The Essence of Engineering and Meta-Engineering: A Work in Progress

Nagib Callaos
Universidad Simon Bolivar, and
The Institute of Systemics, Cybernetics and Informatics
www.sciiis.org/Nagib-Callaos

(First Unfinished Draft)

Abstract

We will try, in this initial draft, to initiate a process for a continuous clarification of the notion of Engineering. This is an unfinished and, in our opinion, an unfinishable defining process, because Engineering is evolving as institution, profession, and concept. To describe Engineering is also an evolving process which can be made continuously clearer and more precise, but it will always have the potential to be come even clearer and more precise.

Accordingly, we will try to take a small step in this process trying to find the essence of the term and identify what is **common** to different kinds of engineering activities, and to diverse definitions of the term. These commonalities will be taken as required **necessary** conditions for any Engineering activity. With these necessary conditions we will suggest a hypothetical definition, which will be used to define, in turn, the concept of Meta-Engineering.

We will differentiate between Science and Engineering, and we will show that they oppose each other in important aspects. This opposition is polar, not a contradictory one, which will allow us to identify an integrative perspective of both of them, and to synergistically relate them via cybernetic loops. We will also show the synergic relationships between Engineering and Industry. These two integrative perspectives will allow us to describe the role of Engineering as a 'cybernetic bridge' between Science and Industry, and between them and society.

We will also identify important changes that should be made in Engineering Education as consequences of the implication of the definition we are suggesting and as new requirements generated by the Globalization Phenomenon and the increasing necessity of preparing 'global engineers'.

In a second step we will try to find the characteristics of engineering activities that **differentiate** them as profession from other professions like Medicine and Law. This second step will be taken in a second version of this draft following this first one.

Motive and Purpose

According to Sir Robert Malpas (2000), Fellow of the Royal Academy of Engineering, “The so-called ‘new economy’ was created, and continues to be created, through the process of engineering… It becomes evident that engineering permeates society and the economy.” (pp. 6, 9) Engineering is having a significant role in changing the World; but, is Engineering changing and adapting to the World being changed by it?

James Duderstadt (2008), President Emeritus of The University of Michigan, affirmed, in the report related to the Millennium Project, that “the changing workforce and technology needs of a global knowledge economy are **dramatically changing the nature of engineering practice, demanding far broader skills than simply the mastery of scientific and technological disciplines**…During the past several years there have been numerous studies conducted by organizations such as the National Academies, federal agencies, business organizations, and professional societies suggesting **the need for new paradigms in engineering practice, research, and education** that better address the needs of a 21st century nation in a rapidly changing world.” (p. 1; emphasis added)

For an adequate paradigm shift we need to have a certain level of consensus and certainty about what is Engineering. Is there an adequate level of consensus about what Engineering is and/or what it should be?

When trying to define or capture the essence of what Engineering is, St. Agustine’s puzzle regarding “time” comes to mind. St. Augustine said: everyone knows what time is until you start to think about it and then you realize you do not know. Analogously, every engineer (and even non-engineers) thinks he/she knows what engineering is until he/she starts to think about its essence or tries to find some consensus about its definition.

In spite of the evident facts about the importance of Engineering in our present and future, few engineers or engineering professors can answer, clearly and with no difficulties, the question of “what is engineering?” Addressing an engineering audience, Igor Aleksander, Fellow of the Royal Academy of Engineering, affirmed that “Most of us here do engineering, but if anybody asks us to explain what it is, we find it very difficult. However, that does not stop people from trying.” (Aleksander, 2006; pp.2-3).

To address this issue, The Royal Academy of Engineering brought out a publication titled *The Universe of Engineering*, which attempts to define Engineering. Referring to this publication, Aleksander stated that “it is a blanket – it covers everything.”(p. 4). In this sense, the definition of engineering attempted by The Royal Academy of Engineering is a comprehensive, and **extensional** one; and it is a very good input, along with other similar publications, for attempting an **intentional** definition, where the most essential characteristics, common to different Engineering disciplines and activities, would be distilled from the comprehensive ones provided by its extensional definitions. This article is a very first and humble step oriented to the elaboration of an intentional definition of

"Engineering", which would provide the essence and the conceptual infrastructure common to different engineering activities and disciplines. This essential definition will be used to also define Meta-Engineering with an analytical perspective which might promote further research on this issue.

Usefulness: Necessary condition.

From the literature associated with the nature of Engineering, it can easily be distilled that a necessary (but not sufficient) condition for an engineering activity is to produce **useful things**, to generate **human benefit**. The most representative engineering councils, academies or professional associations, and most knowledgeable authors, include this essential aspect in their definitions of engineering. Let us see some typical examples.

Malpas (2000), for example, in a report prepared by a joint Royal Academy of Engineering/Engineering Council Working Group, affirms clearly that "[t]he engineering process converts scientific, engineering and other knowledge and experience into something **useful"** (p. 11; emphasis added)

The Accreditation Board of Engineering and Technology defines Engineering as "The profession in which a knowledge of the mathematical and natural sciences gained by study, experience, and practice is applied with judgment to develop ways to **utilize**, economically, the materials and forces of nature for the **benefit** of mankind" (Davis, 1998; pp 205; emphasis added)

The Canadian Engineering Qualification Board (Canadian Council of Professional Engineers) states that "The 'practice of professional engineering' means any act of planning, designing, composing, evaluating, advising, reporting, directing or supervising, or managing any of the foregoing, that requires the application of engineering principles, and that concerns the **safeguarding of life, health, property, economic interests, the public welfare or the environment (**Canadian Council of Professional Engineers, 1993; emphasis added)

Aleksander (2006), when enumerating common conceptions of engineering, says that Engineering is characterized by "Creating something **useful** using maths and science.' (p. 6; emphasis added) He affirms that engineers "try to make sure that their frameworks of thought turn out to be something that is of **human benefit**." (p. 4; emphasis added)

Prausnitz (1991) asserts that "Engineering is the application of science for human **benefit**." (Emphasis added)

Hawley (2006) confirms that "engineering is the process that converts science into technology and then into **wealth creating** products." (p.6; emphasis ours)

These differing definitions of Engineering coincide in making it explicit that engineering activities produce useful products and/or human benefit.

Know-How Knowledge and *technê* : Necessary Conditions

The English language philosopher Gilbert Ryle affirmed that "*know-that*" and "*know-how*" are different kinds of knowledge, and those who confuse them make a categorial mistake (Ryle, 1949). I know that "2+4=6", that "Paris is the capital of France", and that "the Moon rotates around the Earth and the Earth rotates around the Sun." To know-that is to know **facts**. But, the term know-how is related to the knowledge of **how to do** things or to **skills**: I know how to "build a bridge," or I know how to "ride a bicycle" refer, respectively, about **how to do** and to a **skill**. I cannot ride a bicycle reading books and accumulating knowledge about facts. I cannot build a bridge by means of just observing a bridge.

Know-what and know-how are frequently intertwined, especially in Engineering. For example, I cannot develop software, which certainly needs know-how, without knowing the rules of the chosen programming language and the requirements to be met by the software, as well as its inputs and outputs, which are all instances of know-that. In spite of being frequently intertwined, know-how and know-what are different categories of knowledge and should not be conflated.

This distinction of these (interrelated) categories of knowledge is much older than Ryle, having been made explicit by Aristotle, in his *Nicomachean Ethics*, when he distinguished between *epistêmê* (theoretical knowledge; knowing-what in Ryle's terms) and *technê* (craft or practical knowledge; know-how in Ryle's distinction) (Parry, 2003; Fenstermacher, 2005).

McCarthy (2006), referring to both categories of knowledge, affirms that "it is clear that engineers seek to acquire knowledge in all of their endeavors…. Engineering is 'know-how" (p. 48). Maplas (2000) states that "Engineering has two components, *engineering knowledge*, the 'know what', and *engineering process*, the 'know how'...teaching and recognition of the engineering process does not figure as highly as it should in academia, nor in the Engineering Institutions." (p. 7)

To deal with this situation, some authors even recommend to center reflections with regards to engineering activities in its know-how component, and even to reduce these reflections to the conception, application and employment of methods and methodologies, as well as on the conception, apprehension and practice of efficient and effective processes. With this regards, Aleksander (2006) affirms: "I would suggest that engineering from a philosophical perspective is a critical assessment and pursuit of method and processes" (p. 6). When maximizing the abstraction of the notion of Engineering, as to make it the object of philosophical reflections, Aleksander seems to define Engineering by its methodical and procedural aspect. It seems that, for Aleksander, the know-how, the methodical and the procedural knowledge is the most essential and a defining characteristic of Engineering. From our conceptual perspective, in this article, know-how, methodical and the procedural knowledge form part of the essence of Engineering, and, as such, are necessary conditions in engineering activities but they are not sufficient. There are more essential ingredients and necessary conditions in activities that are to be denoted as engineering activities. Furthermore, it is good to notice that "[p]rocedural knowledge also seems to involve some propositional knowledge. If you know how to drive a car (in the procedural knowledge sense) then you presumably know certain facts about driving (e.g., which way the car will go if you turn the steering wheel to the left)…What is important is that propositional knowledge is not enough to give you either personal knowledge [see below] or procedural knowledge. Personal knowledge involves acquiring propositional knowledge in a certain way, and procedural knowledge may entail propositional knowledge, but the same propositional knowledge certainly does not entail procedural knowledge… Whatever the connections between the various types of knowledge may be, however, it is propositional knowledge that is in view in most epistemology." (Holt, 2006)

But, on the other hand, it is evident that engineering activities are not reduced or limited by *episteme* or *scientia*, or applied science. They also require *technê*. ***Scientia* and *technê* are two different dimensions of Engineering that should not be conflated with each other.** Different engineering activities might have more or less degrees of *Scientia*, but they certainly should have an adequate level of *technê* if they are to be differentiated from scientific activities.

Engineering and Science

McCarthy (2006) affirms that one characterization of the distinction between Science and Engineering "is that science aims to build theories that are **true**, while engineering aims to make things that **work**. The disciplines have different aims – models or theories for science, artifacts or processes for engineers... Science aims to **understand** the world, whereas engineering aims to **change** it." (p. 48; emphasis added) Davis asserts that "Technology bakes our bread; science only help us to understand how…technology is not merely applied science." (Davis, 1998; p.7; emphasis added)

Science and Engineering, although complementing each other, have different purposes and do not use exactly the same kind of knowledge. The logic of Science is the logic of the "**what-is**"; the logic of Engineering is the logic of "**what-might-be**", the logic of "**what-is-possible**". Science is oriented and determined for "what-already-exists"; Engineering is oriented by purposes and objectives toward "what-is-not-existent-yet". Truth is the purpose of Science; to produce useful things and to generate human benefit is the purpose of Engineering. In science, truth is an **end**; in Engineering truth is a **mean** for generating human benefit and usefulness. Science is, for many scientists and philosophers (especially Aristotelians and Thomists or Neo-Thomists), an **end in itself**; but engineering activities are a **mean** for the production of useful things and the generation of human benefit. Scientific knowledge is a necessary input for how it is usually defined Engineering as a profession in modern times, but it is a desirable input for the general notion of Engineering.

“Science and engineering depend on each other – and upon business process skills – for the successful conversion of knowledge and experience into something **useful**. They need therefore to work more closely together.” (Malpas, 2000; p. 8) In technological innovations Science, Engineering and business process skills combine synergistically in order to transform scientific knowledge into products or services useful to society, or into technological innovations. This is one of the reasons why there is an increasing awareness about the high desirability of including **entrepreneurship** skills and motivation in the (academic and/or corporate) preparation of engineers.

In any case, Science and Engineering need each other for their own existence. “For a start, -- McCarthy (2006) writes -- engineering is central to theoretical science’s search for knowledge. The most fundamental physical theories are supported by experimental data which would not be attainable without engineering. The particle accelerators built to reveal the fundamental building blocks of nature would not be possible without impressive feats of engineering. It takes something like the satellite Gravity Probe B, a product of engineering rather than of ‘pure’ science, to test our understanding of the structure of time and space and the nature of gravity.” (p. 48) “It is the engineering process which is converting the ‘new knowledge’ of science and engineering into new computer software and hardware, mobile telephones that can link to the internet, digital television, medical implants, new drugs, pharmaceuticals, machines which can learn, etc.” (Malpas, 2000; p. 10) “The engineering process converts scientific, engineering and other knowledge and experience into something **useful**, so although science and engineering are intertwined, **engineering is not a subset of science**.” (Malpas, 2000; p. 11)

As we noticed above, Scientific knowledge is a “know-that”, a knowledge about facts, supported by the logic of the “what-is”. This is why this kind of knowledge is also called **descriptive**, **declarative** or **propositional** knowledge. Engineering is nurtured by this kind of knowledge but it also needs **prescriptive**, **procedural** and **non-propositional** knowledge. Consequently, Science and Engineering could be seen as opposites, **polar opposites**, requiring (not contradicting) each other. In this way, the generated dialectical relationships between Science and Engineering remove any hierarchical relation between them. Science is no more intellectually “superior” to Engineering; and Engineering is no more pragmatically or praxeologically “superior” to Science. Even so, McCarthy (2006) suggests that Engineering may provide the certainty that Science is lacking. But, before quoting McCarthy with regards to this issue let us first provide a brief background on it.

Science history proves that scientific theories have always, up to the present, been rejected by new theories. Based on this fact, Popper based his Philosophy of Science and respective epistemology on what has been called the “falsifiable truth”, according to which a preposition is scientific as long as it could be falsified in the future; i.e., scientific truth is a falsifiable truth. “Popper’s ‘falsificationism’ reverses the usual view that accumulated experience leads to scientific hypothesis; rather, freely conjectured hypothesis precede, and are tested against experience…He considers knowledge in the traditional sense of **certainty**, or in the modern sense of **justified true belief** , to be

unobtainable." (Jarvie, 1998; p. 533; emphasis added) Popper rational significantly contributed to what has been named "Pessimistic induction or Meta-Induction."

Pierre Maurice Marie Duhem (1914), a French physicist, mathematician and philosopher of Science, and Quine (1951), one of the most influential logician and philosopher, put "severe strain on the idea that science reveals the truth." (Lipton, 2005; p. 1261) "The argument against scientific truth is the pessimistic induction, and the evidence it appeals to is from the history of science…That evidence strongly suggests that scientific theories have a sell-by date. **The history of science is a graveyard of theories that were empirically successful for a time**, but are now known to be false, and of theoretical entities— the crystalline spheres, phlogiston, caloric, the ether and their ilk—that we now know do not exist. Science does not have a good track record for truth, and this provides the basis for a simple empirical generalization. Put crudely, all past theories have turned out to be false, therefore it is probable that all present and future theories will be false as well. That is the pessimistic induction." (Lipton, 2005; p. 1265; emphasis added)

In face of this uncertainty with regards to scientific truth, McCarthy (2006) proposes Engineering processes and products as an alternative for achieving certainty. With this regards she affirms that if "the philosopher focuses not just on a few cases in theoretical science, but instead turns his attention to applied science and engineering, he might reach quite different conclusions about the progress [and the certainty] of knowledge. For, although there are revolutions in engineering, the products of **engineering knowledge are not going to be overturned in the way that some scientific theories have been**. Phlogiston theory was plain wrong, and explanations in terms of phlogiston have never worked. But **technologies that become obsolete do so because they are improved upon, or become redundant, and not because they have never really worked in the first place**. So, while the philosopher might argue that any scientific theory might come to be rejected, he cannot claim that we might one day wake up to find that the bridges that have been constructed according to older engineering methods have all collapsed, or that all methods of transport have ground to a halt because the underpinning knowledge was defective. This shows that **knowledge of what works, the 'know-how' that engineering provides, is secure knowledge**. Engineering knowledge is also genuinely cumulative – improved all the time by building on, and not re-writing, what went before. Hence, if philosophers look at engineering practice as well as scientific theory when they consider progress, they may not be led into scepticism. In this way, a philosophy of engineering might prove enlightening to the pessimistic philosopher!" McCarthy (2006; p. 48; emphasis added)

So, as we might conclude, scientific and engineering activities are related to each other and integrated in a more comprehensive whole, in which Science provides the "know-that", the propositional knowledge that engineering activities and thinking need as one of its inputs, and the processes and technologies produced by Engineering support scientific activities and provide a rational scientific progress and a possible ground for philosophical reflections with regards to the epistemic stand of scientific theories. According to this perspective, scientific and engineering activities might be related through (positive and negative) feedback and feedforward loops, in order to generate mutual synergies where the whole would be greater than the sum of its parts.

Propositional knowledge is seen as objective, public knowledge of the external world. It represents abstract, formal, logical and mathematical descriptions of causal and interactional relationships among concepts, constructs and events associated with the external world. Heron (1981) affirms that "the outcome of research is stated in propositions which claim to be assertions of facts or truths" (p. 27; in Higgs and Jones, 2000; p. 27). Propositional knowledge might be generated by different research paradigms (positivistic, empiric-analytic, interpretative, critical, etc,) and is usually **represented in papers and books** which support its potential communicational processes. Engineering knowledge is also **represented in artifacts, tools and technologies**. The purpose **Reverse Engineering** is to "read", to unveil the knowledge embedded in the artifact, tool, or technology which is the object of the respective reverse Engineering process. Concepts and terms related to propositional knowledge are: descriptive knowledge (where facts are "passively" observed, represented and stated in verbal and/or mathematical terms); discursive language (rational knowledge; a mode of generating and organizing knowledge that is rooted in language and mediated by reasoning); and declarative knowledge (understanding and awareness of factual information about the world.). Terms related to Engineering knowledge (which combines propositional and non-propositional knowledge) are patents, technological innovations, inventions, designs, projects, drafts, artifacts, system analysis, design, implementation and deployments, systems documentation, manuals, etc.

What Schön (1987) affirms with regards to professions in general is completely applicable to the Engineering profession. He emphasizes that there is an intensified concern with regards to the increasing gap between the propositional knowledge being taught in professional schools and practical knowledge and "actual competencies required of practitioners in the field." Schön indicates that to deal with the crisis created by this growing gap it is necessary to recognize that outstanding, effective and excellent professionals do not have necessarily more propositional knowledge, but 'wisdom', 'talent', 'intuition' and 'artistry'. Non-propositional knowledge, including *technê*, procedural (Biggs and Telfer, 1987), prescriptive (McGinn, 1978; Mitcham, 1978, Perrin, 1990), practical (Heron, 1981; Benner, 1984), tacit and personal (Polanyi, 1962; 1967) knowledge, is required for effective professional practice. Propositional and non-propositional knowledge do not contradict each other. On the contrary, an effective professional practice depends on their integration. The testimony of effective practitioners (from different professions with a wide range on disciplines) is a serious evidence of it. In the context of Engineering, propositional and non-propositional knowledge are certainly polar opposites, requiring each other, and systemically relating to each other in a whole which is larger than the sum of its parts.

An adequate integration of different non-propositional and propositional knowledge is a necessary condition for an effective practice of the Engineering profession.

Science and Engineering oppose each other in other aspects, but always synergistically, in polar opposition, and not contradicting each other. Scientific thinking, especially in the empirical sciences, for example, mainly (but no uniquely) proceeds from **the concrete to the general**, from concrete observations to the formulation of general hypothesis and general laws. Engineering thinking proceeds mainly (but not uniquely) **from the general to the concrete**, from scientific abstractions to concrete designs, artifacts, tools and technologies. In this sense, scientific results are mainly produced by **abstract thinking**, while Engineering products and services also require **concrete reasoning** in order to concretize, to make real, the designed product or service. Another way to present this kind of opposition between scientific and Engineering thinking or reasoning is to notice that while scientific activities are essentially oriented to the **necessary**, Engineering is oriented to the **contingent**. Steven Goldman presents this opposition in an article's abstract which, in our opinion, is insuperable in its combination of density and clarity. "Engineering problem solving – affirms Goldman (2004) in his article's abstract -- employs a **contingency** based form of reasoning that stands in sharp contrast to the **necessity** based model of rationality that has dominated Western philosophy since Plato and that underlies modern science. The concept 'necessity' is cognate with the concepts **'certainty', 'universality', 'abstractness' and 'theory'**. Engineering by contrast is characterised by **wilfulness, particularity, probability, concreteness and practice**. The identification of rationality with necessity has impoverished our ability to apply reason effectively to action. This article locates the contingency based reasoning of engineering in a philosophical tradition extending from pre-Socratic philosophers to American pragmatism, and suggests how a contingency based philosophy of engineering might enable more effective technological action." (p. 163; emphasis added)

An adequate integration of "certainty, universality, abstractness and theory" with "wilfulness, particularity, probability, concreteness and practice" is highly desirable -- if not necessary – for both: scientific advancement and engineering increasing capacity in generating goods and services with a continuously growing efficacy (i. e. adequate blend of efficiency and effectiveness)

Figure 1 shows the fundamental synergic relationships between Science and Engineering through mutual positive feedback loops. Regulative feedback loops may also exist via negative feedback and feed-forward loops.

Tacit or Personal Knowledge: Necessary Condition

Engineering professionals need propositional (scientific) knowledge related to the domain area where they want to generate required "non-existent-yet" useful products, and – using Norman's (2007) term – 'future objects'. But, as we indicated above, to do so they also need, as a **necessary condition**, **non-propositional** knowledge. They need different forms of non-propositional knowledge, including what Polanyi (1962; 1967) identified as **tacit** or **personal** knowledge.

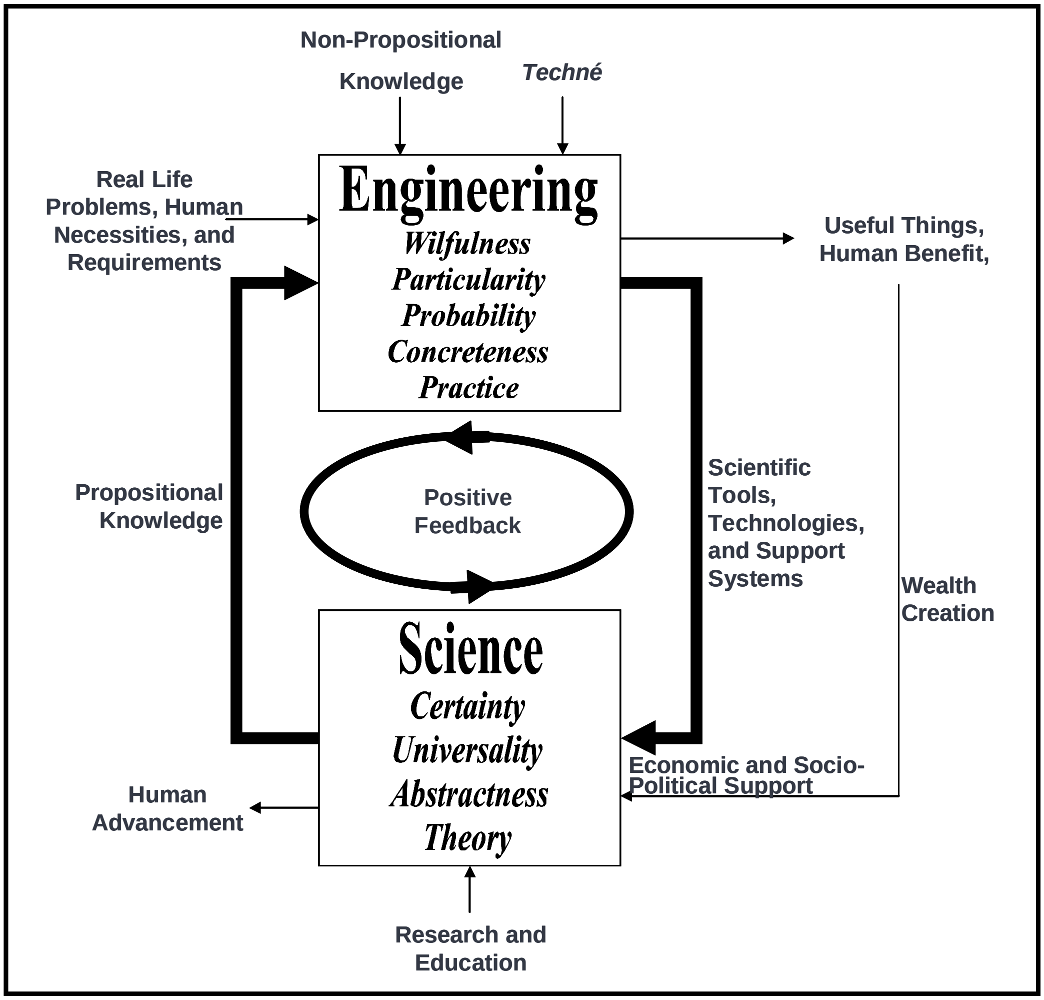

Figure 1

Tacit knowledge is implicit, and is related to the outcome of individual skill, practice and experience (Polanyi, 1967). Tacit knowledge cannot be easily made explicit or represented formally. Visual representations like pictures, diagrams, and descriptions, help to expose tacit knowledge, but it largely is embedded in experience as personal knowledge and it results from individual practice.

Tacit knowledge cannot usually be transmitted verbally, through oral or written form. It is subjective, personal knowledge. It is usually not mediated by reasoning or logic; it is immediate knowledge. Tacit knowledge is usually learned by **working side by side with an expert**. Perrin (1990) affirms that operational knowledge usually "remains tacit because it cannot be articulated fast enough, and because it is impossible to articulate all that is necessary to a successful performance and also because exhaustive attention to details produces an incoherent message" (p. 7).

Polanyi (1967), a chemist and a philosopher, showed that all human action involves, in some degree, some form of tacit knowledge. engineering activities involve a higher degree of tacit knowledge than scientific activities. Tacit knowledge is embedded in engineering activities more than is usually recognized. Tacit knowledge has not disappeared with the use of more sophisticated Engineering ways, which is based to a larger extent on the application of science and propositional knowledge. "On the contrary – affirms Perrin (1990) --, new forms of know-how have appeared and all these non-codified techniques play an important role in industrial production and in technical and technological innovation" (p. 6) Even the so-called high-tech industries, such as telecommunications, electronics, software development, aircraft production, etc. rely intensely on tacit knowledge acquired through practice and experience. Considerable technological and industrial innovations are generated through non-explicit methods and techniques. (Rosenberg, 1982; Vicenti 1984; Herschbach, 1995).

On the other hand, Holt (2006) affirms, "Personal knowledge does seem to involve knowledge of at least some propositions. Simply having met someone is not enough to know them (in the personal knowledge sense); you also have to know a few things about them (in the propositional knowledge sense)."

It is evident that engineering activities and thinking require three kinds of knowledge, i.e., personal/tacit, propositional, and (as we indicated above) procedural knowledge. Intuition is also an ingredient in many Engineering practice, because "engineering, practiced as a process, is a hugely **creative** activity [especially in its designing phase]." (Malpas, 2000; p. 10). But "Whilst, for an experienced engineer, **intuition** is important [especially in the creative phase], it cannot be solely relied upon." (Hawley, 2006; p.6)

Practice and Praxis: Necessary Conditions

Being tacit/personal knowledge and Know-How/*technê* necessary conditions in engineering activities, it is evident that practice and praxis are also necessary conditions. They are required to acquire tacit/personal knowledge, to support the know-how and process knowledge, and to generate *technê*, in order to produce technical or artificial things, i.e. artifacts.

In general, the concept of practice is used in a variety of ways, especially when it is used in the context of a professional practice. "It can refer to specific actions (such as the act of giving this drug to this patient); to a kind of act (the giving a drug, for instance); to a group of systemically related activities pursued for some common end (such as the practice of medicine [or engineering]); or more broadly still to a set of social institutions (for example, political and economic arrangements with different distributions of rights and goods). Finally, the concept of 'moral practice' is often used in contrast to 'ethical theory' to refer to the embodiment of ethical life in the specific responses and institutions of particular communities." (O'Neil, 1998; p.357) We have been mainly using the concept of practice as a "group of systemically related activities pursued for some common end”, which is to produce useful things, or to generate human benefit. We will also use the concept of practice in its sense of “moral or ethical practice”.

Practice and praxis have the same etymological root: the Greek term *prâxis* which means “doing”. *Praxis* was formed on *prāk-*, base of *prāssein*, which means “do”. The term practice derives from *praktikē* (practical science), which is the feminine *praktikós* (active, who acts, who does) and derives from *prāssó* (I do, I accomplish, I perform) (Hoad, 1993; Corominas, 1990). We might tentatively conclude that Praxis is basically “a doing”, “action”, and practice has the sense of an “accomplished doing”, an “accomplishment”; i.e. “a special skill or ability acquired by training or practice.” (Merriam-Webster dictionary) In this sense, a practice, especially when it is a professional practice, is praxis by means of a special skill or ability acquired by training.

If we take into account that the professions are connected with “a code of ethics” (Davis, 1998; p. 9), we can conclude that

- **praxis is a doing or acting;**
- **professional praxis is a moral or ethical doing or acting;**
- **practice is an accomplished doing, or skill;**
- **then professional praxis is ethical and accomplished doing via acquired skill or *téchnē*;**
- **and engineering praxis is ethical and accomplished doing via acquired skill or *téchnē* in order to produce useful things and/or human benefit.**

Furthermore, by *prâxis* the Greeks basically meant two concepts: “the action of Carrying out something” and “moral action.” (Ferrater-Mora, 1969; Vol. II, p. 467) These two meanings of *prâxis* are essential and necessary in engineering activities. A dictionary definition of the verb “to engineer”, according to Malpas (2000), is “To make things happen, with more or less subtlety” or skill. (p. 3) Consequently, **Engineering is a skillful praxis,** where skill is achieved (partly at least) with professional experience and/or knowledgeable practice. Davis (1998) distinguishes “between engineering as occupation and engineering as a profession.” (p. 3). If we take the Greek meaning of Praxis, which includes “moral action” we can conclude that engineering activities include a moral or ethical doing in both cases: as occupation and as profession.

Praxis could be a) external, when it is oriented to do something transcending the agent, or b) internal when its end, its *telos*, is the same agent. (Ferrater-Mora, 1969; Vol. II, p. 467) Engineering praxis might similarly be **external**, when it is oriented to generate products or services useful to other people, or **internal**, when it is oriented to acquire the required skill, method or *technê*, or when it is oriented to the self instilment of ethical professional practice and general moral principles that will also guide the professional action of the engineer.

Praxis refers to a **practical activity,** as differentiated from a **theoretical** one. But this does not mean that Theory and Practice are not related. On the contrary, good practical activities are usually related to a theoretical knowledge, especially in professional activities like in Engineering. On the other side, theory generation processes are usually supported by practical activities. Philosophers and scientists dedicated to theoretical thinking need to be supported by practical activities in order to be able to produce theoretical knowledge. This has always been perceived and conceived in this way, even in philosophers like Aristotle, who conceived theoretical knowledge as more important to practical knowledge, and meditation as superior to manual jobs. Theory and practice does not necessarily exclude each other; hence, the complementariness and the synergic relationships between Science and Engineering, and the rational supporting the conviction of an increasing number of engineers and philosophers with regards to the synergism that would certainly be generated if philosophical reflections are oriented to the engineering realm, and Engineering praxis is done under the light of pertinent philosophical reflections. (See, for example, Bucciarrelli, 2003; McCarthy, 2006; Keith, 2006)

The Greeks used the term "*praxtikòs*" (practical) to refer to what is adequate to a transaction or business and to what is **effective** in praxis. (Ferrater-Mora, 1969; Vol. II, p. 467) Effective praxis is that which achieve its objectives. Consequently, an engineering activity is necessarily a "*praxtikòs*", it is an activity where there should be an objective and in which the objective should be achieved. This achieved objective might be the initial one, which originated the engineering activity, or a modified version of it, where the modification is generated by the learning process that usually accompanies engineering activities, changes made by the user of the final product or service, and/or adaptation to the discovery of new information or to changes in the environment. Objective(s) might be achieved in different degrees. Objective(s) achievement is not necessarily a "yes" or "no" answer. Engineering effectiveness is not necessarily a binary one as to be 'effective' or 'not-effective'. Engineering activities can have different degrees of achievements or effectiveness.

Defining Engineering

Elsewhere (Callaos, 1995a), in a meta-defining process, we identified more than 30 different definitions of "definition", and concluded that a systemic definition should be done as comprehensive as possible, including the essence of as many definitions as it is possible to do it with few words and a brief text. Here we attempt a systemic definition which should have the following characteristics:

1. From the epistemological perspective, a systemic definition is oriented toward the *pragmatic-teleological* truth of Singer-Churchman (Churchman, 1971). This will be achieved by means of:

   1.1. Taking into account the "*telos*", "*the purposes of the definer*" as Ackoff stressed it (Ackoff, 1962). Our purpose is to capture the conceptual essence, maximizing the number of different definitions which essence will be covered, and minimizing the quantity of words used in the attempted definition.

1.2. Relating the definition to past and present usage of the word in order to serve the *pragmatic communications needs* (Ackoff, 1962). We have been doing so above, at least in part.

1.3. Making the definition *operational* (Ackoff, 1962; Bridgman, 1927; 1938, Stevens, 1935) in order to be useful in a pragmatic context.

2. From the methodological perspective, the variety of past and present usage of the word defined should be structured by means of a logical infra-structure, or by means of a bootstrapping process (Alvarez de Lorenzana, 1987). In this way the definition will be *comprehensive, open* and *adaptive*, both as a product and as a process, and we will have the bases that could support a progressive "spiraling" process according to the *Evolutionary* Paradigm (Alvarez de Lorenzana, 1987; Laszlo, 1987).

Ackoff (1962) stressed the fact by which "historical analysis of the use of a concept can often reveal a trend in the evolution of the concept or a consistent theme of meaning which persist through numerous variations" (p.148). This is why he exhorts to initiate a scientific defining process by formulating a **tentative definition** based on the evolving core identified by a historical analysis. It is our experience that Ackoff's instruction is a valuable and a practical one, and that taking it to an extreme, by going to the etymological meaning of the word being defined, is also helpful because it would suggest a pre-tentative definition. The *suggestive* effect of historical linguistic analysis had been stressed by several authors (Navarte, 1981; p.158). Being the root of following meanings, the etymological definition suggest, frequently, a general concept from which more specific ones are generated through history. This is why we think that the etymological source may help us into abstracting a general definition from the varieties of the specific ones that appeared through history. This is why we made short etymological considerations above.

Based on the partial conclusions we made above, with regards to the necessary conditions required in engineering activities, we can attempt the following definition:

> Engineering is the development of new Knowledge (***scientia***), new 'made things' (***techné***) and/or new ways of working and doing (***praxis***) with the purpose of creating new **useful** products (artifacts) or services.

Scientia, *Techné* and *praxis* are three important dimensions (Figure 2) of a comprehensive conception of Engineering as a whole (occupation and/or profession) Engineering, as *Scientia*, or more specifically as *Scientia Ingenieriae*, is mostly developed in academia; as *techné* is mainly practiced in industry generating technological innovations; and as *praxis* is carried out mostly in technical and non-technical organizations, supporting managerial activities and technical procedures, via methodical and methodological design and implementation. An engineer might be more oriented toward one of these dimensions, to a combination of two of them, or systemically integrating the three of them. Large engineering organizations and large industrial corporations with internal Research and Development organization usually work according to the three dimensions. Different individual engineers might be more oriented to one of the three dimensions, but the activities of the organization or the corporation, as a whole, are usually three-dimensionally oriented. In general, Engineering activities are located on the triangular three-dimensional plane shown in Figure 2. The volume inside the pyramid shown in Figure 2 represents activities that are just partly engineering. The more Engineering is an occupation or a profession, the nearer it is to the three-dimensional plane; the more equilibrated the engineering activities are the more proximate are to the center of the plane; and the more one-dimensionally oriented is the engineering activity, the closer it is to one of the three vertices of the three-dimensional plane.

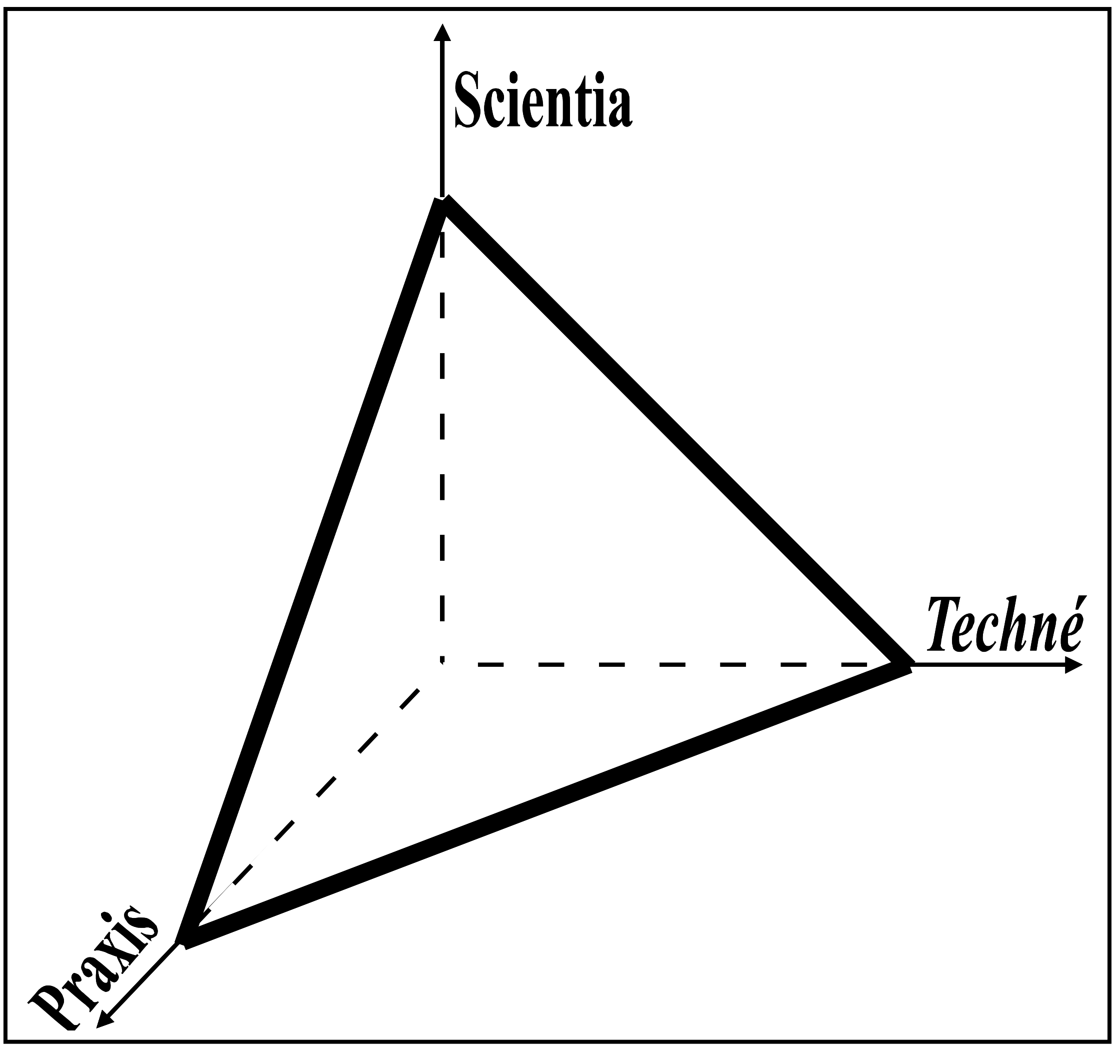

Figure 2

In general, Engineering is supported by three kinds of activities, which are associated to the three mentioned dimensions, which in turn are related to three kinds of Knowledge (discussed above): propositional knowledge, or know-what, which is associated with *Scientia* and/or *Scientia Ingenieriae*; procedural knowledge or know-how, which is associated to *Techné*; and tacit/personal knowledge which is associated with *praxis* (Figure 3).

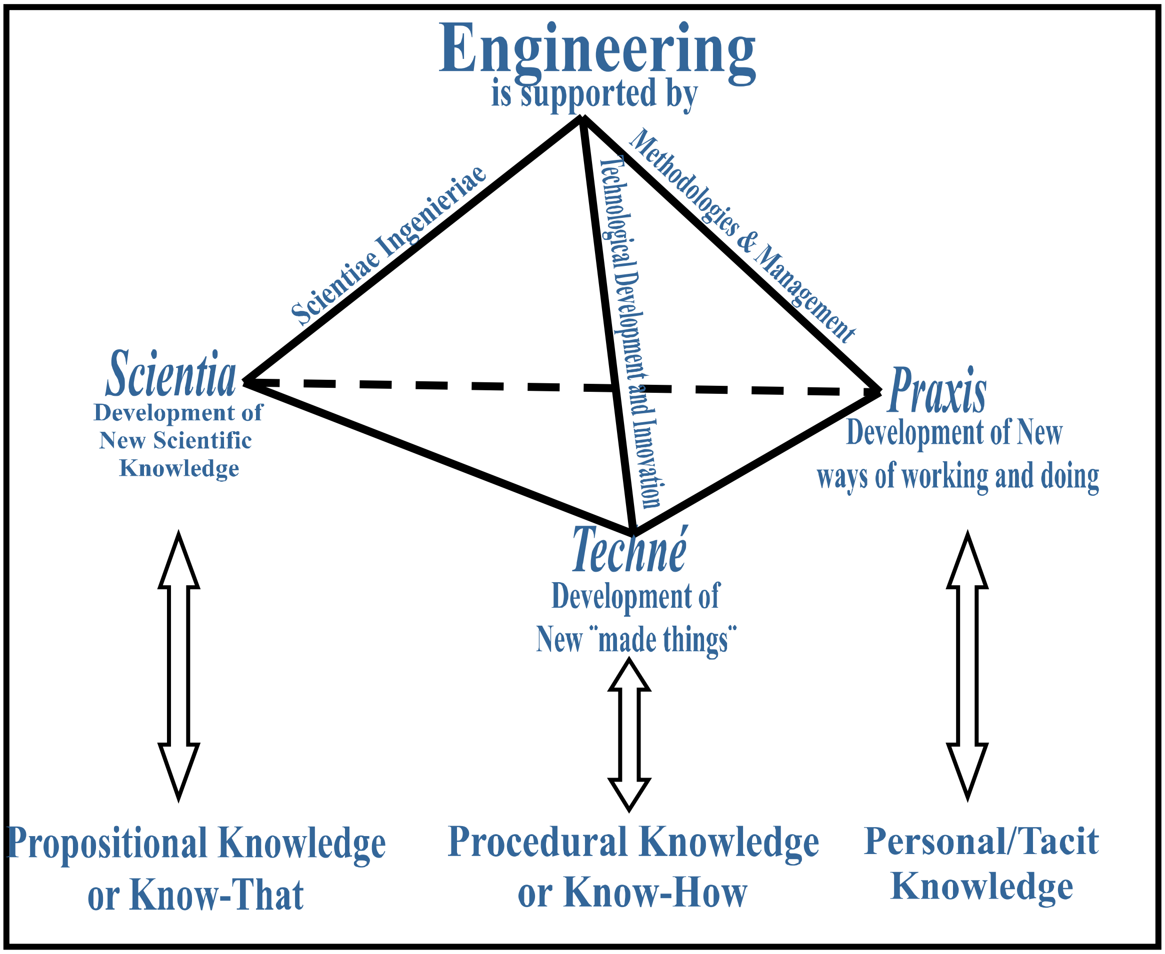

Figure 3

Engineering processes use propositional knowledge, know-that or scientific knowledge in order to bring about useful products and services, by means of their know-how, their *techné*, craft or art, through professional praxis. Engineering products require, in turn, of business processes in order to transform its useful-products into products-actually-in-use and, hence to transform their useful products and services in wealth creation and human benefit. As it is shown in Figure 4, engineering processes provide two major inputs to industry and business processes in order to transform the three-dimensional engineering know-how into technological innovations and usual goods & services. One of these major inputs is related to what might be called Traditional Engineering, or Engineering based in

Natural Science knowledge (beside the required non-propositional knowledge and praxis), and the second major input is associated with what might be named as Non-Traditional Engineering. By means of traditional engineering, the basic input provided to Industry and Business Organizations is related to useful and usable products designed according to user or client requirements and economically feasible for the targeted market. Non-Traditional engineering products and processes are provided to support traditional business processes, making them more efficient and/or more effective. Examples of input provided by what we are calling non-traditional engineering professions are: Software Engineering, Computer Engineering, Information Systems Engineering, Decision Support Systems, Management Support Systems, Management Information systems, Knowledge Systems, Expert Systems, Executive Support Systems, Operations Research, Management Engineering, etc.

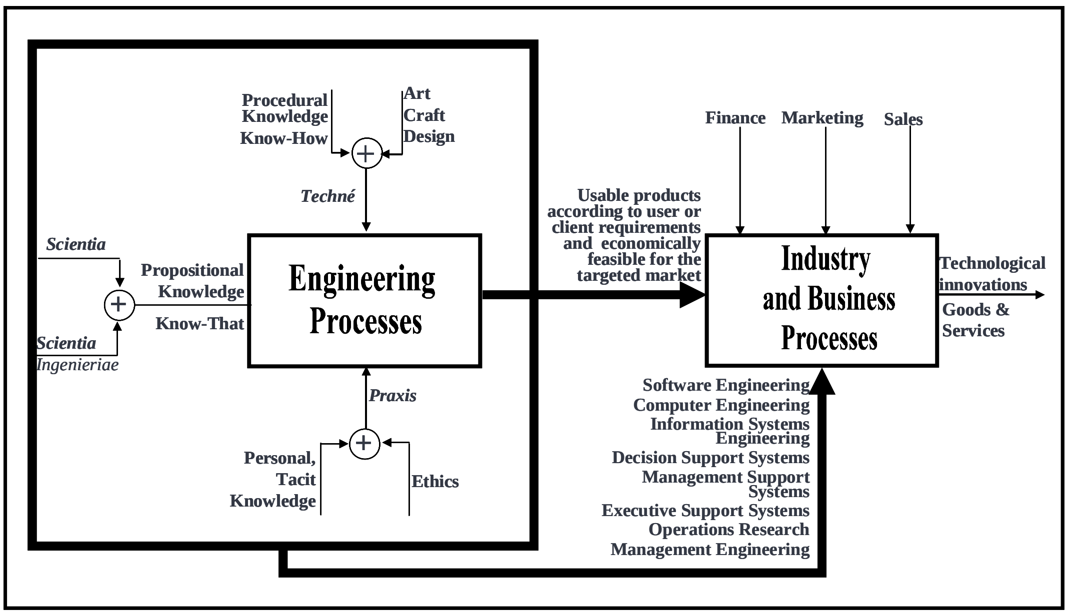

Figure 4

It is important to notice that Engineering relates to industry and business organizations through complementary and **synergistic** relationships, via **positive feedback loops** (Figure 5). There also are – though frequently in implicit way – mutually regulative control via negative feedback or feedforward.

As we said, Figure 2 above, schematically shows the positive feedback loops that support the synergistic relationships between Engineering and Science; and Figure 5 shows analogous positive loops between Engineering and industry and business organizations. Figure 6 integrates both mentioned figures indicating the bridging function of Engineering between Science and Industry. Two kinds of feedback loops are shown if Figure 6, totaling 4 main loops. Two loops are based on an **adequate combination of different kinds of knowledge.** Two other loops are mediated by **wealth creation**, which results thanks to the Engineering function associated to bridging Science and Industry/Business.

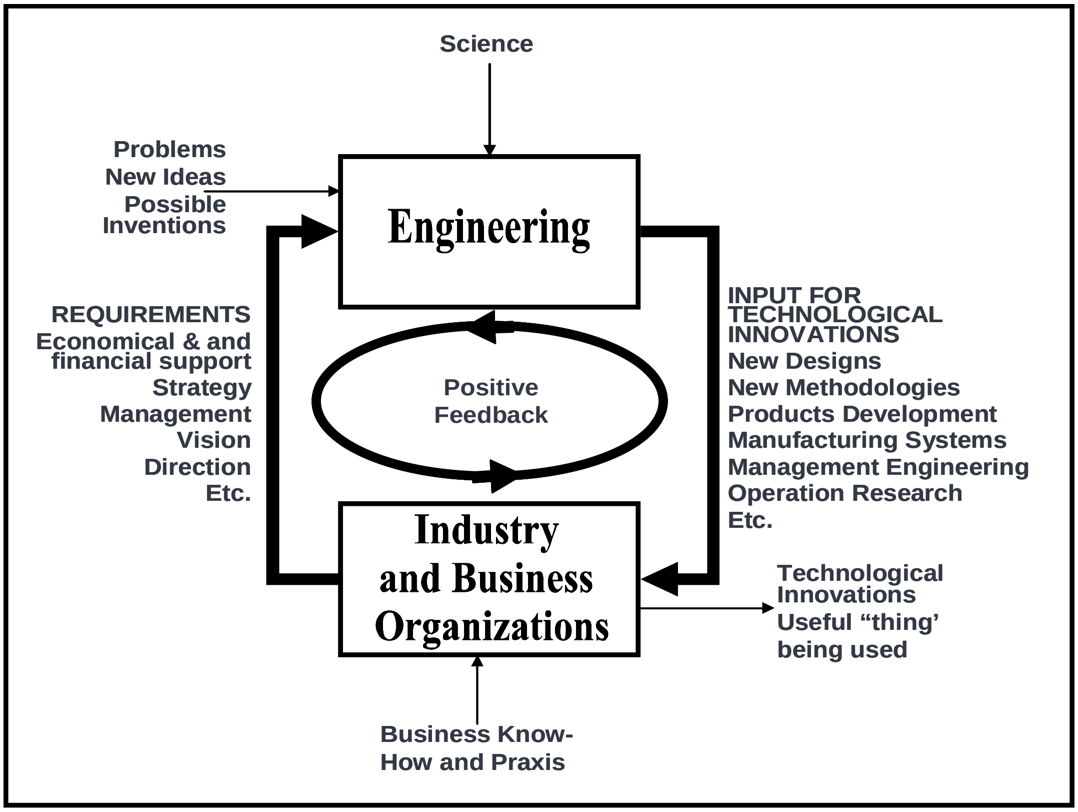

Figure 5

Who are Engineers?

Are engineers just those with an academic title of Engineering? There seems to be a consensus that we should also include those who call themselves, or are called (in the organization where they work) engineers, and those who do engineering activities without belonging to any of the two mentioned sets. The first group represents the engineers as professionals; the second group represents those who are engineers by occupation; and the third group represents those who are engineers as consultants or practitioners. Malpas (2000) affirms that "[a] better understanding of engineering also makes it evident that "*the wider engineering community*", the people who practise engineering, is larger than generally recognised. It comprises not only those who call themselves engineers, but all those who practice engineering, wittingly or unwittingly, in the course of their professional activities, people who do not necessarily wish to identify themselves with engineering." (p.7)

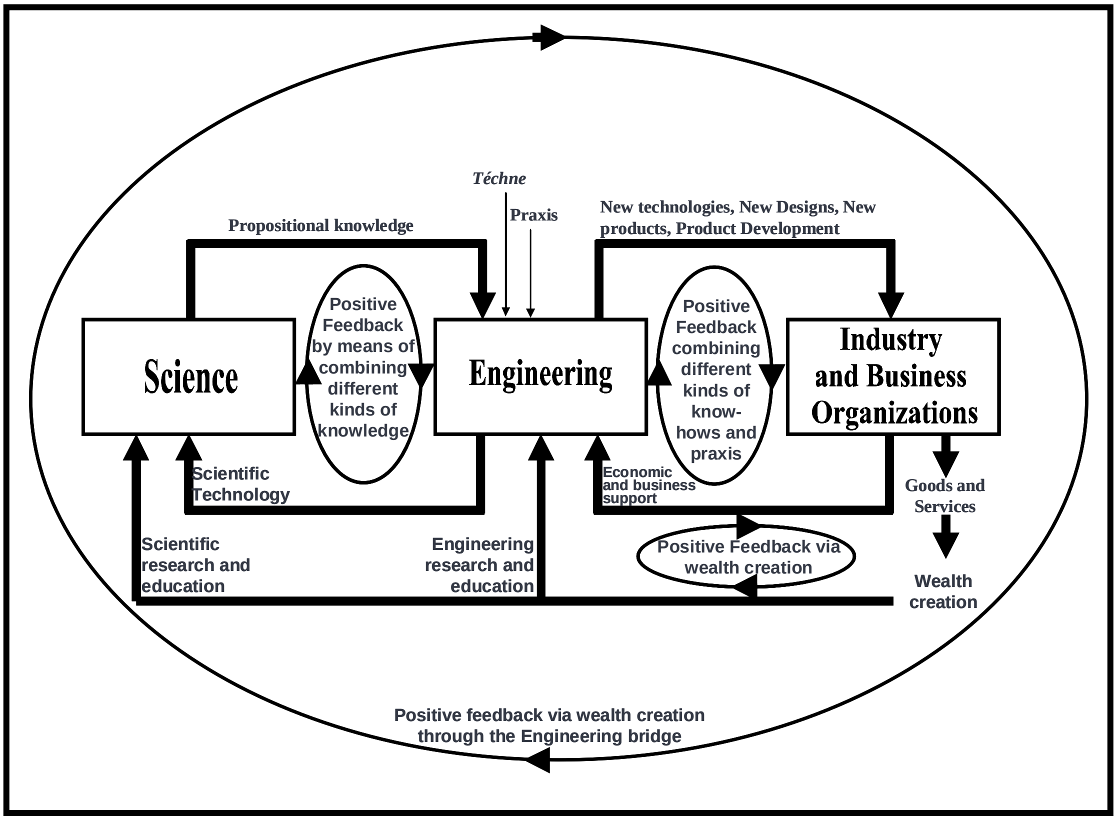

Figure 6

In a report prepared by The Royal Academy of Engineering, the following figures were among those that were found as relevant: “There are about 2,000,000 people in the UK who call themselves engineers. About three quarters of them have a professional engineering qualification…There are no reliable figures even to estimate the numbers of people whose title does not include engineer, but who practise engineering in the course of their work, *scientists*, *technologists*, *metallurgists*, *computer programmers*, and many more.” (Malpas, 2000; p. 7) If we generalize these results, we might estimate that for countries similar to the UK, about the 75% of the people who call themselves engineers have professional qualifications; 25% are called engineers because of their occupation or title in the organization they work; and there is no reliable figure about those who practice Engineering but they do not have the Engineering professional or occupational title.

The Engineering Universe

The Royal Academy of Engineering identified, in the same report indicated above, the following disciplines shown in Figure 7, along with their respective applications fields.

APPLICATIONS / DISCIPLINES	Mathematics	Physics	Chemistry	Bio-sciences	Materials Science	Civil Engineering incl. Structural & Building Svs.	Mechanical Engineering & Aearospace, Marine & Agriculture	Electrical Engineering incl. Power Gen. & Power Trans.	Chemical Engineering & Mining & Oil/Gas/Nuc.	Electronics Engineering incl. Computing, Comms/Control also IT field (& Software)	Medical Engineering & Bio-Engineering
Healthcare & Social	●	●	●	●	●		●		●	●	●
Leisure & Entertainment	●	●	●		●	●	●			●	
Education	●				●					●	
Commerce, Trade & Finance	●									●	
Communications & IT	●	●								●	
Defence & Security	●	●	●	●	●	●	●			●	
Transport	●	●	●		●		●	●		●	
Agriculture & Food	●		●	●	●		●		●		●
Engineered Materials	●	●	●	●	●	●	●		●	●	●
Energy & Natural Resources	●	●	●	●	●		●	●	●	●	●
Built Environment	●	●	●	●	●	●	●	●		●	

Source: *The Royal Academy of Engineering* (Malpas, 2000; p. 15)

"[T]he presence or absence of a "dot" is not based on a quantitative analysis. A more detailed representation is possible, with indications of strengths of interactions. This diagram is intended to give a broad view." (Malpas, 2000; p. 15)

Figure 7

The Matrix Shown in Figure 7 represents the most important of what The Royal Academy of Engineering named the Universe of Engineering. Indeed, it is a very comprehensive representation. But, emerging areas in Engineering should be included in the Universe of Engineering; which although they are not frequently included in Engineering academic disciplines or in professional titles, they are actually acceleratingly growing engineering activities. As example, making a Google search (on 1/13/2008) we found a significant number of web pages containing the names of some of these new emerging fields of non-traditional disciplines in Engineering. Table 1 shows some of these Google searches. The Table 2 shows the results for the same kind if Google searches for traditional engineering disciplines, indicated in the matrix provided by *The Royal Academy of Engineering*; which we reproduced in Figure 7. We can notice from the mentioned tables:

1. **Non-traditional** areas or fields of Engineering are mentioned in **16,111,466** web pages, and The average of the traditional number of web pages in which **traditional** Engineering disciplines are mentioned is **10,848,250.**

2. The total number of web pages mentioning non-traditional engineering areas overcomes the number mentioning any other traditional engineering discipline.

3. Organizational Engineering alone is mentioned by 6,115,000 web pages, which is more than the number of web pages mentioning Electronic Engineering (4,400,000) and the number of Medical Engineering + Bio-Engineering (705,000). Furthermore, this number is not far from the traditional Engineering average.

Consequently, we propose to add to the disciplines identified by *The Royal Academy of Engineering* the following general engineering fields or areas:

- Organizational and Management Engineering.
- Corporative and Business Engineering
- Social Systems Engineering and Social Technologies and Design.

Engineering activities belonging to each of these areas are certainly mentioned in more than 5,000,000 web pages; which is not very far from the number of web pages referring to traditional Engineering and certainly above the number of web pages referring to some disciplines like Electronic Engineering and Bio-Medical Engineering.

Engineering Disciplines and Professional Fields

We propose the following set of engineering disciplines and professional fields; which are based on what was concluded in *The Royal Academy of Engineering*'s report; the professional fields we proposed above; and Knowledge Engineering, because along with its related sub-areas, is mentioned by more than 1,000,000 web pages and because it is one of the engineering fields growing with one of the most accelerated rate. Furthermore, combining Knowledge Engineering with the highly related field of Knowledge Management we find the astounding number of about 30,000,000 web pages referring to both fields.

Engineering Field or Area	Number of Web Pages
Organizational Engineering + Organization Engineering + Organization Design + Organizational Design	6,115,000
Social Engineering	2,130,000
Re-Engineering	1,520,000
Service Engineering + Services Engineering	1,307,000
Business Engineering + Business Re-Engineering + Business Design	1,201,900
Social System Engineering +Social Systems Engineering + Societal Engineering + Social Design	1,105,785
Global Engineering	827,000
Financial Engineering + Finance Engineering	806,000
Project Engineering	574,000
Management Engineering	403,000
Business Technologies	308,000
Method Engineering + Methods Engineering	228,200
Social Technology + Social Technologies	207,900
Team Engineering + Group Engineering	129,400
Human Resources Engineering + Personnel Engineering + Training Systems Engineering	117,500
Economic Engineering + Economical Engineering + Economics Engineering	85,850
Corporate Engineering	40,000
Administration Engineering + Administrative Engineering	39,500
Strategic Engineering + Executive Engineering	35,000
Soft- Engineering	29,100
Entrepreneurial Engineering	3,090
Total	**17,213,225**

Table 1

Engineering Discipline	Number of Web Pages
Civil Engineering	15,300,000
Mechanical Engineering	14,600,000
Electrical Engineering	16,000,000
Electronic Engineering + Electronics Engineering	4,400,000
Chemical Engineering	9,780,000
Medical Engineering + Bio-Engineering	705,000
Computer Engineering + Information Engineering + Data Engineering	8,001,000
Software Engineering	18,000,000
Total	**86,786,000**
Average	**10,848,250**

Table 2

Civil Engineering including Structural Engineering and Building Services

Mechanical Engineering including Industrial Engineering, Operations Research, Aerospace, Marine and Agricultural Engineering, Mechatronics, Robotics

Electrical Engineering including Power Generation and Transmission, and Power Systems, Technologies and Economics

Chemical Engineering and Mining

Materials Sciences and Engineering

Energy Engineering, including, Petroleum and Nuclear Engineering, Energy Management Engineering, and Energy Conservation & Energy Efficiency

Electronics Engineering, including Communications Systems Engineering and Control

Computer Engineering, including Software Engineering, Requirements engineering and Information Systems Engineering and Information Technologies.

Medical Engineering and Bio-Engineering

Applied Sciences, including applications of Mathematics, Physics, Chemistry, Bio-sciences

Organizational and Management Engineering, including Method Engineering, Project Engineering, and Team Engineering.

Knowledge Engineering and Management

Corporative and Business Engineering, including Service Engineering, Entrepreneurial Engineering, Financial Engineering, Administrative Engineering, Economic Engineering, Global Engineering, Business Processes Re-Engineering, Personnel Engineering, strategic Engineering, and Soft Engineering.

Social Systems Engineering and Social Technologies and Design, including social technologies, Cognitive Engineering and Human-Systems Integration

Engineering Education

An international study, commissioned by Continental AG, involving eight universities (from six countries in four continents) known for their engineering program, concluded that "[d]espite their diverse histories, cultures, economies, and engineering infrastructures, it is apparent that all six countries recognize **the need for a dramatically different kind of enginee**r and, remarkably, they agree substantially on their desired traits. **The highly analytical, technically-focused engineering “nerd” is a person of the past**. They seek engineers who are technically adept, culturally aware, and broadly knowledgeable; **engineers who exhibit an entrepreneurial** spirit and who are innovative and lifelong learners; engineers who understand world markets, who know how to translate technological innovation into commercially-viable products and services; and engineers who are professionally nimble, flexible, and mobile. What they seek is a global engineer.” (Continental, 2006; p. 32)

An increasing number of authors and engineering educators are urging for a dramatically different kind of engineers. Duderstadt (2008) affirms that “we are attempting to educate 21st-century engineers with a 20th-century curriculum taught in 19th-century institutions.” (p. 4).

Richard M. Felder (Hoechst Celanese Professor Emeritus of Chemical Engineering at North Carolina State University) et. al. alert about the deficiency of engineering education and the necessity of a meaningful redirection of it. They affirm that:

> “Deficiencies in engineering education have been exhaustively enumerated in recent years. Engineering schools and professors have been told by countless panels and blue-ribbon commissions and, in the United States, by the Accreditation Board for Engineering and Technology that we must strengthen our coverage of fundamentals; teach more about “real-world” engineering **design** and operations, including **quality management**; cover more material in frontier areas of engineering; offer more and better instruction in both oral and written **communication skills** and teamwork skills; provide training in critical and **creative thinking skills** and problem-solving methods; produce graduates who are conversant with engineering **ethics** and the connections between technology and society.” (Felder et. al., 2000; p. 26; emphasis added)

Consequently, attention should be paid to praxis (quality management, communication skills, teamwork skills, ethics, etc) and *techné* (design, creative thinking, problem solving methods, etc.); which combined with a) scientific education (fundamentals), that is predominant in most of present engineering education, and b) more adequate connections between technology and society, would increase the efficacy of engineering activities and processes in meeting their purpose of producing useful things and human benefit.

Passive learning permeates engineering education, but active learning is needed with increasing urgency. Felder et. al. (2000) highlights this issue stating that:

> “In the traditional approach to higher education, the professor dispenses wisdom in the classroom and the students passively absorb it. Research indicates that this mode of instruction can be effective for presenting large bodies of factual information that can be memorized and recalled in the short term. If the objective is to facilitate long-term retention of information, however, or to help the students develop or improve their

> problem-solving or thinking skills or to stimulate their interest in a subject and motivate them to take a deeper approach to studying it, instruction that involves students actively has consistently been found more effective than straight lecturing…The challenge is to involve most or all of the students in productive activities without sacrificing important course content or losing control of the class." Felder et. al. (2000; p. 8)

Engineering students should be trained in **productive** thinking, and not just in **deductive** and **inductive** ones, as mostly are done in traditional engineering education. Deductive and inductive reasoning are required for scientific education, but ***techné*** **and praxis require also productive mental processes**. Design, for example, is not probable without the possibility of producing the mental image of 'what-does-not-exist-yet' and to produce a draft by means of which to communicate this 'not-existent-yet' object, tool, or system to other people. Problem solving processes also require productive mental processes by means of which a 'not-known-before' solution is generated. The production of new ways of doing things because the emergence of unexpected obstacles, impediments, troubles, etc., is frequent in practice. Unexpected problems and obstacles are common in the complex situation that professional engineers are usually immersed in. Consequently, the production method is, for engineers, as necessary and important as the induction and deduction ones. Elsewhere (Callaos, 1995b) we worked out, differentiated and contrasted with more details the methods of induction, deduction and production, associating the last one to Systems Methodology and to Engineering.

Globalization and Engineering

Radical changes are being generated by Globalization, especially with regards to how national economies and transnational corporations around the Globe are designing, producing, distributing and consuming products and services. Engineering activities are at the heart of these changes, producing these changes and being affected by them. Engineers need to be acquainted or, at least, aware, with cultures for an adequate design of product and services for global markets. Consequently, they are required to work with multi-cultural (not just multi- and/or inter-disciplinary) teams, and to be geographically and/or virtually mobile.

This clearly new engineering situation raises many questions, among which are the following:

- What impact Globalization will have on higher education, in general, and what specific impact will have on engineering education?
- How engineering education should change in order to meet the requirements of inevitable growing demand of Global Engineering.
- What skills are required to be a global engineer, beside the skills needed for a good engineer?

- Can engineering educators identify the educational requirements for global engineers without being involved in Global Engineering or, at least, in academic globalization?

- How awareness regarding this problematic situation (requiring urgent solutions) can be instilled in engineering academics? Should professors in engineering areas first get the skills the global engineers they are forming should have?

- How engineering academics should be prepared (meta-prepared) in order to prepare the New Global Engineer?

- What kind of relationships should be maintained among Academy, Industry, and Government in order to facilitate preparation of the global engineer?

- Would Globalization lead to an augmenting status gap between engineers, globally savvy, and good engineers who are not? Would this lead to an increase in unemployment for those engineers who are not prepared, via education or professional praxis, to deal with the changes that globalization is generating in their field of practice?

- What kind of researchers are the adequate ones to find answers to these kinds of questions?

- Is traditional Engineering research adequate for the emerging Global Engineering? If not, which would be the characteristics of the probably emerging new research in engineering?

"Many of today's global challenges can only be addressed through engineers working collaboratively in international networks. Yet the complex phenomenon of globalization and its impact on engineering practice is often not well understood nor well integrated into engineering programs… **engineering education worldwide is not providing an adequate supply of globally prepared engineers**. The ability to live and work in a global community is — today — an important requirement for engineering graduates. They need to have broad engineering skills and know-how, and to be flexible and mobile, and able to work internationally." (Continental, 2005; p.1; emphasis added)

Necessary Changes: As we indicated above "major changes will be necessary in engineering practice, research, and education in the century ahead, changes that go far beyond conventional paradigms. (Duderstadt, 2008, p. 2) Some of the changes required with high priority are, according to different authors, the following;

- "Both new technologies (e.g., info-bio-nano) and the complex mega systems problems arising in contemporary society require highly **interdisciplinary**

engineering teams characterized by broad intellectual span **rather than focused practice within the traditional disciplines**." (Duderstadt, 2008, p. 2; emphasis added)

- "Industry needs a new breed of engineer: technically broad, commercially savvy, and globally adept." (Wennemer and Sattelberger, 2006)
- "[K]nowledge of the fundamentals and dynamics of globalization as well as opportunities to become immersed in study, work, or research abroad are key elements that should be integrated into engineering programs." (Continental, 2006; p.2)
- **"There is an urgent need for research on engineering in a global context."** (Continental, 2006; p.2; emphasis added by Continental)

Meta-Engineering

Meta-Engineering seems to be highly desirable and important in order to engineer the required improvements in **present** engineering activities and/or to engineer the new paradigm required, in the **future**, for the preparation of global engineers.

We are using the term "Meta-Engineering" as a general concept, not with any specific or instrumental meaning.

Some authors use the term "Meta-Engineering" to refer to systems or software that support engineering activities. Enright et. al. (2002), for example, refer to a software development Framework, named *Rapid Realtime Development Environment* (GRRDE), as a "sort of meta-engineering" and indicate that they are referring to "meta-engineering" as "the engineering of an *engineering process*" (p. 52). This meaning is among the most comprehensive ones in the literature. But, from our perspective, it might be understood as referring to just one of the three dimensions we identified as defining the engineering activities.

Dennett (1996) defines Meta-Engineering as "the investigation of the most general constraints on the processes that can lead to the creation and reproduction of designed things." (p. 227). He affirms that "rules of designing [as] the imperatives of meta-engineering that govern the process by which could, in practice, be created." (p. 222).

Meta-Engineering includes, but it is not limited to, the following activities:

- Meta-design, the design of designing methods and methodologies, is an essential part of Meta-Engineering.
- Conception, creation and structuring and engineering meta-methodologies, or methodologies for engineering processes is also essential to meta-engineering.

- Reverse engineering methodologies and activities might also be thought as meta-engineering thinking or practice.

In www.MetaEngineering.org (accessed on January 2, 2008) we find the following affirmation, which some people might take as definition:

"MetaEngineering is the study and refinement of the technology development process. It has three aims:

1. *To provide the means to better delineate design spaces and facilitate their exploration.*
2. *To identify and optimize bottlenecks in the evolution of technology.*
3. *To identify technological design patterns to support re-use at an abstract level, and to characterize their conditions for applicability."*

This obviously is describing the aims of the organization named MetaEngineering, but is does not define the concept or the practice of Meta-Engineering. The aims of the organization MetaEngineering might be taken as meta-engineering activities, but they do not define Meta-Engineering. 'A is B' does not necessarily means that 'B is A'. So, even if the "set 1,2, and 3" (above) is Meta-Engineering, we cannot conclude that Meta-engineering is "set 1,2, and 3".

This kind of confusion, based on implicitly equating 'A is B' with 'B is A' could create undesirable confusions, miscommunications and misunderstanding. Regretfully, the example we referred to above is not the only one that might be found.

John Wollenburg Sias (2005) affirms, in his Ph. D.'s dissertation, that "[d]esign of a successful EPIC [Explicitly Parallel Instruction Computing] compiler is better described as a problem of **meta-engineering (of producing a system to engineer workable solutions in complicated situations)** rather than one of optimization" (p. 16; emphasis added). We should make two comments regarding the way John Wollenburg Sias describes what he means by "meta-engineering" with the remark he made between parentheses:

1. If he is using the word "system" in its most general sense, as to include technologies, methods, human systems, etc. then his meaning of "meta-engineering" is not a specific one. If he means a "computer system" or a "software system" then what he is referring to is meta-engineering, but meta-engineering is definitely not what he is referring to. The alert we referred to above can also be applied here: 'A is B' should not be confused with 'B is A'. Genres should not be confused with their species.

2. The phrase "workable solutions in complicated situations" could be quite ambiguous, especially with regards to "complicated situation". There is no practical way of knowing when a situation is "complicated" and when it is not. "Complications" is a matter of degree, which depends on the perceiver of the situation.

Having made these alerts about the confusion potential regarding how “meta-engineering” might be used, Let us give some examples of meta-engineering before proceeding with a more analytical perspective of this concept, or notion.

Meta-Engineering is sometimes used in the programming languages and software literature. Consequently this is an adequate domain to provide some examples. Meta-software is the kind of software that support software development and, hence, Software Engineering. Consequently, Meta-Software Engineering (to engineer software for software engineering or for software engineering support) might be seen as an example of Meta-Engineering.

D’Hondt et. al. (2003), in a paper related to computer languages arrive to just one conclusion stating: “we can go one step further and examine whether we cannot use a software engineering approach to language engineering: establish interpreters for specific programming paradigms as a kind of reusable components and wire them together using a coroutine based glue language. At the very least this should illustrate that **software meta-engineering and meta-software engineering are but two sides of the same coin.** Experiments are underway.” (p. 5; emphasis added)

Other examples of Meta-Engineering are the following:

- The Design of Computer Aided Design (CAD) is a Meta-Engineering activity if it is oriented to Engineering Design.
- The design of methodologies for Engineering Design is a Meta-Engineering design activity.
- The design of Computer Assisted Manufacturing (CAM) in Industrial engineering.
- Knowledge Engineering is a Meta-Engineering activity if it is oriented to capture, represent and transmit Engineering Knowledge.
- Education Engineering applied in Engineering education.
- Organizational Engineering applied in Engineering Organizations.

Now, based on the essential definition we indicated above with regards to Engineering, let us derive an analytical definition of Meta-Engineering.

We proposed above that “Engineering is the development of new Knowledge (***scientia***), new ‘made things’ (***techné***) and/or new ways of working and doing (***praxis***) with the purpose of creating new **useful** products (artifacts) or services.” Consequently, we can now propose that:

> Meta-Engineering is the development of new Knowledge (***scientia***), new ‘made things’ (***techné***) and/or new ways of working and doing (***praxis***) with the purpose of creating new **useful** products (artifacts) or services **for engineers or engineering organizations.**

As we indicated above, engineering activities have three dimensions: ***scientia, techné*** and ***praxis***. Meta-engineering has the same three dimensions, but at a second level. Table 3 shows lists of representative but not comprehensive, and not excluding, meta-engineering activities or products, as related to their application in Engineering, in general.

If we want to be a little more specific, or analytic, we may also discompose engineering activities in their respective three dimensions. Consequently, each of the three dimensions of the meta-engineering level might apply to the three dimensions of the engineering level, generating 3 x 3 = 9 dimensions or kinds of meta/engineering activities. Table 4 shows representative, but not excluding, examples of the nine kinds of meta-engineering activities.

Meta-Engineering Dimension	**Application in Engineering**
Scientia	Engineering Science: a good example is Simon's "The *Sciences of the Artificial*". The science of Design. Applied Science to Engineering Problems and Activities. Empirical Studies of Engineering Practice. Abstract and Inductive Reasoning Applied to Engineering Practice. Engineering Philosophy. Philosophy of Technology.
Techné	Technological Support for Engineering Practice. Engineering Decision Support Systems. Computer Assisted Engineering Design. Meta-Software Engineering. Meta-methodologies. Re-inventing Engineering. Re-inventing Engineering Education. Meta-Design. Designing Engineering Organizations. Designing Quality Control for Engineering Activities.
Praxis	Engineering Practice. Engineering Profession. Engineering Entrepreneurs. Ethical Engineering. Ethical Design. Engineering Thinking. Engineering Doing. Engineers as Agent of change. Engineering Education. Engineering Training. Engineering Praxiology. Technological Transfer. Engineering Consulting. Engineering Action-Research. Action-Design. Engineering Action-Reflection. Engineering Action-Learning.

Table 3

Meta-Engineering	**Engineerring**		
	Scientia	***Techné***	***Praxis***
Scientia	Engineering Science and Meta-Science	Simon's "*Science of the Artificial*". Philosophy of Technology	Praxiology
Techné	Scientific Engineering Technologies	Meta-Techniques and Meta-Technology	Methods and Methodologies.
Praxis	Scientific Ethic and Scientific Methods and Methodologies	Technological Praxis, Ethics and Effectiveness	Meta-Praxis

Table 4

References

Ackoff, R.L., 1962, *Scientific Method: Optimizing Applied Research Decisions*. New York: John Wiley and Sons.

Aleksander,I, 2006, *What Is Engineering?* The Royal Academy of Engineering, Philosophy of Engineering, Monday, 27 March 2006; pp. 2-6. Accessed on December 15th; available at http://www.raeng.org.uk/policy/philosophy/pdf/Transcript_of_Presentations_on_27_March.pdf (Accessed on December 30, 2007)

Alvarez de Lorenzana, J. M., 1987, "On Evolutionary Systems". *Behavioral Science*, Vol. 32: 19-33.

Benner, P., 1984, *From Novice to Expert: Excellence and Power in Clinical Nursing practice*; London: Addison-Wesley

Biggs, J. B. and Telfer, R., 1987, *The Process of Learning*; Sydney: Prentice-Hall.

Bridgman, P.W., 1927, *The Logic of Modern Physics*; New York: The Macmillan Co.

Bridgman, P.W., 1938, "Operational Analysis", *Philosophy of Science*, Vol.5: 114-131.

Bucciarelly, L. L., 2003, *Engineering Philosophy*, the Netherlands: Delft University Press.

Callaos, N., 1995a, "Significado de definición," *Metodología Sistémica de Sistemas*, Caracas: Universidad Simón Bolivar. (Research done to ascend to the highest academia rank in the University), pp. 35-100

Callaos, N., 1995b, "Inducción, Deducción y Producción," *Metodología Sistémica de Sistemas*, Caracas: Universidad Simón Bolivar. (Research done to ascend to the highest academia rank in the University), pp. 203-234

Canadian Council of Professional Engineers, 1993, *The Canadian Engineering Qualification Board, 1993 Annual Report*, also in "Guideline on the Definition of the Practice of Professional Engineering," *The Canadian Engineering Qualification Board;* available at http://www.engineerscanada.ca/e/files/guideline_definition_with.pdf at (Accessed on December 27, 2007)

Churchman, C.W., 1971, *The Design of Inquiring Systems*. New York: Basic Books Inc., Pub.

Continental AG, 2006, *In Search of Global Engineering Excellence: Educating the Next Generation of Engineers for the Global Workplace*. Hanover, Germany, Continental AG. Available at http://www.conti-online.com (Accessed on December 30, 2007)

Corominas, J., 1990, Breve diccionario Etimológico de la Lengua Castellana; Madrid: Gredos.

Davis, M., 1998, Thinking Like *an Engineer: Studies in the Ethics of a Profession*; Oxford University Press.

D'Hondt, T., Gybels K., D'Hondt, M., and Peeters A., 2003, *Linguistic Symbiosis through coroutined interpretation*, Computer Science Department, Vrije Universiteit Brussel, Pleinlaan 2,1050 Brussels, Belgium. Available at http://prog.vub.ac.be/Publications/2003/vub-prog-tr-03-10.pdf (accessed on January 14, 2008) http://prog.vub.ac.be/Publications/2003/vub-prog-tr-03-10.pdf

Duderstadt, J. J., 2008, *Engineering for a Changing World: A Roadmap to the Future of Engineering Practice, Research, and Education*; The Millennium Project, The University of Michigan.; available at http://milproj.ummu.umich.edu/publications/EngFlex_report/download/EngFlex%20Report.pdf (Accessed on December 30, 2007)

Duhem, P., 1914, *The aim and structure of physical theory*. [Reprinted by Princeton University Press 1954]

Enright, J. P., Sedwick, R. J. and Miller, D. W., 2003, "High-Fidelity Simulation for Spacecraft Autonomy Development," Canadian Aeronautics and Space Journal, Vol. 48, No. 1, March 2002, pp. 51-59.

Felder, R. M. Wood, D. R., Stice, J. E., and Rugarcia A., 2000, "The Future of Engineering Education II. Teaching Methods That Work," *Chemical Engineering. Education, 34*(1), pp. 26–39; available at http://www4.ncsu.edu/unity/lockers/users/f/felder/public/ (Accessed on December 30, 2007)

Fenstermacher, K. D., 2005, 'The tyranny of tacit knowledge: What artificial intelligence tells us about knowledge representation," *Proceedings of the 38th Hawaii International Conference on System Sciences*; pp. 1-10

Ferrater-Mora, J., 1969, *Diccionario de Filosofía*; Buenos Aires: Editorial Sudamericana.

Goldman, S. L., 2004, "Why we need a philosophy of engineering: a work in progress," Interdisciplinary Science Reviews, Volume 29, Number 2, June 2004 , pp. 163-176(14); available at http://www.ingentaconnect.com/content/maney/isr/2004/00000029/00000002/art00007 (Accessed on January 15th, 2008).

Hawley, F., 2006, *What Is Engineering?* The Royal Academy of Engineering, Philosophy of Engineering, Monday, 27 March 2006; pp. 6-9; available at http://www.raeng.org.uk/policy/philosophy/pdf/Transcript_of_Presentations_on_27_March.pdf (Accessed on December 15th, 2008).

Herschbach, D. R., 1995, “Technology as Knowledge: Implications for Instruction,” *Journal of Technology Education*, Volume 7, Number 1, Fall.

Heron, J., 1981, “Philosophical bases for a New Paradigm.” In *Human Enquiry: a Sourcebook of New Paradigm research* (P. Reason and J. Roan, eds.); Chichester: Wiley; pp.19-35.

Higgs, J. and Titchen, A, 2000, “Knowledge and reasoning,” in Higgs, J. and Jones, M., (Eds.) *Clinical Reasoning in the Health Professions*; Edinburgh: Butterworth and Hinemann; pp. 23-32

Hoad, T. F., 1993, *The Concise Oxford Dictionary of English Etymology*; Oxford: Oxford university Press

Holt, T., 2006, “Types of Knowledge: Personal Knowledge,” available at www.theoryofknowledge.info/propositionalknowledge.html (Accessed on January 2, 2008)

Laszlo, E., 1987, "Evolution: The New Paradigm", *World Futures*, Vol. 23: 151-160.

Jarvie, I. C., 1998, “Popper Karl Raimund,” in in *Routledge Encyclopedia of Philosophy* (E. Craig, General Editor); London and New York: Routledge; vol. 7; pp.533-540.

Keith, G., 2006, *Philosophy of Engineering*, London: The royal academy of Engineering.

Lipton, P., 2005, “The Medawar Lecture 2004: The truth about science,” *Philosophical Transactions of the Royal Society B.*, 360, pp. 1259-1269; also available at http://journals.royalsociety.org/content/qrb52v0ebbw08cnr/fulltext.pdf (Accessed on January 15, 2008)

Malpas, R., 2000, *The Universe of Engineering: A UK Perspective*, Royal Academy of Engineering, June 2000.

McCarthy, N., 2006, “Philosophy in the Making”, *Ingenia*, issue 26, March, 2006; pp. 47-51.

McGinn, R.E.,1978, “What is technology?” *Research in Philosophy and Technology, 1*,179-197.

Mitcham, C.,1978, “Types of technology,” *Research in philosophy and technology, I*, 229-294.

Navarte, C., 1981, *Problemas de Método y Teoría*. Santiago de Chile: Universidad de Chile.

Norman, D. A., 2007, *The Design of Future Things*; Basic Books.

O’Neil, J., 1998, “Theory and Practice,” in *Routledge Encyclopedia of Philosophy* (E. Craig, General Editor); London and New York: Routledge; Vol. 9, pp.356-359.

Parry, R., 2003, "Epistêmê and Technê," Stanford University. Last accessed: December 23, 2007; available at http://plato.stanford.edu/archives/sum2003/entries/episteme-techne. (Accessed on December 30, 2007)

Perrin, J., 1990, “The inseparability of technology and work organization,” *History and Technology*, *7*(1), 1-13

Plotkin, H. C., 2003, *The Imagined World Made Real: Towards a Natural Science of Culture*; Rutgers University Press.

Polanyi, M., 1962, *Personal Knowledge: Towards a Post-Critical Philosophy*; Chicago: The University of Chicago Press.

Polanyi, M., 1967, *The tacit dimension*. New York: Doubleday Anchor.

Popper, K. R., 1959, 2002, The Logic of Scientific Discovery, London: Routledge

Prausnitz, J. M., 1991, “From Appolo to Prometheus and Hercules: Goals and methods of chemical engineering.”, *Chem.-Ing.-Tech*. 63, 447-457.

Quine, W. V. O., 1951, “Two dogmas of empiricism.” *Philosophical Review*, 60, 20–43.

Rosenberg, N. (1982). *Inside the black box: Technology and economics*. Cambridge, UK: Cambridge University Press.

Ryle, G., 1949, *The concept of mind*. London: Hutchinson.

Schön, D. A., 1987, *Educating the Reflective Practitioner*; San Francisco: Jossey-Bass.

Sias, J. W., 2005, *A Systematic Approach To Delivering Instruction-Level Parallelism In Epic Systems*; Urbana, Illinois: Dissertation, University Of Illinois At Urbana-Champaign, Stevens, S. S., 1935, "*The Operational Basis of Psychology*", American Journal of Psychology, Vol. 47: 323-330.

Vincenti, W.G. (1984). Technological knowledge without science: The innovation of flush riveting in American airplanes, ca. 1930-ca. 1950. *Technology and Culture, 25*(3), pp. 540-576.

Wennemer, and Sattelberger, T., 2006, "Foreword", *In Search of Global Engineering Excellence Educating the Next Generation of Engineers for the Global Workplace*; Hanover/Germany: Continental AG; available at http://www.conti-online.com (Accessed on December, 2007)