentation, and use of modern engineering tools, the new ABET criteria stressed issues of particular relevance to technological literacy. In the new criteria, ABET required programs to show that they teach engineering students to recognize the relationship between technology and society and to recognize “the impact of engineering solutions in a global and societal context.” The EC2000 criteria also included an emphasis on the ethical responsibilities of engineers. To keep accreditation of their degree programs, institutions must show that these topics are covered, must assess and evaluate student learning, and work to continuously improve instruction in these areas. Similar requirements were included in new ABET standards for baccalaureate engineering technology degree programs (ABET, 2014b).

ITEA(now ITEEA) “Standards for Technological Literacy”

In 2000 what was then called the International Technology Education Association (ITEA) published Standards for Technological Literacy: Content for the Study of Technology (International Technology Education Association, 2000). The intent of the ITEA effort was to encourage educational curricula providing technological literacy to all K-12 students. The ITEA standards project was a wide-reaching effort. More than a hundred reviewers from engineering, K-12 education, and the sciences, participated in the process. The project represents one of the first large-scale standards efforts in the US to specifically address the topic of technology independently from science and mathematics. Given the magnitude of the effort, it is not surprising to find that the resulting ITEA 2000 Standards are comprehensive in scope. The standards consist of five major categories subdivided into 20 specific standards. The five main categories used to by the ITEA to define technological literacy are listed in Table 2.

1. Understanding the Nature of Technology.
2. Understanding of Technology and Society.
3. Understanding of Design.
4. Abilities for a Technological World.
5. Understanding of the Designed World

Table 2: ITEA Categories Defining Technological Literacy

The ITEA standards enumerate a thorough set of features that characterize an understanding of technology. The nature of technology includes abilities needed by K-12 students to distinguish technology from other aspects of their environment. The importance of examining the interaction between technology and the society responsible for its creation is highlighted. The methods used to create technology through a rational design process are considered as a separate area of the standards. Also included are specific capabilities or competencies such as selecting technological products appropriate for a specific set of requirements, or knowledge of how to carryout problem-solving in technological systems. The Designed World category of the standards identifies certain domains of the human-built world as topics of study such as communication, manufacturing, and energy technologies.

National Academy of Engineering: “Technically Speaking” and “Tech Tally”

During the same time period that ITEA was addressing technological literacy in the K-12 realm, the National Academy of Engineering (NAE) started an initiative developing awareness of the importance of public understanding of technology. This lead to the publication of Technically Speaking in 2002 (Pearson and Young, 2002) and Tech Tally in 2006 (Garmire and Pearson, 2006). Technically Speaking was intended to reach a wide audience. This NAE initiative sought to achieve recognition that technology consists of the broad array of products and processes that are created by engineers to satisfy human needs and wants. Technically Speaking also attempted to clarify that engineering and science are distinct but related activities. Tech Tally surveyed the state-of-the-art in measuring the understanding of technology. The combination of Technically Speaking and Tech Tally defined technological literacy in terms of four content areas of technological literacy. The four content areas of technological knowledge are defined and listed in Table 3. These are: technology and society; design; products and systems; and characteristics, concepts, and connections. Technically Speaking also envisioned another dimension of technological literacy related to the level of cognitive engagement in each content area. This knowledge in the technical realm was then seen as categorized in a series of increasingly sophisticated levels consisting of knowledge, capabilities, and ways of thinking and acting.

1. Technology and Society
2. Design
3. Products and Systems
4. Characteristics, Concepts, and Connections

Table 3: National Academy of Engineering Technological Literacy Content Areas.

At this point an approximate convergence can be seen between the National Academy of Engineering and International Technology Education Association efforts regarding the major areas that define technological literacy or the broad understanding of the diverse array of products and processes that are created by people to satisfy human needs and wants. Technological literacy is viewed as the four main areas identified by the correspondence between the two groups. One area is the relationship between technology and society. A second area is the design process used in the creation of technology and relations to other disciplines. The third area is the general nature and character of technology. The fourth area concerns the specific domains or broad areas of technology such as manufacturing, communications, medical technology, and energy.

Engineering standards for K – 12 Education

The attention given to technological innovation as central to economic competiveness, and the association of engineering with technological innovation contributed to a recognition that some introduction to engineering should be included as part of the K-12 curriculum in the United States. A perceived shortage of engineers was attributed in part to the lack of familiarity with engineering as a career option at a time when middle and high school student's aspirations for the future are being formed. Coincident with these developments were episodes of significant national publicity for FIRST a high school robotics competition with a name coined to promote STEM careers (For Inspiration and Recognition of Science and Technology, FIRST, 2014). In this era consensus grew among educational policy makers that it would be appropriate to include engineering education in the K-12 curriculum rather than waiting until the undergraduate years. Project Lead the Way has developed curriculum at the middle and high school levels and has extensive training programs for teachers. In 2013, the company brought out a program for K-5, giving them a full K-12 curriculum. The company reports that their curriculum has been adopted by over 5,000 programs in across the United States (Project Lead the Way, 2014). The Museum of Science in Boston has developed a National Center for Technological Literacy. According to their website, the center has developed a K-12 program, the Gateway Project, has museum and online programs, and has been active in developing state standards, including the first statewide standards in Massachusetts (National Center for Technological Literacy, 2014). These developments lead to the discussion of what standards might be appropriate for engineering when taught at the K-12 level. The National Academy of Engineering considered the idea of engineering standards for K-12 students (National Academy of Engineering, 2010). In the process this work has outlined what is engineering and what type of engineering capabilities are broadly applicable across the entire K-12 population. In effect, K-12 engineering standards begin to serve as a working definition of engineering literacy. Discussions about national standards for engineering by the NAE Committee on Standards for K-12 Engineering converged on three broad areas. While the committee chose not to press for engineering standards in K-12 education at that time, the committee did identify some general principles for K-12 Engineering Education. These principles are summarized in Table 4.

1. K-12 Engineering Education should emphasize engineering design. 2. K-12 Engineering Education should incorporate important and developmentally appropriate mathematics, science, and technology knowledge and skills. 3. K-12 Engineering Education should promote engineering habits of mind

Table 4: General Principles for K-12 Engineering Education, NAE Committee on Standards for K-12 Engineering

Engineering habits of mind were defined to include "essential skills for citizens in the 21st century" including creativity, systems thinking, collaboration, communication and attention to ethical considerations. At this point in time the general principles of K-12 engineering standards did not include specific reference to the topic of technology and society. A key point of the K-12 standards is the centering of engineering literacy for all students on the process of design. The design process is identified as the essential characteristic of engineering. The definitions of engineering literacy were coincident with familiarity with the process used by engineers to create technological products, process, and systems.

Next Generation Science Standards

The Next Generation Science Standards (NGSS) released in April 2013 finds topics of engineering and technological literacy interwoven with traditional science topics. The NGSS were the result of a collaboration between twenty six US states (Next Generation Science Standards, 2013). The standards draw heavily from work of the National Research Council Committee on New K-12 Science Education Standards (National Academy of Science, 2012), and are based on three dimensions advocated by the committee: Science and Engineering Practices, Crosscutting Concepts, and Disciplinary Core Ideas. While the organization of the standards is complex: five of 13 major topics are listed in Table 5.

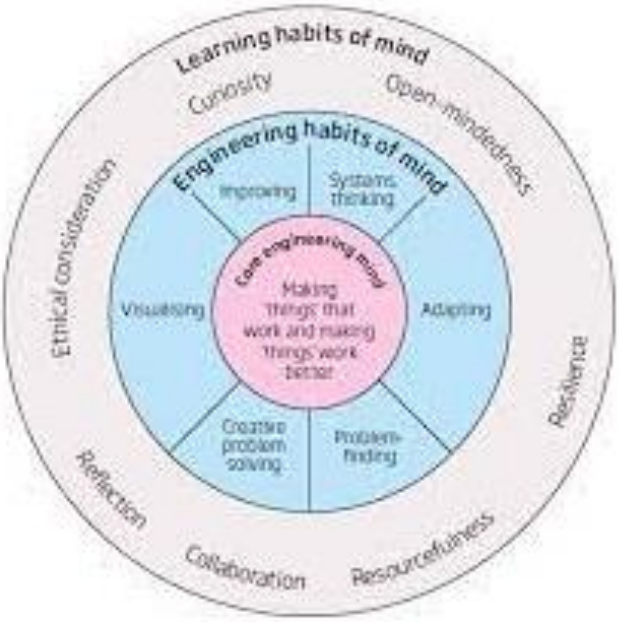
1. Science and Engineering Practices 2. Crosscutting Concepts 3. Nature of Science 4. Engineering Design 5. Science, Technology, Society and the Environmen

Table 5: Some Major Topics in the Next Generation Science Standards.

Perhaps the most significant development in these standards is the overt and deliberate effort to convey parity between engineering and science in the standards. In addition, the relationships and reciprocal interactions between engineering, technology, and science on society and the natural world feature prominently in the standards.

Engineering Habits of Mind:

Engineering habits of mind were defined to include “essential skills for citizens in the 21st century” including creativity, systems thinking, collaboration, communication and attention to ethical considerations.



When asked the question ‘What do engineers do?’ our respondents repeatedly stressed that the desire to ‘make things that work’ or make things ‘work better’ was the driving force behind what made them become engineers:

Great engineers constantly challenge the 'norm' and are always looking for improvements and innovation in everything they do. They are never fully satisfied with a product or outcome and will try and modify and improve what they have designed or produced to make it better.

We also found considerable consensus among all respondents that our six EHoM were appropriate descriptors for the characteristic ways in which engineers think and act when faced with challenging problems relating to making and improving things. However, despite an overall agreement on the importance of all six, there were some differences of opinion on the relative importance of each at different education levels.

Systems thinking was universally supported as an important EHoM but was felt to be particularly difficult to cultivate, perhaps being of most importance the more advanced the level of engineering became:

The idea that everything you do sort of builds to making you into a rounded, capable person who can link all the knowledge together is the one that perhaps we could work on.

Problem-finding was also regarded as a sophisticated EHoM and more likely to be exercised by experienced engineers or by learners after they had successfully built up a repertoire of approaches to problem solving based on given problems:

Some respondents wondered whether 'finding' was the best term, suggesting 'formulating' or 'framing' as alternatives. But the majority agreed that separating out problem-finding from problem-solving was important.

Visualising was regarded as an important EHOM for all education sectors to cultivate, since it enabled an engineer to take an abstract idea and communicate a practical solution in a more concrete form:

To be able to take something abstract and then make it into a practical solution, you have to have that sort of visualisation to be able to do that.

Improving, or a relentless drive to improve products, was regarded as a core characteristic of an engineer. It was the result of constant tinkering and experimenting to find better solutions:

They [engineers] are never fully satisfied with a product or outcome and will try and modify and improve what they have designed or produced to make it better

However, this was not just for the sake of it, the underlying drive was to move society forward:

It's all about making things easier for people's lives...whether it's a product that you're making simpler to use, or making something quicker to use… its improving people's lives.

Creative problem-solving provoked strong reactions. There were those who thought that it was the most important EHOM:

This was predominantly the perspective expressed by those engaged in primary education, while those involved in post-compulsory engineering education expressed doubts, not about the importance of problem solving itself as an EHoM, but about preceding it with the adjective 'creative'. These respondents were in no doubt about the importance of creativity in engineering, because:

You often have to bring ideas from different disciplines and different divisions to solve the problem.

However, other thought that being creative might be in conflict with the requirements to consider previous solutions to problems and to adhere to recognised standards:

It is common in engineering to use concepts that are not original. Engineers would not normally think that they were being creative unless at least one of the options involved a new concept. Therefore the qualification of problem solving by the adjective creative excludes a lot of engineering work.

Adapting is an EHoM about which respondents had mixed views. Primary level educators thought that it was too sophisticated a concept for entry level engineers and could only be cultivated after they had some experience to draw on to make judgements. However, experienced engineers and those within higher education thought that it was an important EHoM:

[Adapting] is very important; a lot of engineering is doing the same things only slightly differently.

Several respondents suggested that it was unlikely that all our EHoM would be found in one engineer and stressed the overall importance of the team in successful engineering projects. Nevertheless, they argued that engineers should be sufficiently self-aware to know when it was appropriate to draw on the skills of others in the team: I think good engineers, certainly in a team, can do that. They can do what they have to do but they can also sort of observe themselves doing it and ask, "Am I using the appropriate skills at the appropriate points in all of this?

Engineers, as MacLeod puts it, rarely operate in one mode only, but are able to move between 'two modes of thinking' and as a consequence of these discussions we realised that much of the engineer's world is necessarily about holding a series of tensions in balance, for example, between using creativity to invent new ways of doing things and using logic to make things work:

Having found agreement on our six EHoM, we chose to represent our model in Fig.2 as series of concentric circles because it allowed us to: a) articulate at the core of the model the driving force of engineering – 'making stuff'; b) distinguish between two sets of habits of mind important to engineers, placing the more specific EHoM closer to the core, but recognising the relevance of a broader set of learning habits.

We recognise that the term 'making' refers principally to traditional engineering disciplines and also that engineers engage in all sorts of activity which may not involve making things [15]. However, even engineers such as chemical or software engineers who do not 'make' physical products as such, are involved in the sub-elements of making such as designing and implementing. It is this extended definition of 'making' to which we attach central importance.