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From Philosophy of Technology to Philosophy of Engineering*

De la Filosofía de la Tecnología a la Filosofía de la ingeniería

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Abstract

A popular belief, inherited from the early 20th century, says that engineering is the application of scientific knowledge. However, after the understanding of the concepts of technique and technology, behind a mere linguistic issue, appear in the stage engineering with, more than ethical issues, as it has been considered in the tradition of philosophy of technology or, even, sociology of technology. After a detailed dissertation of the nature of knowledge in engineering and the inspection of the process to conduct research in engineering contrasted to the way the scientific method produces new scientific knowledge, it is inferred that besides creating two different kinds of human knowledge, science and engineering require different research methods, even coincident in some points.

Keywords: philosophy of engineering; philosophy of technology; research in engineering; epistemology of engineering; engineering thinking.

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RESUMEN

La creencia generalizada, heredada del inicio del siglo XX, dice que la ingeniería es la aplicación del conocimiento científico. Sin embargo, mediante la comprensión de los conceptos de técnica y tecnología, más allá de un asunto lingüístico, aparece la escena la ingeniería con más líneas de trabajo que solo los asuntos éticos que han sido de amplia consideración en la tradición de la filosofía de la ingeniería o incluso en la sociología de la tecnología. Con una detallada disertación sobre la naturaleza del conocimiento en ingeniería y la inspección del proceso para conducir investigación en ingeniería, en contraste con la forma como el método científico genera conocimiento científico, se infiere que además de crear dos diferentes clases de conocimiento humano, la ciencia y la ingeniería requieren de diferentes métodos de investigación, si bien coinciden en algunos puntos.

Palabras clave: filosofía de la ingeniería; filosofía de la tecnología; investigación en ingeniería; epistemología de la ingeniería; pensamiento de ingeniería.

1. Introduction

Since the twentieth century, some assert that it is difficult to distinguish between science and engineering or make a distinction between what scientists and non-scientists do, for instance, engineers (Keys 2009). Others claim that what scientists and engineers do complement each other or work very close, or simply that engineering is a branch of science or the application of scientific knowledge. This defines three models to understand between science and technology (Channell 2009).

However, there is no such difficulty at all. The kind of that apparent difficulty comes from a faulty comprehension of the historical and conceptual (Channell 2009; Mitcham & Schatzberg 2009) evolution of science and engineering, and the philosophical distinctions, both ontological and epistemological distinctions, between them.

It is shown how incomplete or inappropriate distinctions between technique, technology, and science, as well as some misconceptions on what is knowledge in engineering produced practical contradictions such as the wide belief that engineering is just the application of scientific knowledge which derives in the formal impossibility to produce new knowledge in engineering and, at the same time, would prevent the rationality of any doctoral (research) degree in engineering. In this paper there is no difference between engineering and engineering sciences (Mitcham & Schatzberg 2009), without disregarding differences between the two of them.

This research aims to state distinctions between science and engineering not by comparing the results of the work of scientists and engineers but through a comparison on the reasoning preceding what people on each discipline do, and on epistemological issues such as what is engineering knowledge and how to produce new knowledge in engineering, and the "weltanschauung" both in science and engineering. In doing so, as a methodological path, the modern concepts of technique and technology are revisited, then a distinction between engineering and technology is introduced (McCarthy 2011) followed by a characterization of the relationship between science and engineering. What should be understood as technology science is a departing point to deal with the brief history of philosophy of engineering as a discipline of philosophy, what knowledge in engineering is, and its research method to end with a comparison between science and engineering.

Engineering has a detached relationship with philosophy. Ethics is the main concern of many publications of philosophy in engineering (Heywood 2008), but it is not enough (Mitcham 2015). Some papers on philosophy of engineering may be traced back to 1966 (Greber 1966), but it is a philosophical discipline of recent development.

The document is structured as follows: This introduction, a section to make a distinction between technique and technology, then, the main section disserting the differences between science and technology, emphasizing that engineering is not applied science and introducing a comparison of the research process in science and the research process in engineering. Conclusions and further research are the final sections.

2. The Distinction Between Technique and Technology

Artifacts play a central role when talking on technique and technology (Newberry 2013).While the words “technique” and “technology” are used indistinctly to refer to artifacts, their meaning is somewhat different and belongs to different conceptual and, even, conceptual and historical contexts (Mitcham & Schatzberg 2009). The distinction between technique and technology is undertaken in this section.

2.1. The Interest in “Technique”

At the beginning of the twentieth-century philosophers were (still) asking what technique is. An answer given to this question was: the acts modifying nature (Ortega y Gasset 1965). These acts were described as procedures allowing humankind to get on his/her initiative what nature does not provide and is needed. In other words, “technique” is defined as a way humankind imposes over nature since humans do not resign to their environment (Santandreu Niell 1992). This idea advises that technique is inherent to the human race. However, the same idea does not mean that procedures to modify the environment to more appropriate conditions are of the exclusive practice of human beings, since insects like ants, mammals such as beavers, or birds like woodpeckers modify their environment also.

On the other hand, technique opposes to the adaptation of the individual to his/her environment. This is to say, while biological adaptation is a modification of the subject to the environment, technique may be understood as those acts directed from human beings to adapt nature to both their objective and superfluous needs. Technique and (natural) adaptation move in opposing directions.

Technical acts may be characterized by:

1. Their base is the human mind and the human aspiration to creative self-fulfillment.

2. Ensure the satisfaction of human needs,
3. Get this satisfaction with minimal effort, this optimization step is identified as efficiency, and
4. Create new possibilities with objects that may not be found in nature.

Therefore, the reason and cause of "technique" are outside technical artifacts. The cause of technique is to free humankind to allow human beings to be human: to insert the world into the 'human world', since the human being is not part of nature, but the human being has an interpretation of nature.

However, technical artifacts do not necessarily accomplish the optimization step. Then, it is valid to ask if artifacts such as telephones, vehicles, and Internet have led to waste not just individual but social time and effort (Mumford 1963; Veblen 1898). Sometimes, they are obstacles to the ends they pretend to favor. To summarize, technique means the set of procedures to get a specific result.

2.2. Technology: a Wider Concept than Technique

The distinction between technique and technology is not a matter of linguistics. This issue has been under interest since the nineteenth century. There is no general agreement about what technology is (Black 1976). While technique may be conceived as the cluster of competencies and skills in doing something or any particular activity, as a series of steps to perform an action accurately and efficiently, technology may be defined as the conscious systematic organization of any technique (Espinas 1987; Mauss 2004) to control the world through the use of artifacts.

Although thinking about technology may be traced back to ancient Greeks, the philosophy of technology is considered to be a field of philosophy since the second half of the nineteenth century (Kapp 1877). Concerning structured knowledge, there is no record of interdependence between science and technique before the nineteenth century (Habermas 1984). In this way, it is proper to speak of technology in modern terms since the last quarter of that century.

Despite the development of more than a century in philosophy of technology, some philosophers were still defending technology as a relevant field of philosophy (Bunge 1976) in the last quarter of the twentieth century, not because artifacts in themselves have a philosophical interest but in the technological processes where may be distinguished human knowledge. On the other hand, others (Giere 1976) commented in the meeting of the Philosophy of Science Association titled "Are There Any Philosophically Interesting Questions in Technology?" that something strange is in this title. Furthermore, in the symposium "Philosophy of Technology" sounds strange in a "Philosophy of Science" meeting, and suggested to understand the "philosophy of technology" not as a philosophical field but as "applied philosophy" since just epistemology is the field where the philosophy of technology demonstrated contributions. This is comprehensible since the philosophy of technology was pervaded by the focus on the moral implications of technology on society and human beings (Heidegger 1977) even the Heideggerian *dasein*.

According to Mitcham, there are two trends in philosophy of technology (Mitcham 1989): first, the philosophy of technology from the inside in which the main objective is the comprehension of the technological way of being-in-the-world, and philosophy of technology of humanities aiming to find a trans-technological point of view to understand the meaning of technology. This trend is a hermeneutical approach to technology (Mitcham 1989) to accomplish a comprehensive understanding of technology instead of a logical explanation. This stands on the principle of the primacy of humanities over technology since humanities conceived technology and not that technology conceived humanities.

Since technology is a new form to exist in the world, technology becomes a religious experience, and the religious experience takes a technological meaning (Dessauer 1964) with moral meaning.

In a linear timeline, technology has evolved in three phases (Mumford 1963):

1. Since ancient time to 1750: Technology of intuitive (Ortega y Gasset 1965) or random techniques (Mumford 1963) using water and wind, in modern terms: just techniques,

2. 1750-1900: Technologies of empirical (Ortega y Gasset 1965) or craftsman techniques (Mumford 1963) based on coal and iron, and
3. 1900 – up to the present day: Technologies of the technician or engineer (Ortega y Gasset) based on electricity and metal alloy. The keys to these technologies are rationality, artificiality, automation of the technical election, self-growing, indivisibility, universalism, and autonomy (Ellul 2018).

The "scientification" of technique occurring in the last quarter of the nineteenth century is a characteristic of late capitalism. Since capitalism looks for a permanent increase in the productivity of labor by introducing new techniques, including what is called industrial management at the dawn of the twentieth century (López-Cruz 2002, 2006; Habermas 1984; Taylor 1919), there is a permanent demand for new techniques. Those techniques new techniques come from creations. Creations proceed either from random outcomes from the daily practice of using current techniques in current activities or from research groups or institutes. Those creations in the forward march of the industrial Revolution were called "technical inventions" until the late nineteenth century, thereafter a new word —now a buzzword— to distinguish "invention" as an act of intellectual creativity undertaken without paying attention to eventual profits, from "innovation" used to mean the incorporation of creations into firms (Schumpeter 1961). After the second world war "innovation" went on to signify, formally speaking, the implementation of creations: the introduction on the market (product innovation) or use within a production process (process innovation) or a new marketing method involving significant changes in product design or packaging, product placement, product promotion or pricing (marketing innovation) or new organizational method in the firm's business practices, workplace organization or external relations (organizational innovation) (Organization for Economic Co-operation and Development [OECD] 2018).

Since capitalism may not be left innovations to free "inspirations" due to efficiency reasons, capitalism systematized innovations by linking research in universities and research centers to industries, or production centers. Since then, technical progress and scientific progress are intertwined as technological sciences. Now technological development and scientific progress feed mutually, making science and technology the first productive power (Habermas 1984). However, science is not a technique, but science uses techniques in its validation processes. Because of this close and strong relationship, science and technology are two powerful political, economic, social, and cultural institutions (Vessuri 2001). Besides, there is a permanent relation between science, technology, and engineering (Pitt 2010; Poel 2010), but still differences.

Recent views of technology claims technology not as an artifact or knowledge incorporated to a process or artifact, but as the core of organizational absorptive capacity to enable organizational knowledge (López-Cruz 2017a): technology as routine capability (Swanson 2019).

A distinction between technological sciences and natural sciences is that technological theories need not prove they are true but they do need to prove that function (Mitcham 1989), that they produce useful results. This difference will be inherited to philosophy of engineering.

3. Philosophy of Engineering

The epistemological prejudice of the western philosophy that predicative knowledge (know-that) represents a superior form of knowledge, or the knowledge itself, leads to the explicative knowledge (know-why) or *episteme*, which is science *par excellence*. In contrast, operative knowledge (know-how) was left as simple *empeiria*: since contemplation is stated as the base of knowledge, the theoretical division between subject and object epistemologically discredits practice (Boon 2011). It suffices to recall comments of people when their personal computer slows to react to a command or definitely locks down: people use to say that their computer is "thinking". People find similar "contemplation" and "no reaction" or "no activity", while find (any) action not associated with thinking or knowledge. This a historical consequence of the prevalence of Plato and Aristotle thought that *technai* is a true knowledge but contingent knowledge (*doxa*). According to ancient Greeks, contingency makes this knowledge inferior to invariable and immutable knowledge represented by episteme: science (Medina 1995). In this context, *techné* is a subordinate application of *episteme*. Needless to say that philosophy of technology is different from philosophy of science (Agassi 1988).

While philosophy of technology is a centennial body of knowledge, philosophy of engineering is a newborn discipline in philosophy (see Figure 1), a body of knowledge in construction (Jaramillo Patiño 2015).

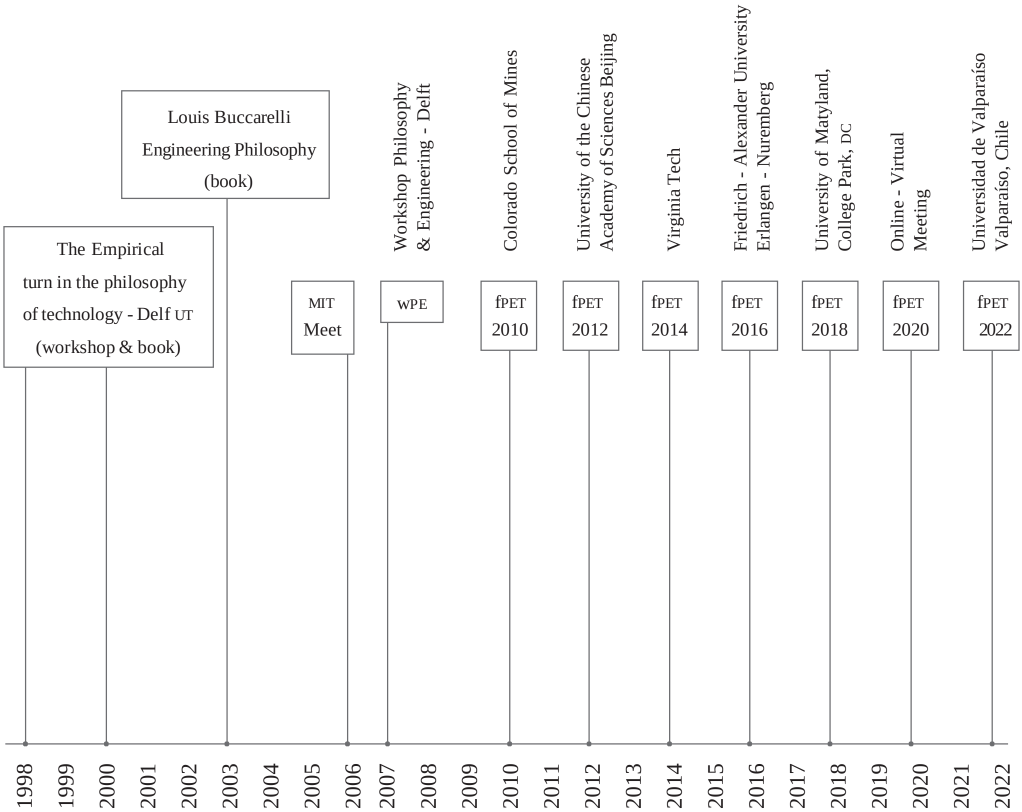


Figura 1. Timeline for philosophy of engineering body of knowledge.
Source: Prepared by the author.

The results of the workshop "Empirical turn in the philosophy of technology" in Delft University of Technology, Netherlands (see Figure 1), and the publishing of the results in 2000, next to the MIT meeting in 2006 and the Workshop in Philosophy & Engineering set the beginning of an academic community with a particular interest in philosophy of engineering and the appearance of dissemination instruments. But the publication of "Philosophy and Engineering: An emerging agenda" in 2010 (Poel & Goldberg 2010) and the first biennial Forum on Philosophy of Engineering & Technology fPET completed the research agenda to conform philosophy of engineering as an actual discipline in philosophy. fPET-2020 was conducted in November 2020 as an online Forum.

3.1. Science and Applied Sciences

It is an undisputed fact that modern science is fundamental for mankind. Beginnings of modern science date approximately since the fifteenth century (Hooykaas 1987; Taylor, Hoyler & Evans 2008) when the Polish astronomer Nicolaus Copernicus initiated a cosmological change to a heliocentric theory which controverted the idea of the earth as the center of the universe based on the belief that human beings were at the top of God's creation: theocentrism.

From the Middle Ages to the Renaissance in Europe western thinking changed from theocentrism to anthropocentrism. This change of focus put science in the role of a new doctrine since Francis Bacon's Novum organum was published. Its subtitle "… or true directions concerning the interpretation of nature" aims to understand the universe. Since then, scientific knowledge has allowed us to understand, explain, and predict natural phenomena. Knowledge in the philosophy of nature, now Physics and its many branches including astronomy, but also chemistry, and biology created concepts and theories to better understand the universe. Besides, the application of scientific knowledge has provided humankind with practical results that transform the world. The hidden side of scientific knowledge, and positivism in general, is that is prone to being just a matter of social prestige (Grundmann 2017; Lorenz 2016), not necessarily a matter of knowledge-generating studies.

Many disciplines use scientific knowledge available, but this does not make them Science. For instance, medicine does use scientific knowledge and methods, but medicine is not "applied science" (Petroski 2010). The recent COVID-19 pandemic has shown that medical doctors use all relevant scientific knowledge available to them, but they do not wait for complete scientific understanding to conduct acts to save a life. The Hippocratic Oath "*... I will prescribe regimen for the good of my patients according to my ability and my judgment and never do harm to anyone...*" states what any physician in an emergency room knows that his actions are based on his abilities and good judgment, not in a complete knowledge about causes and effects. This is to say that in emergency rooms is difficult to predict or predetermine if any medical procedure will be the very best to get a result, never mind based on a complete study of the situation or based on an extended survey to establish the best procedure to follow to get the desired result, because usually there is no enough time to do so.

Under emergency circumstances, physicians act guided by the goal of saving lives, not for the goal of *reasserting* the truth or seeking for a scientific theory. Medicine is more teleological than analytical or rationalist. In some sense, engineering actions are similar to those of medicine as a discipline: engineering is prevailing teleological (Petroski 1982; Poser 2013).

Medicine aims to heal the patient and to keep the life-quality of human beings in a more inward-oriented focus. As regards engineering, the artifacts of its many disciplines are aimed to transform the environment of human beings, not just in physical-natural contexts but in psychological-artificial extensions of those same human beings as modern artificial intelligence works in a world of artificial things (McCarthy 2009) in specific contexts.

Meanwhile, it is popular to think of philosophy as some abstract discipline or type of knowledge that has nothing to do with activities to obtain practical results (McCarthy 2007), even more, some people see themselves as "pragmatic" and, therefore, they consider themselves outside any philosophical reasoning. Needless to say that those assertions are not founded on the school of pragmatism (Dewey 2005; Hocking 1940) ignoring that in pragmatism, the experience is processual, transactional, socially mediated, and not categorically prefigured as “rational” or “emotional”. What those claiming to be pragmatics is just something like a kind of clumsy pragmatism, not because they think they are not related to the difference between the concrete and the abstract, the particular and the universal, producing “results” and theorizing, or modeling by design and developing new products or services, but because they feel (or they think they know) that they understand the difference between foundational concepts of pragmatism and, therefore, attesting that there is no need to ask questions or critically think about what they do, how they do, why they do, and so on.

However, when engineers have to deal with complex problems there is a need to seek methods of conceptual clarification and clear argument, and even ‘good judgment’, that philosophy provides (McCarthy 2007). Definitely, engineers need a sort of Hippocratic oath (Grimson & Murphy 2013). This is not the same as borrowing from philosophy some concepts, or methods to aid engineers in dealing with complex problems (McCarthy 2007). Philosophy of engineering is not how philosophy “applies” to engineering neither how engineering supports philosophy activities.

3.2. Does Engineering Have Its proper Knowledge?

This question asks for knowledge that pertains to engineering in the same sense that algebra, calculus, topology, and so on, is mathematical knowledge, and the study of the movement of bodies in the macro-universe belongs to physics, or the study of the structure and organization of cells and living organisms characterizes the knowledge field of biology. In addition to mathematics, all of them, physics, chemistry, and biology are natural sciences.

Some people think that the core knowledge of engineering is calculus or mathematics in general. Because the engineering curricula include calculus, finite element analysis, set theory, abstract algebra, differential equations, or linear algebra courses it might be concluded that these are engineering knowledge and not branches of mathematics. Needless to say, mathematics should be in the toolbox of engineers, but it does not mean that mathematics is the core knowledge of engineering. Even worse, on the other way, some may conclude that engineering is just a practical branch of mathematics.

Similarly, there are relationships between engineering and mechanics —statics and dynamics—, electricity, magnetism, and thermodynamics courses. Those are typical courses of engineering curricula but they are not courses on engineering knowledge but physics courses. Once again, this does not make engineering a practical branch of physics. At best, those courses regard the way to apply natural sciences knowledge to engineering, but they are not courses developing or deploying engineering knowledge. The same is true for chemistry, biology, probability, and statistics courses. Then, it is worth asking: what is the knowledge of engineering which is not the knowledge of science or any other discipline? In other words, does engineering owns some sort of knowledge? If engineers know something, what is that what engineers know? Do the different branches of engineering have some sort of knowledge in common that is not the knowledge of other disciplines outside engineering?

Engineering specialties in the twentieth century have to do with systems and technological artifacts in systems: mechanical systems, electrical systems, electronic systems, computing systems, chemical systems, ecosystems or environmental systems, industrial systems, biomedical systems, hydrological systems, for example, systems everywhere (Bertalanffy 1969).

Furthermore, if it were accepted that research aims for new knowledge, does research in engineering produces new engineering knowledge? If the premise is that engineering is just a branch of science then, as expected, research in engineering should be understood as the application of the scientific method and, therefore, results of engineering research are scientific results, that is to say, products in the scientific framework such as (scientific) theories to be used as any scientific theory is used for: a scientific theory stands to explain, enhance comprehend, or predict.

An alternate possibility would be to think that engineering is to apply scientific knowledge to develop solutions to technical problems. In such a fashion, there is no need to conduct any research in engineering because it would suffice to wait for results in scientific research and then apply the new knowledge to develop engineering solutions. As a further consequence, what should be the answers to the questions: Is a Ph.D. in Engineering worth it? A Ph.D. in engineering would be a research doctorate, or just a "professional" doctorate, focusing less on research and more on the application of existing knowledge within technical expertise?

Mankind history and engineering research show that engineering is the application of scientific knowledge but also is a field that develops, creates, and innovates to produce engineering artifacts in specific and special knowledge preceding, or when necessary, independent of scientific knowledge. From an anthropological point of view, cognition is not only scientific knowledge but, also, traditional knowledge and common sense. Since engineering practitioners need all available knowledge to address specific situations and transform them in desired situations, sometimes scientific knowledge is not enough. Practitioners need all available knowledge including those knowledge coming from experience: own experience as well as other practitioners' experience, some piece of knowledge that is not the result of scientific research, a piece of knowledge called "practical knowledge". Knowledge in the form of rules in processes, procedures, and methods of action, or sociotechnical systems preceded by a teleological purpose: practical effectiveness (Banse & Grunwald 2009).

3.3. What Is Engineering?

To understand what engineering knowledge means, proceeds a previous inquiry on what is engineering. A range of concepts are given about engineering: from what engineers do in terms of what sort of artifacts produce —this is as a profession— to concepts focusing on the essence of what engineering is.

In the line of "doing", engineering is defined as an ability "The ability to see how existing technology could be applied in order to meet a need stated in the form of set of interacting requirements, and then to create a product which, when put into service, meets that need" (Aslaksen 2007 102). Some, define engineering through the role of practitioners: "The role of an engineer is to make practical use of converting theory in useful applications to provide for mankind's material needs and well-being" (Beakley et ál. 1986 165), which is a laudable intention that puts engineering in the role of a consumer of applicable scientific knowledge (López-Cruz 2017b). Conceptions of engineering as applied science are behind descriptions such as "science is about discovering the truth of our understanding of Nature, engineering is about using that understanding for beneficial purposes" (Aslaksen 2013 68).

Engineering as applied science does not need any philosophical framework, just a code of ethics as any clerical activity. In this perspective, engineering may seem philosophically inadequate (Goldberg 2013; Mitcham 2009).

The fall of the Berlin Wall (*Mauerfall* in German), on 9 November 1989, the dissolution of the Soviet Union between 1990 and 1991, as well as other political and economic facts, changed the face of the end of the twentieth century. After the second world war, the upcoming cold war era transformed engineering research as a fact of importance in the United States of America security since "Powerful new tactics of defense and offense are developed around new weapons created by scientific and engineering research" (Bush 1945 175). This could be one of the determinants of the conception of engineering as applied science. During the second part of that century "… the economies of scale were dominant, large hierarchical organizations were the rule, and engineers became increasingly scientific in response to perceptions of the status of science after the war" (Goldberg 2009 176). But, the end of cold-war revealed the need to debunk the myth of engineering as applied science (Koen 2013).

To start the process of conceptualizing of engineering and launch substantive work without further delay, since the Empirical Turn of Philosophy of Technology in 1998 (Li 2020; Mitcham, Kroes & Meijers 2020) Engineering gains in Delft the right to be an object of philosophical reflection outside science or technology, independent of science and technology. This allowed discussing structural differences between science and engineering (Poser 1998) summarized in the assert of Theodore

Von Karman, "Scientists discover the world that exists; engineers create the world that never was" (Bucciarelli 2003 169). In simple words "engineering is different from science" (Pollock 2009 167). Besides, the publication of "Philosophy of Engineering" (Bucciarelli 2003) in Delft was another milestone in the development of Philosophy of Engineering. In 2007 the first "Workshop on Philosophy and Engineering" (WPE) in Delft marked the formal beginning of Conferences on Philosophy on Engineering. In 2010 philosophy of engineering continues to strengthen with the 2010 Forum on Philosophy, Engineering, and Technology (fPET-2010) held on 9-10 May 2010 at the Colorado School of Mines in Golden, CO (Koen 2013). Since then on a biennial basis up to November 2020, as an online forum because of the COVID-19 pandemics. fPET-2022 is planned to be held in Valparaiso, Chile.

Engineering starts to be conceived as a process "… a purposeful process of creative design that produces a product" (Pollock 2009 167) and not the application of scientific knowledge. In essence, engineering is a set of conscious and purposeful processes and actions conducted by human beings to transform the real world (Olaya 2012, 2013).

Then, engineering calls for a particular sort of action, a purposeful dynamics of human beings guided or supported by processes, procedures, technical artifacts, and the know-how to provide the extension of the possibilities of action. Therefore, it is still valid to conceive an engineer as Sir William Fairbain did: a person "who seeks in his mind, who sets his mental powers in action, in order to discover or devise some means of succeeding in a difficult task he may have to perform" (Burke 1979; Koen 2013).

This calls for asking what action is, as well as what possibilities of action are: the sort of actions as mentioned before. Then the question of agency comes into the scene, what is that called agency? and what criteria are to be used to distinguish between and what is an agent and what is not? Some dissertations show that a distinction between a strong agency and a weak agency is not enough to explain agency (Parente 2016). At least, understanding agency as the capacity, condition, or state of acting or of exerting power to produce some effect, is just a definition that leads (historically led) to a discussion on the origin of the intentionality of the effect or result of the action. This conceptualization of agency suggests that the class of human artifacts integrate a homogeneous set of instruments.

Although a hammer and a gun are artifacts, the main expected effect of their functionality is different. While the first is designed to deliver an impact to an object, mainly a tool, the second is designed to launch solid projectiles, it is a weapon. Both of them may be used to harm someone as well as to put nails on the wall. This line of reasoning traditionally led to assign a human being the 'responsibility' of the action freeing artifacts of moral trade-offs and by the same reasons their designers. History has proved this reasoning is mistaken. Crematoria or crematory ovens designed, constructed, and operated by nazi engineers Kurt Prüfer and Karl Schultze, just to mention a couple of them, is the counterexample to prove it wrong.

The high efficiency of the Topf & Söhne crematory ovens for the incineration of human corpses is indisputable. The engineers did not incinerate with their own hands corpses, this was done by the ovens efficiently, the correct concept related to the action performed here is not "responsibility", not to avoid the ethical discussion. The concept is "accountability" which allows the inspection of the sociosystem or social system where humans (engineers) and artifacts (ovens) appear (Garcia-Diaz & Olaya 2017). But not to assume a sociological view of technology (Latour 1990 y Latour 2017) but to adopt a systems view of 'agency' to tackle its complexity.

Indeed, responsibility is not a category or characteristic applicable to artificial agents. Responsibility is irrelevant to define agent capability since in artificial agents accountability takes place of responsibility. Even industrial robots differ a great deal from software bDI agents. While the first obey a prescribed program to produce a product under the premise of efficiency, assuming a deterministic world, BDI intelligent agents act under a heuristic method coping with a non-deterministic world of uncertainty as the Heisenberg's uncertainty principle imposes. But in both cases, there should be traceability to allow accountability on actions of these agents.

Human artifacts are not all of them in the same class. A criterion to distinguish between some artifacts and others is their capability to adapt or 're-program' their original design to perform different actions under some rules or criteria which are evolving also. They adapt or evolve not on an individual basis but a population one. Individual changes may perpetuate in time as a result of the decisions the individual made and their evolutionary environment. Under this view, change occurs individually and emerges in the adaptive capabilities of the population. In this way, causality is not the criterion to state the ontological state of the agent, but their capability to make decisions. But understanding the process of making decisions not in a 'pre-programmed' fixed course of action, such as in the "if-then-else" ruled computer programs, but in courses of action governed by a dynamic rule database that changes its records according to both individual and societal evolution. This happens because individuals are not able to calculate and decide their 'optimal" strategy. Even more, efficiency may be replaced by effectivity (Axelrod 1997; Bonabeau 2002).

In short, "agency" in artifacts is not to be discussed on passive mechanical artifacts, but in the sense of modern engineered artifacts, which are not simplistic technical tools such as hammers, bridges, or airplanes but those autonomous artifacts whose autonomy is based on their 'capability of agency' consisting not in what is the "problem" that solves (El-Zein & Hedemenn 2016) but what are those public interests that serve to, not who was its designer conferring this capability, or in the possible social relationships or sociological links with their environment but in their capacity to adapt, not despite their inherent or internal restrictions or external constraints, but because the autonomy comes from the fact that the artificial agent counts with a dynamic capability to change its governing rules since internal restrictions and external constraints. A starting point for these artifacts was the design of BDI agents (Weiss 1999; Woolridge 2009), which are agents acting under the primacy of beliefs, desires, and intentions in rational action (Wooldridge 2000), making decisions under bounded rationality (Simon 1990).

Agency in artifacts makes sense just when artifacts exhibit the capacity to make decisions beyond if-then-else mediated actions. As the Heideggerian Dasein states human beings 'are' but not just in a present static manner but in the sense of the potential and capability to 'become' (Mitcham 2001), also, similarly Gibson's affordances (Gibson 1977; Gibson 1979) complete the ecological triad human-artificial-natural.

3.4. The Scientific Method produces Scientific Knowledge, What Method does Engineering Knowledge produce?

Far beyond scientific knowledge produced by a scientific, rational, logical method, engineering reasoning needs well-known and proven recipes to maintain the *statu quo* of known production processes and, also needs to be free of recipes to address the challenge of creating acts. Since not all knowledge exists in the form of beliefs, nor can it be expressed in the propositional form necessary for codification in a 'scientific' theory, as the knowledge-how (McCarthy 2007) or tacit knowledge (Nonaka & Takeuchi 1995, 2007), other forms of knowledge representation are used in engineering. Frequently, models are used for this purpose. However, models of engineering are different from models in science (Pirtle 2010). Models in science are used to represent what is already in an environment, with the corresponding purpose of knowledge in science: explain, predict, for instance. Usually, models in engineering are designs of what is not (yet) in an environment but is purposeful planned to be there. Even models seem to be similar in science and engineering, they are preceded by different reasoning processes.

Engineering epitomizes common sense as a fundamental method of reasoning (Pitt 2013) and looking forward to devising actions changing the present for some desired future (Schmidt 2013) instead of looking backward to explain the past or to describe the present (Koen 2013; Vincenti 1990). Therefore, knowledge in engineering has to do with the way the world is changed not with its understanding (Auyang 2009; McCarthy 2008).

Similarly, actions to maintain what engineers do, actions to produce new knowledge in engineering, and the way actions are organized by scientists to produce theories and verify or validate them, are alike. They are grouped under the notion of "project". A project is a temporary effort to create a unique product, service, or result (Project Management Institute [PMI] 2013). This notion of "project" is enough general to fit in science, engineering, and any other activity involving budget, time, and technical constraints. While in science a project is a secondary consideration next to the scientific method, the notion of "project" is central to "action of engineering”. This comes from the fact of the need to manage technical specifications as constraints, where technical specifications may refer to resolution limits in scale, precision, or accuracy, but to the minimal characteristics that the result, usually an artifact, should exhibit to consider it fulfills what is expected to transform a specific situation in the universe.

Under these circumstances, some propose to modify the scientific method to meet engineering research (Staples 2015). However, superfluous modifications to the scientific method stand on the assumption that engineering is applied science: applied physics, applied biology, or applied chemistry:

> The claim that engineering is applied science rests on the assumption that physical science and engineering share a common understanding of the world and its properties, an understanding based on a shared body of knowledge generated primarily by scientists and always by "the scientific method." A presupposition of this assumption is that science and engineering take the same world as their object. Neither of these seems to me to be true. Scientific knowledge and engineering knowledge are two fundamentally different kinds of knowledge, and, bizarre though it may sound at first hearing, they have different worlds as their objects (Goldman 1990 180).

Knowledge in engineering differs from knowledge in science because each one obeys different epistemologies. Valid knowledge in science stands of the principle that everything must have a reason, cause, or ground: the principle of sufficient reason. This is expected for knowledge that claims to be universally valid, identified as universal laws or theoretical knowledge, and stable knowledge, something valid until a better theory replaces it. In contrast, because of the contingency-based model of rationality in engineering, the principle of insufficient reason grounds engineering (Goldman 2004; López-Cruz 2017b).

In a hypothetical example requiring a formulation of antifreeze to add to a car engine coolant system guided by the scientific method, the results may depend on the distance between research centers (or universities) and firms (industry). While gathering data in the firm (industry) could produce a model of practical results of how much antifreeze is needed in different weathers (see Figure 2), a slightly general approach from antifreeze properties produces a model explaining how the antifreeze.

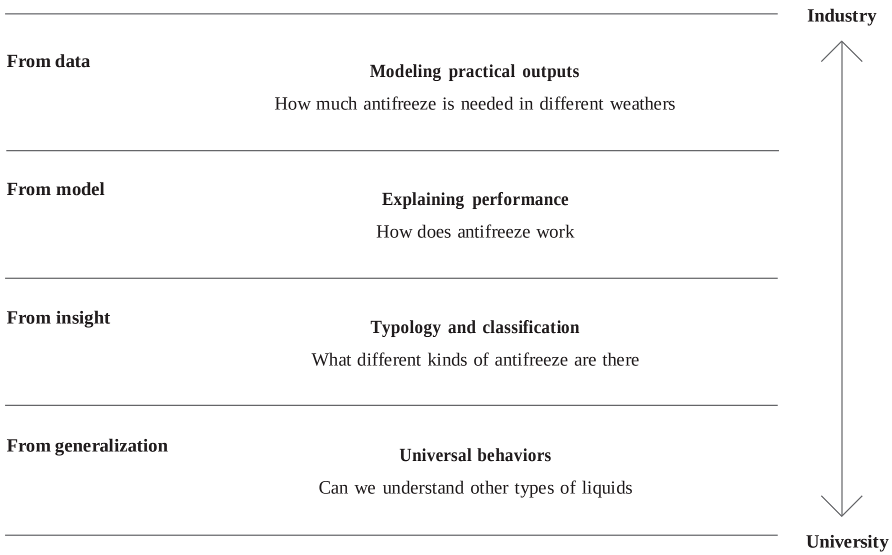


Figura 2. Different perspectives (scales, for instance) on the same object using the scientific method just change the informational results of research.
Source: Baumberg (2018 83).

Near scientific research centers and universities, far from firms (industry), scientists (or people working on the scientific method guide) identify variables and state a relationship between them, may predict the performance of different types of cooling fluids, generating a typology and a classification of antifreeze liquids (see Figure 2). At the other end of the spectrum, scientists develop the thermodynamics of cooling liquids, experiment in controlled conditions or laboratory conditions, and conclude statements on universal behaviors of antifreeze.

Some say (Baumberg 2018) that while near research centers or universities results are pure science or the research itself (at such), then applied science, and when next to firms (industry) is engineering or technology (inside the firms), in this paper is shown how this is the application of the same scientific method at different environments. No such of these scenarios are engineering.

Other researchers (Drexler 2013) propose a difference between research in science and design in engineering just as a matter of information flow: information flows in the same direction but opposed senses. They propose that in science information flows from the physical system (the object of study) (see Figure 3) to an abstract model (theory) employing two steps: first measuring on the physical system to gather data and complete a concrete description, and then compare data and hypothesis (or something like that) to derive (prove) the theory.

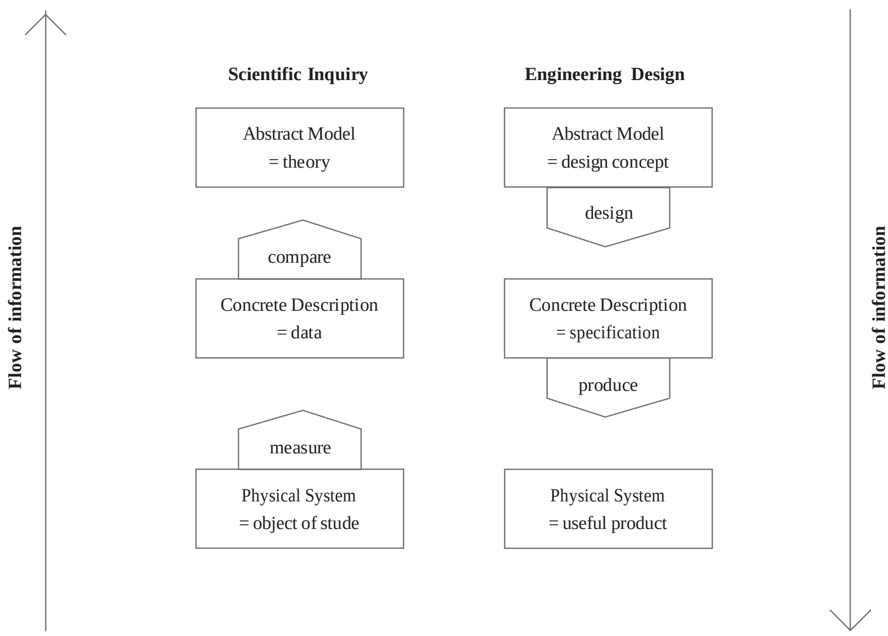


Figura 3. According to some researchers (Drexler 2013), the difference between the research in science and engineering is just the opposite sense in the direction of the information flow between an abstract model and a physical system.
Source: Prepared by the author.

On the other hand, engineering research is seen as a flow from an abstract model (in this case a design concept) to the physical system (in this case a useful product) (see Figure 3). Information flows through design into a concrete description (a specification) and then through a production process to the physical systems (a useful product) (see Figure 3).

As seen, this is just an oversimplification because lacks an epistemological framework. Table 1 summarizes basic epistemological differences between Engineering and Science, which attends a reference to an epistemological framework in philosophy of engineering.

Element	**Engineering**	**Science**
Object of study	Man-made objects.	Objects in nature.
Taxonomy	Functionality.	Physical characteristics.
Knowledge	Hardly generalizable.	Looks for universality.
Knowledge	Task specific.	Theory bounded.
Knowledge	Unjustified.	Justified.
Knowledge	Historical.	Ahistorical (pretensions of eternity).
Solutions	Analytical solutions not required if there is a good solution available.	Analytical solutions required.
Main goal	Effectiveness and satisfaction.	True.
Available resources	Restrictions incorporated into the design.	Limitation to generalization.
Results	Provides the best change.	Seeks to test and proof hypothesis.
Models	For guiding knowledge and further design of systems.	To represent the world that exists.
Models	Functional abstractions.	Models must attend laws of science.
Models	Decision rules from the model serve as starting point.	Models make abstractions of the world.
Purpose of the research method	Engineering method works in ill-defined situations.	Scientific method enhances understanding of the world.
Research method	Applies in uncertainty (unkown probability distribution).	Uncertainity is managed by designing (or adjusting) known probability distributions.

Table 1. A basic comparison between epistemology of engineering and sciences
Source: Prepared by the author.

3.5. The Engineering Method and the Scientific Method processes

A methodology to make apparent the engineering method to produce engineering knowledge, both processes of research in science as well as in engineering will be graphically explained in order to be compared.

The scientific method sets the universe (the physical system or a part of the universe) as a departure point asking something to know about a natural system which in turn derives in research objectives (see Figure 4) looking for the answer of the question. This question is very often identified as a problem. As well as scientists, engineering deals with phenomena of the universe to be transformed in any manner. Persuaded by the conviction they can change some part of the universe: engineers ideate transition strategies from the present situation to the future situation. The engineer seeks an answer to a problem consistent with the resources available to him (Koen 2013).

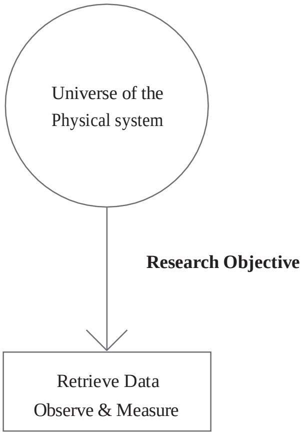


Figura 4. Both scientists and engineers select a starting point in the universe. While scientists look for an answer to a problem, engineers seek an answer to a problem in accordance with the resources available to them. This is not seen in this diagram and it is hardly distinguished in practice. The differences may be found in project schedules.
Source: Prepared by the author.

The differences between scientists and engineers in this early phase of the research process are hardly seen as different. Differences cannot be inferred from a diagram process (see Figure 4) or even in practice. Looking for these differences imply to have access to project schedules and, sometimes, access to detailed information or data in the composition of each project charter.

By statistical, experimental, measuring, or observation techniques, the scientist or the engineer retrieve data to construct databases of raw data. The difference between scientific research in the past and the twentieth-century is the high probability to get access to a high volume of data regarding the research object. Even engineering research may have access to the environment needed to be studied, it should not be forgotten that the engineer studies —in a research process— the environment to transform it by using new means. Therefore, engineering research as scientific research prepare and explore data, the data set in engineering is intended, frequently customized, to look for innovation and improvement opportunities (see Figure 5).

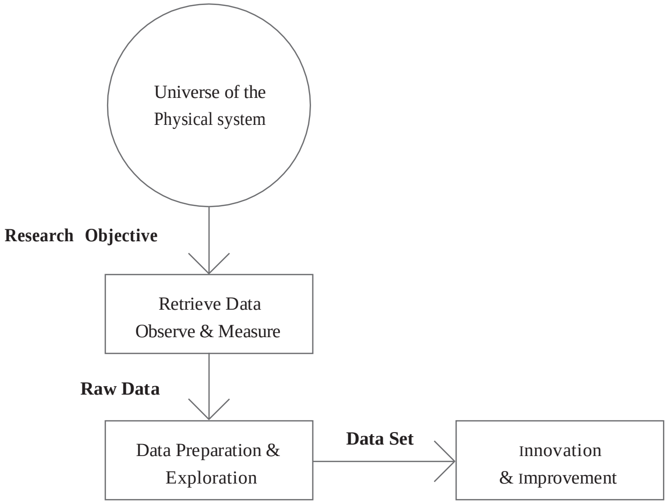


Figura 5. Engineers prepare and explore data retrieved from measures aiming to find a way to improve or innovate

Source: Prepared by the author.

Engineers work on data sets to find insights on alternate ways of doing things, those results are raw data for the process of modeling (see Figure 6). This does not mean that "Innovation & Improvement" processes (see Figure 5) is idempotent on data, this is just to admit the fact that, in many engineering research process, there is no available historical data, or historical data do not give an insight on new things to do. Innovation is different from invention but both share the fact that they have to do with things that have not existed before and, if have existed, they have existed in different ways, shapes or, even, cultural, political, or economic contexts.

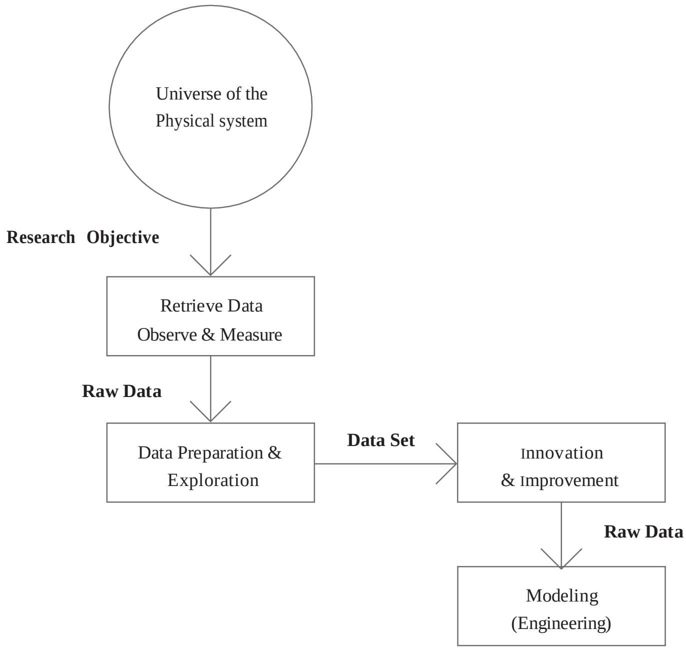


Figura 6. Modeling in engineering uses data resulting from innovation & improvement processes. This because historical data do not give an insight into new things to do.
Source: Prepared by the author.

Models in engineering are different from models in science. Not because of techniques used to represent or describe. They are different in at least two concerns: what they represent and the design criteria. Models in engineering, this means in research processes in engineering, must refer to something that does not exist because it is intended to change the world or at least a part of it. Due to this fact, models in engineering get into test processes. But the final objective of the tests is not to verify how the model conforms to the real world, because the real world is what is to be changed. The aim is to check functional dependability (see Figure 7).

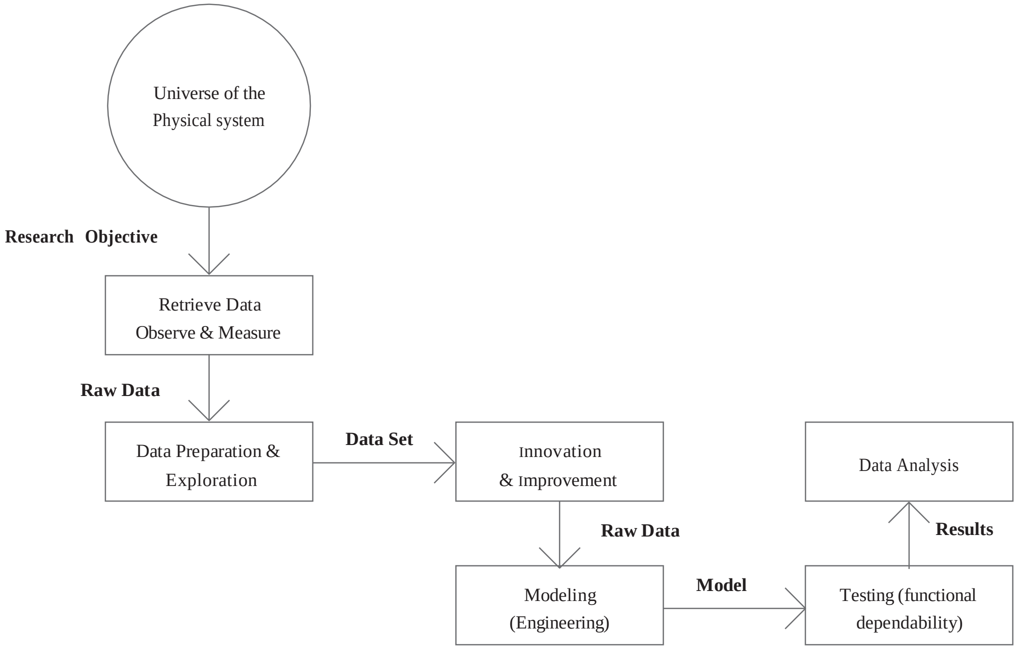


Figura 7. Models in engineering are representations of something intended to change the universe or at least a little part of the world. Even more, some of those models represent something that has never been. Therefore, the functionality of models needs to be tested and the results of tests should be studied.
Source: Prepared by the author.

The results of this test are analyzed to state criteria to be used during assessment in the verification & validity of the model. It is time to insist that the verification needs to respond to some functionality (see Figure 8), but functionality may be restricted or "incorporated" into the model according to available resources in the context of the engineering research process, in addition to the inherent natural limitations, as "natural laws" impose.

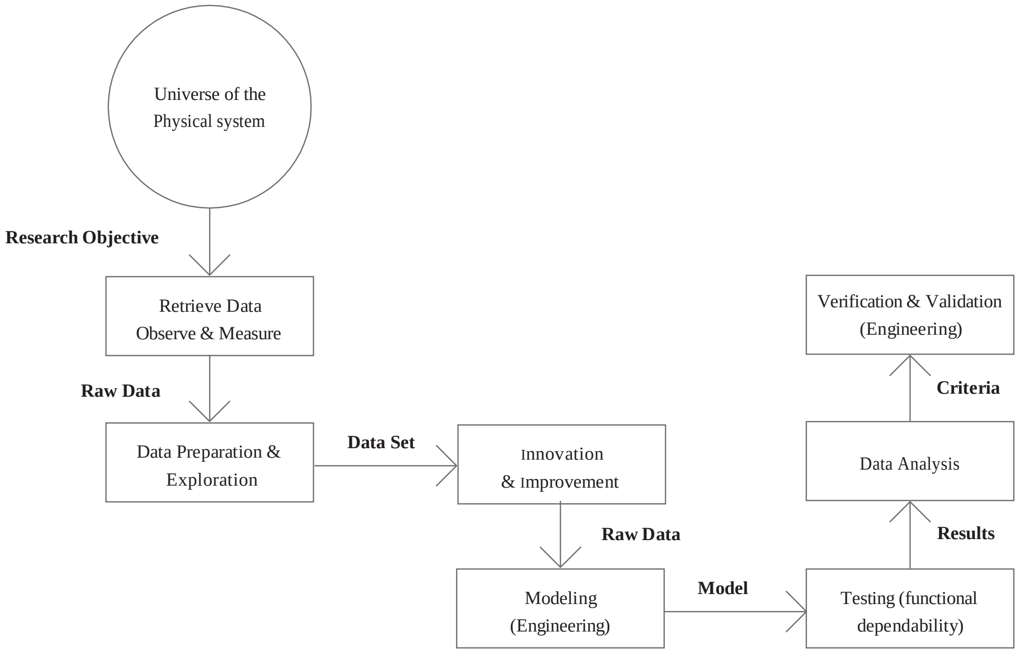


Figura 8. Models in engineering are verified and validated under different circumstances of another sort of model because of the character of 'new emerging' artifact.
Source: Prepared by the author.

Once known restrictions of the model are identified, the degree the model satisfies the expectations to change the world is to be assessed. The requirements are not declared in terms of the conformance to represent accurately the real world, but to the extent that the model may refer to a result that induces a change in the context where the final ‘engineering product’ of the research is to be integrated. If the change is minimal or is not economically viable (see Figure 9), there is a need to loop back to observe and measure what is needed to change.

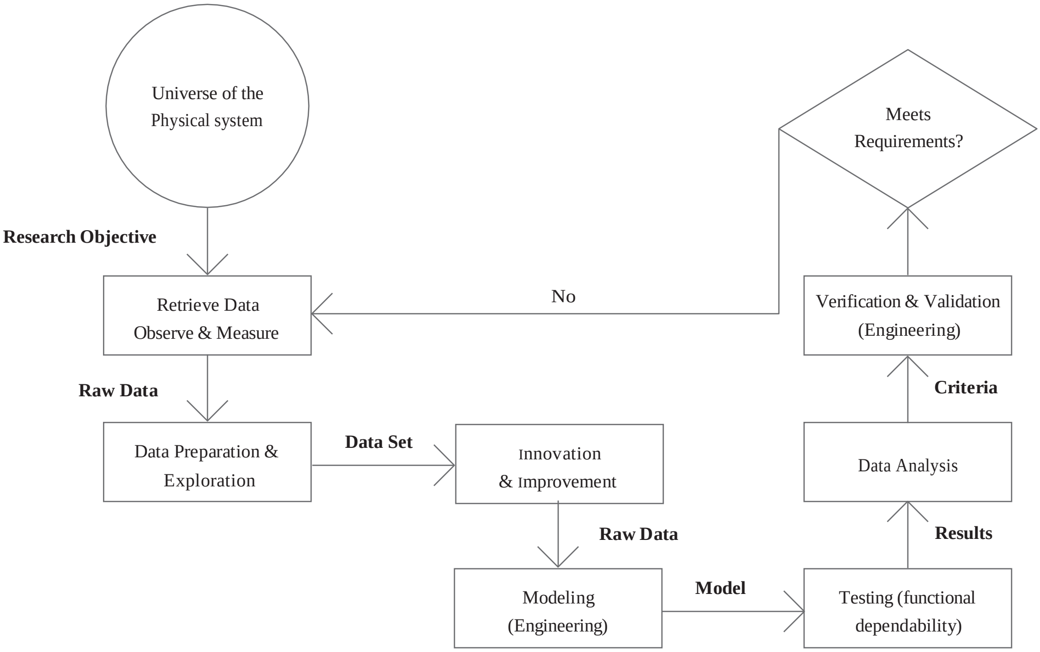


Figura 9. The engineering verification and validation process allow identifying the extent the model accomplishes expectations to change the world.
Source: Prepared by the author.

An alternate path, the desired path, maybe that there is a positive result of the validation process, in the sense previously specified. Again, the engineering model is not based on an eternal o absolute value system, the pretension of the model is not to be true. Engineers' priority is not to model something eternal or universal. In the engineering value system conformance to functionality has a higher priority than truth, eternity, or universality.

Since the model passed the assessment, proceeds the construction and deployment of the artifact o product. Ever, but especially since the second part of the twentieth century with the development of the rationality of the optimization, the production process is conducted if the budget for it is still/yet available.

The possibility to make an actual change in the real world depends on the construction or fabrication of the artifact that is supposed to transform, change, or adapt something real (see Figure 10) and that it is incorporated into the real world. In short, once in real-world terms, a change has occurred. That the world is somehow different after the artifact has been purposefully inserted or incorporated into it (see Figure 11).

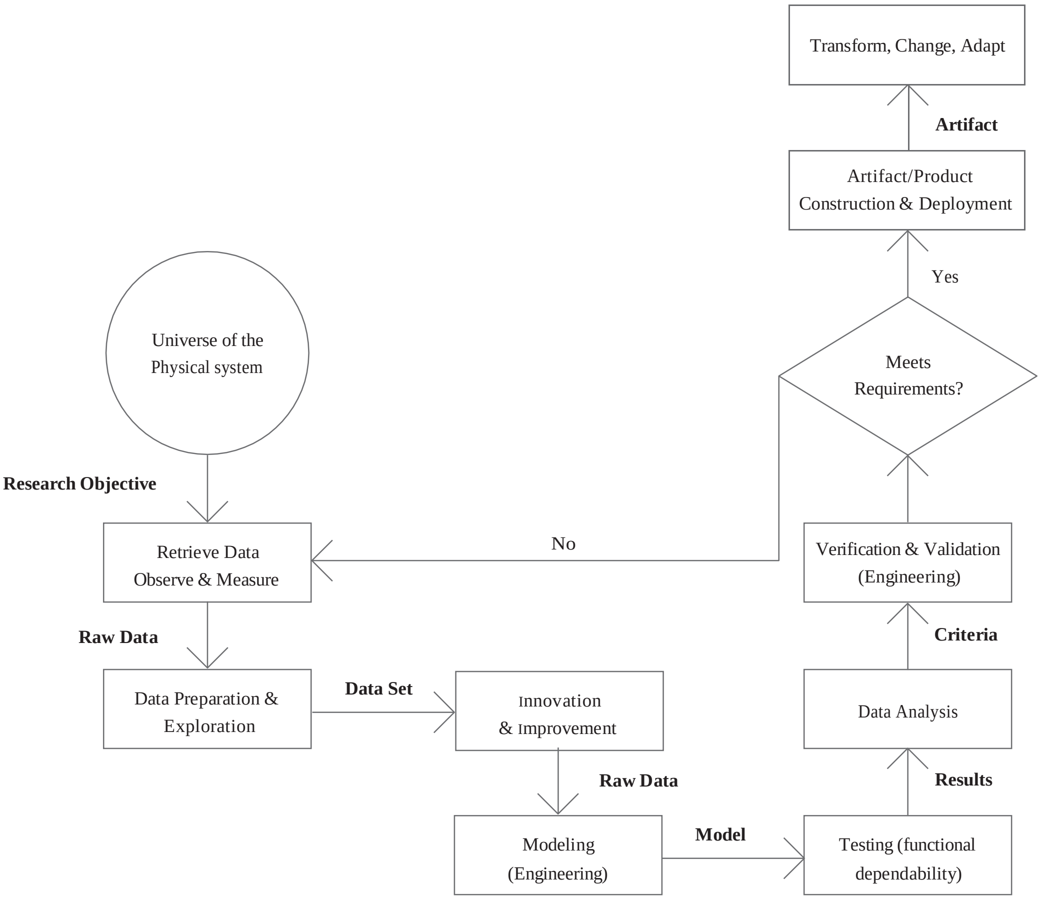


Figura 10. When the model has been approved in an engineering requirements assessment the process of construction and deployment of the artifact or product.
Source: Prepared by the author.

When the artifact has been incorporated into the world, it may be observed and measured, it changes in any way the universe and, in this sense, there appears a feedback loop of engineering consisting of deploying new artifacts, some replacing others or, simply, increasing the repertory of artifacts.

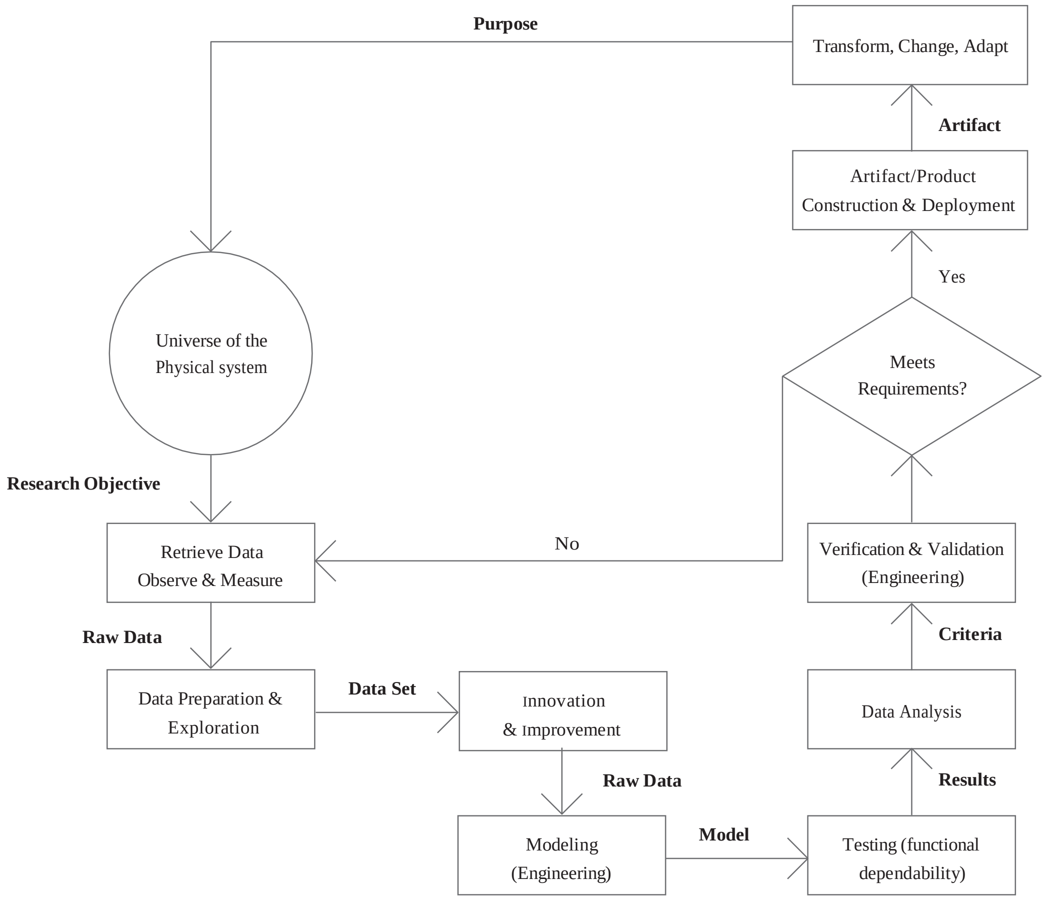


Figura 11. The complete feedback loop model of engineering research.
Source: Prepared by the author.

The scientific research process is governed obviously by the scientific method in any of the many representations. The many variants may look different but they agree in their epistemological framework: they intend to span the frontiers of knowledge: the knowledge of the world, the knowledge on how the universe behaves which serves to describe and increase our comprehension of the universe, which is certainly necessary, to predict the occurrence of phenomena such as the weather. The utility to predict is not a matter of controversy. Prediction serves to improve agricultural production, to maintain human beings' health, and, in general, to preserve humankind, which is certainly important.

Scientific research follows the process as engineering (see Figure 4) but differs in further steps (see Figure 12). After observing the universe, scientists ask questions to formulate a hypothesis. With this in mind, scientists model the studied phenomena. In their essence, models in science are different from models in engineering.

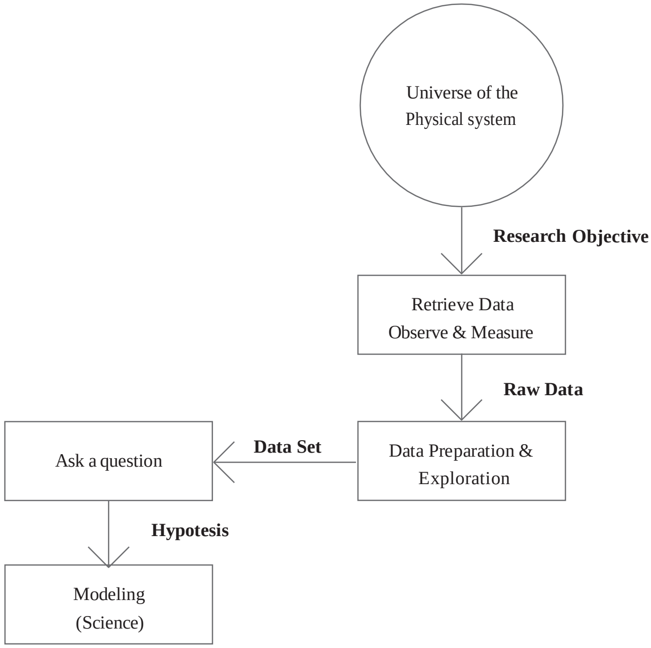


Figura 12. Scientific research shares the first steps in the engineering research process but differs in the process of formulation of a hypothesis.
Source: Prepared by the author.

With models constructed about real phenomena, on the base of observations, measuring data and other proved (this means that they are proved to be true) scientific theories, scientists assess the accuracy and precision of scientific models (see Figure 13) and depending on how accurate and precise they are, which is, in turn, studied by further steps in the research process by ‘comparing’ the hypothesis against the data that have been analyzed, decide to accept or reject the hypothesis (see Figure 14).

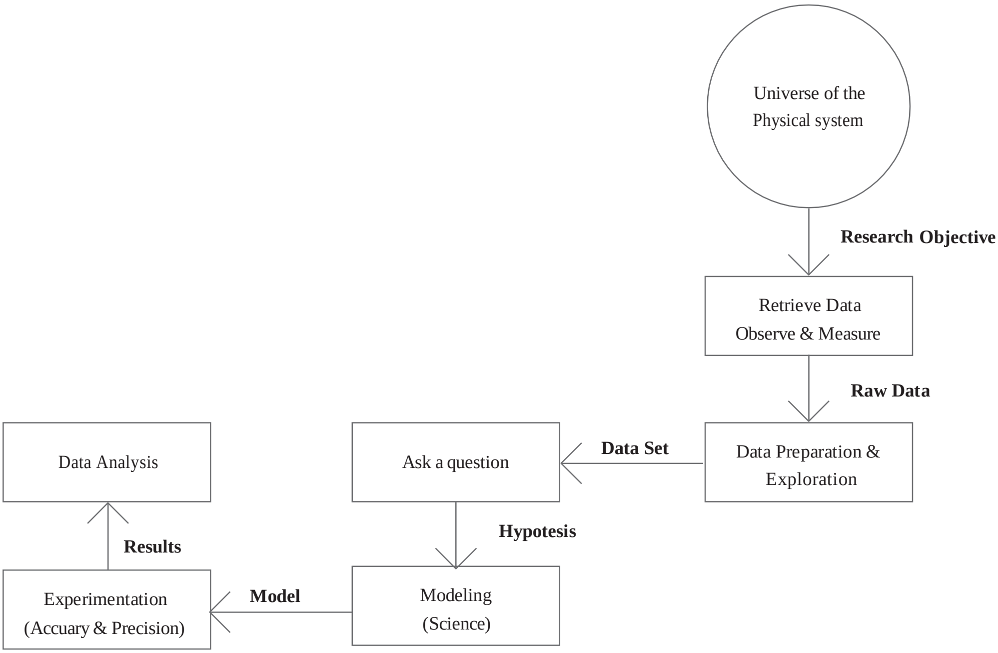


Figura 13. Scientific research models' priorities are accuracy and precision regarding the representation of real-world phenomena.
Source: Prepared by the author.

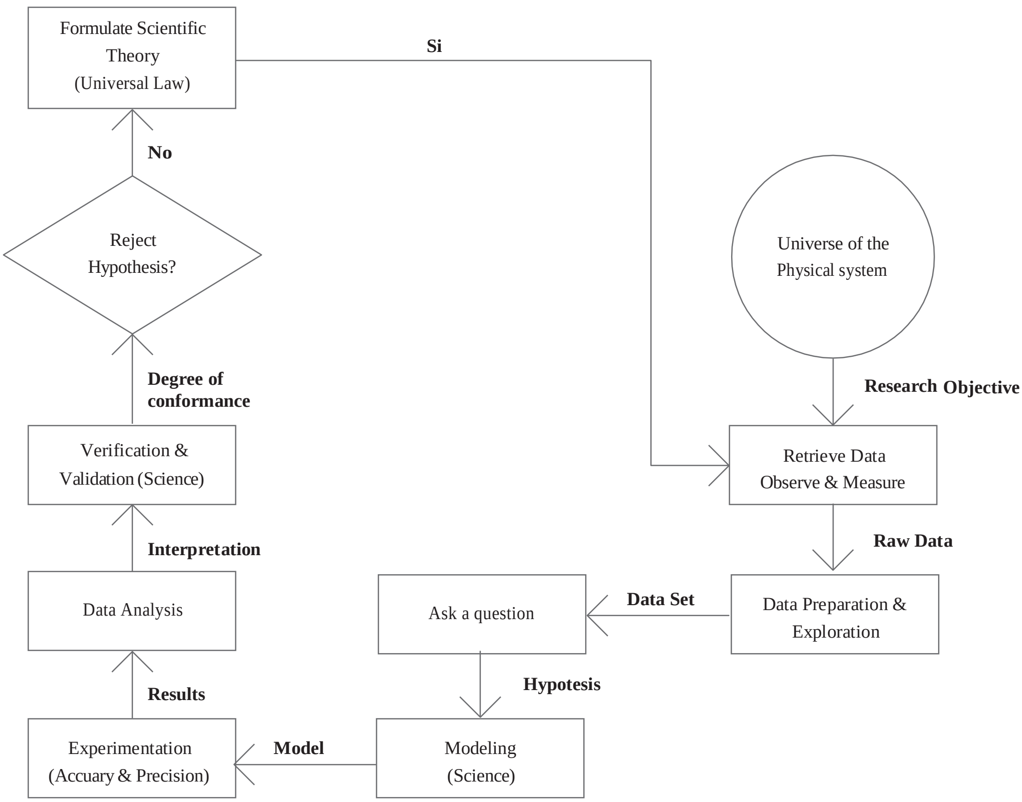


Figura 14. A decisive step in scientific research is to decide if the hypothesis is rejected or not. When the hypothesis is not rejected there exists a path to construct a scientific theory.
Source: Prepared by the author.

The rejection of the hypothesis moves scientists to the beginning of the process (see Figure 14), in a similar way as engineering research does when requirements regarding the expectations to change the world are not enough satisfied (see Figure 11).

When the hypothesis is accepted, a scientific theory may be formulated (see Figure 15).

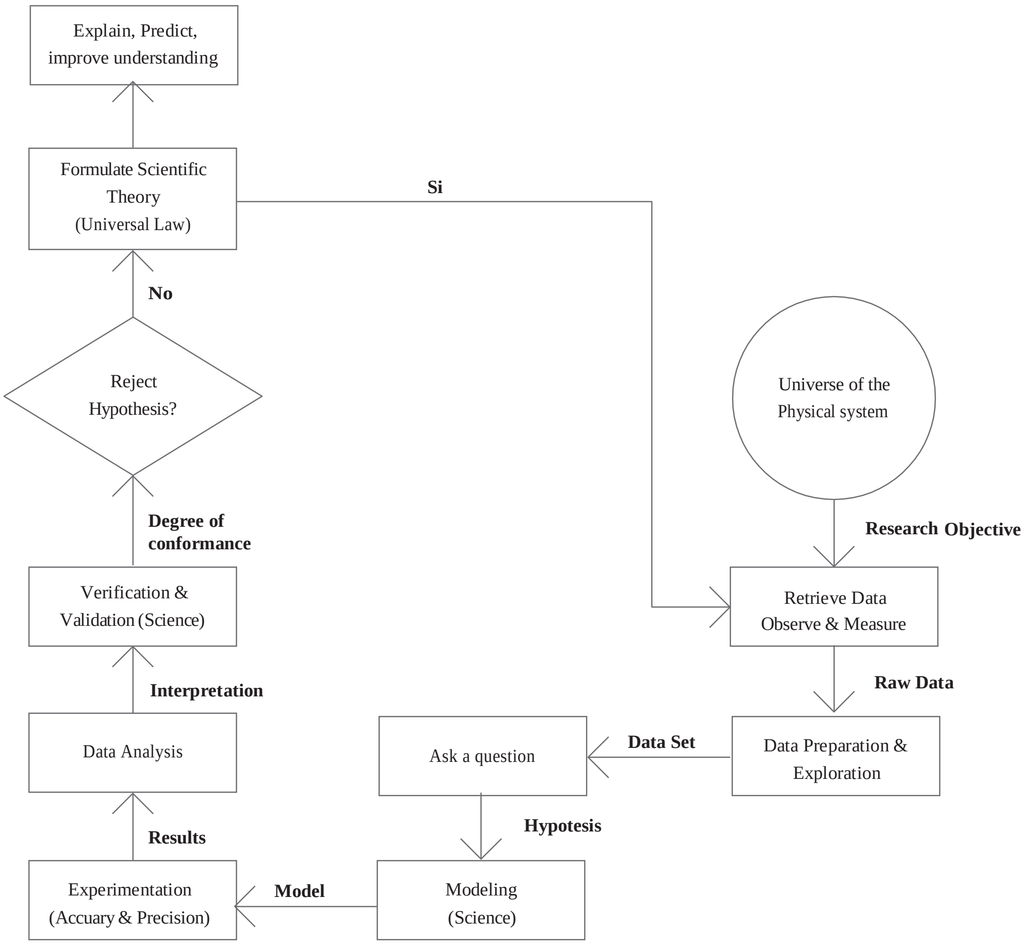


Figura 15. With a scientific theory, the scientific community has additional or corrected tools to explain and predict phenomena of the universe. In this way is said that knowledge in the repertory of humankind about the universe has increased.
Source: Prepared by the author.

This new scientific may invalidate some other —previous— scientific theories. But the new theory enables the scientific community with renewed tools to explain how real-world phenomena function and in some cases, the new theory provides means to predict the behavior of phenomena.

In summary, new knowledge in the form of scientific theories provides the scientific community with new means to improve understanding of the world. It should be noted in Figure 16 that the arrow from the box "Explain, Predict, improve understanding" points to the box in the diagram "Universe of the physical system". In effect, scientific theories predicate on the universe. However, it should be noticed

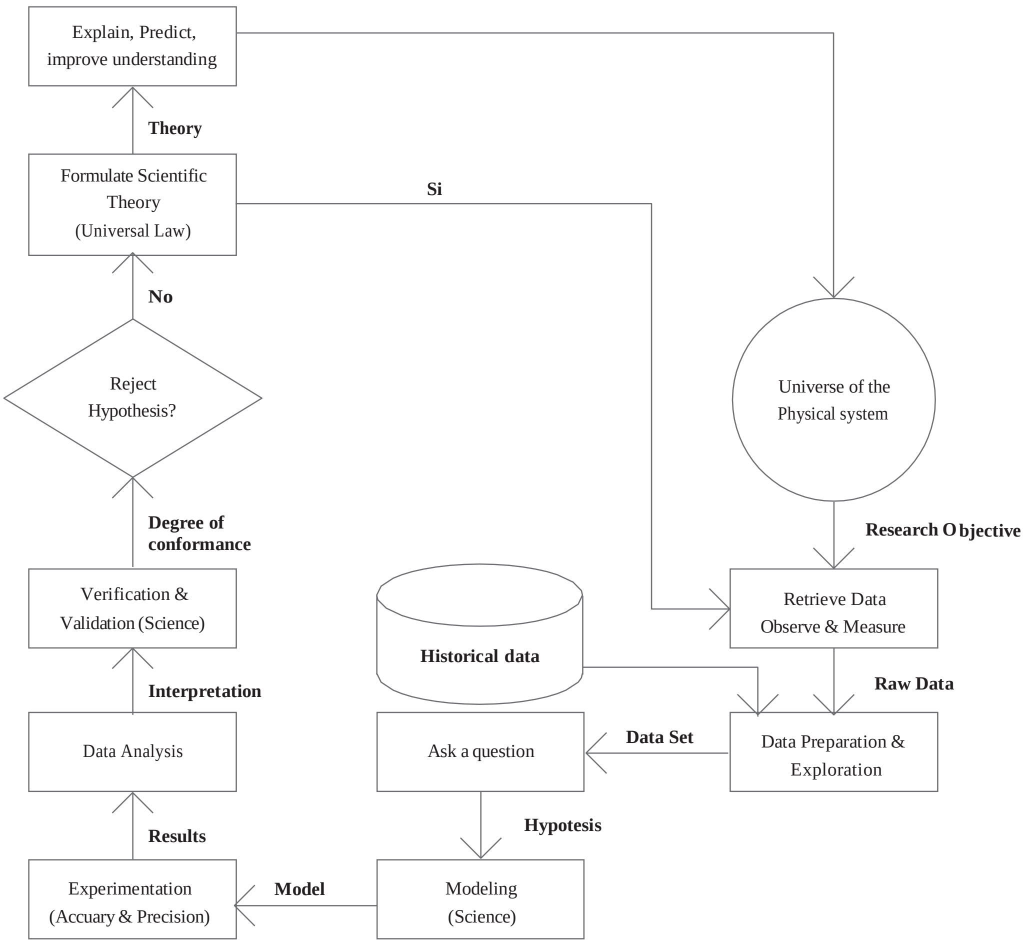
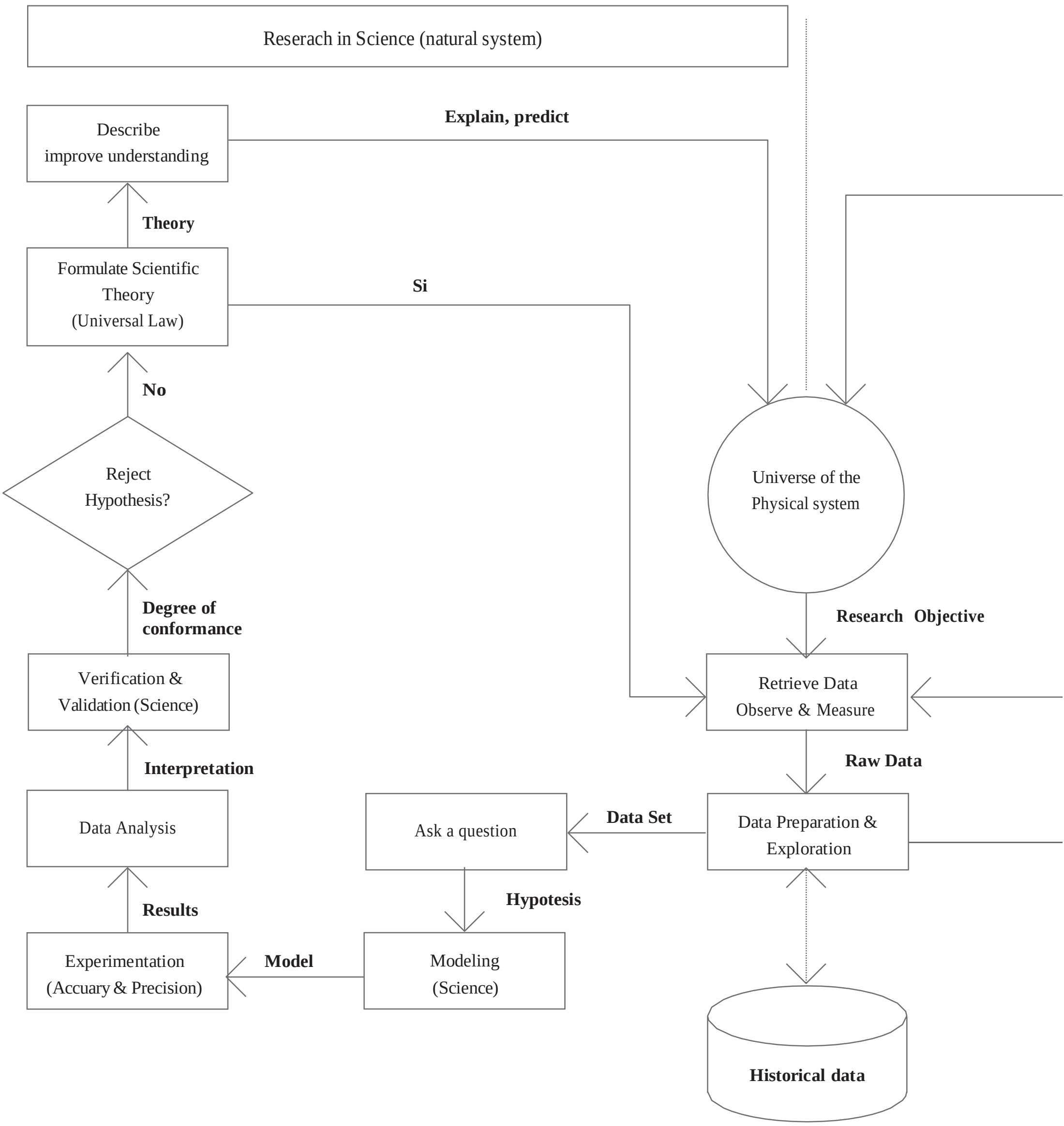


Figura 16. The process of the scientific method.
Source: Prepared by the author.

also, that the same arrow has no label. This means that scientific theories are not to be inserted into the real world, scientific theories are not incorporated into the real world, they explain the world but are not part of it, which is substantially different from the results in engineering research.



A comparison between the two research processes (see Figure 17) parallels their point of affinity but especially emphasizes their dissimilarities. Both concerns on the universe in different ways and have access, provided the authorizations, to the same historical data. Neither one is better than the other.

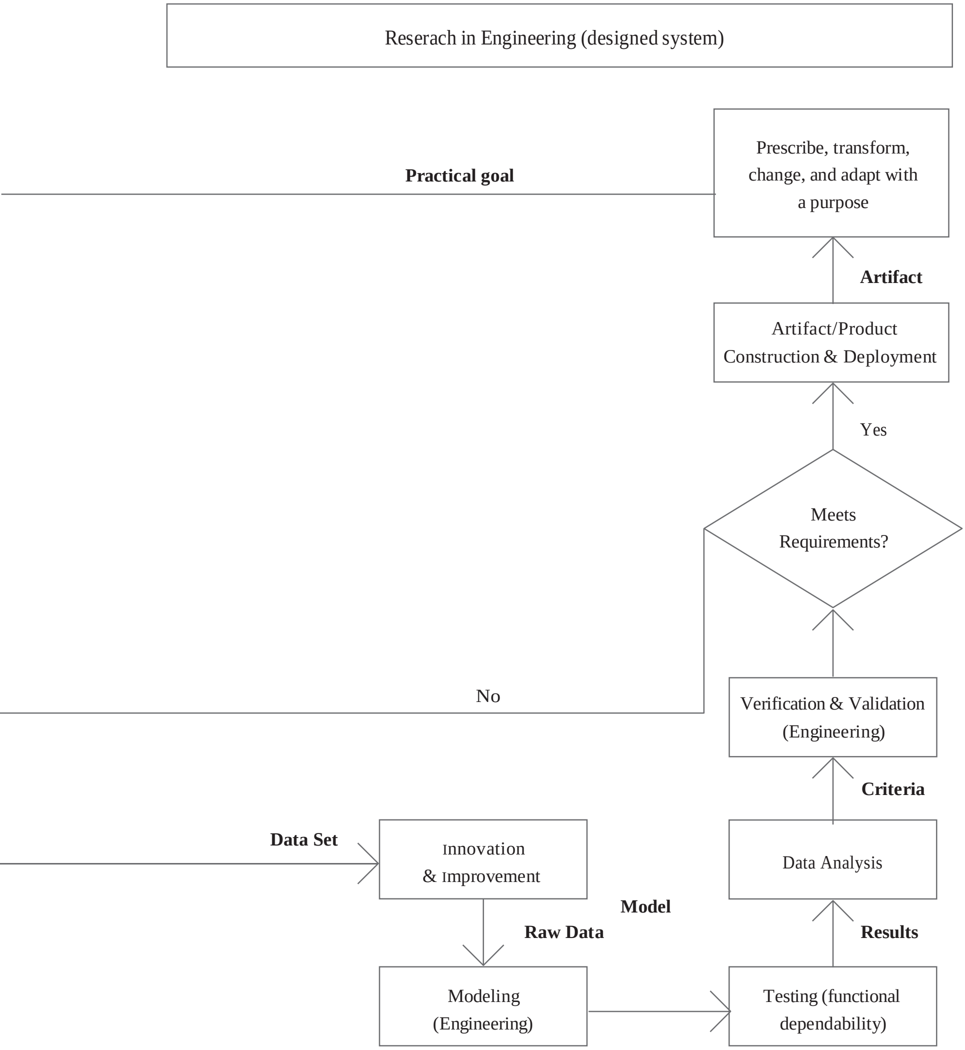


Figura 17. A comparison between the research process in science and engineering.
Source: Prepared by the author.

This is an independent comparison of the previous methodological comparison of the structures of scientific research and engineering design (Eekels & Roozenburg 1991).

Conclusion

A distinction between technique and technology has been introduced both in historical and epistemological terms. While technique is understood as a set of procedures, competencies, and skills to conduct actions oriented to get a specific result, and in that sense inherent but not exclusive to humankind, technology refers to a recent and wider concept to identify a conscious and systematic organization of a technique. In short, formally speaking, technology is not an artifact.

Philosophy of technology has been introduced since the last quarter of the nineteenth century in parallel to the "scientification" of technique as a strategy of late industrial capitalism to increase productivity in labor. This link to production processes derives a relationship to innovation and the economy of development in the twentieth century.

The epistemological prejudices of western philosophy regarding technique and technology, as well as misunderstandings emerging from political and economic interests of the United States of America during the cold war, lead to conceive engineering as applied science. However, the end of the cold war and the emergence of the systemic and complex thinking acted as driver and background to think of engineering as a specific body of knowledge as a technology but a specific kind of technology. The publication of "The empirical turn of Philosophy of Technology" (Mitcham, Kroes & Meijers 2000) in 1998 is one of many milestones in the new philosophy of engineering.

Philosophy of engineering comes to identify epistemological and ontological issues in Engineering, not just ethical ones, which next to specific publications such as "Engineering Philosophy" (Bucciarelli 2003) in 2003 and conferences and workshops since the first decade in the twenty-first century in Delft (Netherlands) as well in the Golden, Colorado (USA) in 2010, gave birth to philosophy of engineering.

Engineering is conceived as the purposeful and conscious processes and human actions to transform the real world. Engineering attends a different epistemological framework than science and uses different methods to produce new knowledge. This is comprehensible not just because of the differences in epistemological frameworks, but because of the differences in nature and aim of the results of research. Therefore, simply looking at engineering as applied science reduces humankind possibility to transform the world purposefully and consciously.

The main contributions of this research are a clear and contextualized distinction between technique, technology, science and engineering, and the introduction of a diagrammatic comparison and description of the differences and process similarities between research in science (scientific method) and research in engineering.

Further Research

There are many opportunities to continue the development of this research. At first, the development of ontological concepts and issues in engineering, which is a low explored field. Secondly, a further and detailed study of the engineering methods to produce new knowledge and, next to this, contribute strengthen concepts on what is engineering knowledge, the way it may be organized next to scientific knowledge to show that even engineering may apply some scientific knowledge, engineering is not the application of scientific knowledge, in the same manner as science may use some engineered artifacts but science is not engineering.

Acknowledgement

I very much appreciate the head of the Department of Humanities, Universidad El Bosque, Colombia, who played a decisive role in supporting the research on 'the differences between research in science and research in engineering' where this paper comes from. I'd also like to extend my gratitude to two anonymous reviewers for their invaluable suggestions to include and develop further ideas relating this research with previous academic documents.

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