Javier Aracil

Making It Useful Even When It Seems to Be Useless

"Man without technology, that is, without reaction upon his medium, is not man."

–José Ortega y Gasset, *Thoughts on Technology*

Technology has allowed us to produce a huge variety of artefacts, creating the artificial world in which most of us live longer and more comfortably than we otherwise would in untamed nature. In fact, nothing is more natural for man than to intervene and redirect nature for his own benefit. Our technological ingenuity and skills enable us to subdue nature and dominate the planet, at least in part, despite the many problems that this entails. For humans, using technology to create an artificial world is as natural as it is for predators to hunt and kill their prey. In this respect, technology is inherent to human beings: there would be no humankind without technology, nor would there be technology without sociability.

In this way, technology has played an essential role in the process of hominization: the transformation of the most evolved apes into human beings. We are direct descendants from those who carved the lithic products that date back to the first steps of genus *Homo* on Earth. These products were the result of exceptional mental faculties, unknown until then in the animal world, except for their subtle insinuation in the higher apes. These faculties allowed primitive hominids to transform what they found in their natural environment into useful tools through which they could extract certain benefits, such as food and shelter. With the help of these primitive skills, their offspring enjoyed an unparalleled success. Later, more speculative behavior gave rise to culture, which includes science, thereby leading to our modern world, along with our 7500 million congeners. Technology has provided the source of intrinsically liberating devices, even if a number of them have proved themselves to be lethal. All this is precisely what defines the technological endeavors that constitute the backbone of our civilization.

This leads to the core of technology: the most natural thing for mankind is to reshape the inhospitable and rough natural world to our advantage in order to create a more comfortable artificial environment, no matter how wonderful wild nature can be. We cannot reject technology because that would mean acting against our nature. The world has been denatured to subordinate our environment to our will. Although we can use technology in accordance with our needs and interests, we must not forget its potential collateral effects.

The Genus *Homo* and Technology

Humankind appeared about two million years ago as one of the products of the evolution of apes, with a brain endowed with mental faculties of a depth unknown to all the other animals. These faculties have led mankind to explore the natural world, and to strive to attain an easier life from it. In this way, humankind became different from everything that had ever populated the Earth, and it not only adapted to the natural world (as do all forms of life), but transformed its habitat progressively to make it more hospitable and comfortable for itself.

In our pursuit of tools to meet our needs, we have imagined and built things that do not occur spontaneously in nature. Thanks to our agile minds

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and hands, we have been able to endow our imagined artefacts with physical reality and we have developed the know-how that has given rise to technology in terms of the skills and knowledge that make up the things that populate the artificial world. Certain animal species are capable of making artefacts, such as birds creating nests and beavers building dams. However, these artefacts are almost always made in the same way, with little or no innovation, since their construction is genetically programmed into those species, while the ones we built result from creative imagination, thanks to the power of our mind added to our sociability. This last facilitates its propagation and use. Any artefact is fashioned first as a leap of imagination before crystallizing as an actual, useful object; this leap is often individual, but the execution, the improvement, and above all the transmission, need a collective substratum. The archaic artefacts of our hunter-gatherer ancestors began the amazing process of enlarging the natural world to build an artificial environment. On the other hand, the artefacts produced by technology provide persuasive proof of the power of our intelligence.

Humankind is primarily a user of the things that populate the world, whether they be natural or artificial. It manipulates them to fulfil its needs and appetites, and strives to take advantage of natural phenomena by redirecting them to its own ends. Hence, knowledge of the natural world contributes substantially, albeit indirectly, towards erecting the artificial world.

We have learned to take advantage of our knowledge of nature. However, there is a great distance between understanding how something works and using it for one's own benefit. Such is the work of engineers, who are mainly concerned with carrying out useful tasks, and undertaking challenges that humans meet in their quest for survival and well-being. This search for usefulness provides the focal activity of engineers.

Almost all the products of technology made in remote times were the result of the activity of individuals or small groups. However, for certain enigmatic purposes, these ancestral humans also built strange and wonderful megalithic monuments of amazing magnificence, whose construction required previous planning for their complex execution, headed by highly qualified leadership. The same skills were later needed to build the fabulous buildings and ships of the ancient civilizations. In the latter activities, it is possible to find the origins of engineers that transformed simple archaic technology into today's engineering, which constitutes the highest form of technology [1]. The marriage of technology and ingenuity spearheaded a radical change in the history of humankind. Their accelerated pace has contributed decisively to spectacular advances in the artificial world and we are therefore now enjoying the golden age of engineering.

Utility and Curiosity

Our mental faculties have led us to benefit from natural phenomena. From the origins of our species, these faculties have been applied to purely utilitarian goals, that is, the optimum use of whatever was available. Much later, similar intellectual faculties allowed us to answer questions regarding the variety of intriguing natural phenomena that occur in our environment. Curiosity led to inquiries that have found regular and predictable patterns in the observations of these phenomena. We have thereby deciphered many secrets of the wondrous world around us and stored valuable knowledge, not merely utilitarian, that over time, has led to what is known today as science (as well as to philosophy and other speculative ways of thinking).

The search for utility and the fulfilment of curiosity allow us to transform and understand the world. These two kinds of activities are intertwined in practice but, although they share the same tools, they have developed peculiar methods for their unequal goals over the years. Engineers seek utility as their main objective, while curiosity remains only a secondary concern. The exact opposite happens with scientists, whose top priority is to strive towards satisfying curiosity. It is worth remembering here not only the *dictum* of the aeronautical engineer Theodore von Kármán: "The scientist describes what is; the engineer creates what never was" [7], but also Herbert Simon's quote: "The engineer is concerned with how things *ought to* be in order to *attain goals*, and to *function*" [9].

Even when engineers handle tools similar to those of scientists, their efforts are not channelled towards ascertaining how nature works, but instead how to devise artefacts that are as useful as possible. Furthermore, their dissimilar goals modulate their methods and have given rise to distinct professions: engineers and scientists, each subject to their own and distinctive norms. In the professional activity of scientists and engineers, decisions are taken not only on the basis of scientific knowledge, but also on experience, trial and error, intuition, and even on random choice and personal whim, in varying proportions. Unequal objectives and priorities are characteristic of these two professions.

Digging Out the Useful Even from the Seemingly Useless

Science is a precise way of knowing about the world, driven by curiosity.

It delivers the body of knowledge regarding natural phenomena that scientists zealously cultivate. On the other hand, as has already been stated, the artefacts that make up the artificial world are created by intervening in the phenomena that occur in the natural world. The study of these phenomena constitutes a major goal for science. However, the conception of artefacts and the imagination and creativity used to conceive their designs, remains something peculiar to and distinctive of engineers. A writer on engineering, Admiral Edwin T. Layton, pointed out: "From the point of view of modern science, design is nothing, from the point of view of engineering, design is everything" [6].

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The artefacts made by engineers are built from natural things. The more that is known about the natural phenomena involved in an artefact, the better it is for its design. Notwithstanding, these devices do not result exclusively from the direct application of scientific knowledge in the strict sense that it provides everything needed for their design. The history of technology goes back to early antiquity, when science had yet to be brought into existence. In recent decades of spectacular scientific attainments, many assume that every slice of knowledge that is incorporated into an engineering project has been derived from science. However, on the contrary, the great technical innovations of the industrial era (the steam engine, aviation, electronics, computers, to name but a few) were born despite extreme shortages of scientific knowledge for the construction of these devices.

Nowadays, certain scholars tend to overestimate science at the expense of engineering, but engineering has its own distinctive features, not subordinated to science. Claiming that engineering is merely applied science assumes that the products of engineering arise without any creative contribution by engineers.

Engineers have stored a pool of knowledge regarding the problems they have had to tackle in each field of engineering. This specific knowledge has been labelled *engineering sciences*, despite the fact that this has been criticized as constituting a contradiction in terms, see Ronald Kline [5]. Nevertheless, engineers not only use science, but extend it, complement it, and modify it according to their specific needs. So they also carry out research on new knowledge, in spite of being restricted to the specific problems they face in their specialized fields. Moreover, they are judged, not for their contribution to new knowledge or for the quality of that incorporated into their achievements, but for the utility and efficiency of their products.

Engineers tend to adopt a global perspective of the problems on which they are working, since they must take into account all the factors involved in a particular device, and arrive at a synthesis that satisfies all the goals set for their performance. Pluralism forms an integral part of engineering methods: nothing should be discarded. In contrast, scientists strive to isolate an individual aspect of the phenomenon under study in order to clarify it in depth with their powerful and sophisticated tools.

Science Nourishes Engineering, but…

Scientists do not hold utility as their main objective. In fact, some scientists boast, at least initially, about the uselessness of their discoveries, and often add that utility does not matter in a first instance, since it will undoubtedly be found in the future. Traditionally it has been said among scientists that they seek pure knowledge; it is not unusual to find a number who say that they are searching for the truth. Although the search for usefulness has paved the way for the emergence of science, it has acquired a dimension in the world of thought that transcends utility. That is why utility has been held in disdain in certain erudite environments ever since the time of the ancient Greeks, especially following the philosopher Plato. Is this attitude now changing?

Science is born from the noble and incorruptible yearning for selfless knowledge by scientists. The fact that their contributions could be widely useful for applied purposes does not so much depend on scientists, but on those who are insightful enough to discover their utility. Obviously, knowledge that is not available cannot be used, but without the ingenuity to attain utility, any knowledge remains useless. It is worth mentioning Einstein's statement: imagination can go much further than knowledge.

Engineers resort to apparently useless science if they are sufficiently clever to make it useful for what they are doing, but that does not mean that their work is a simple derivation from scientific knowledge. On the contrary, it is the sagacity of the engineer that allows its application to solve specific, well-defined problems.

Some scientists try to marry basic research and application by attempting to find practical uses for the knowledge that they engender. In doing so, they postulate a confluence between searching for curiosity and for utility in the vast and fuzzy field of applications, and claim that both can be sought at the same time. Those who think in this way may be reminded of the Latin proverb *"Lepores duos insequens neutrum"* (He who chases two hares, catches neither). However, it is sometimes possible to fulfil both curiosity and utility by the same research, but at different times. Trying to satisfy both requires the adoption of procedures for successive and differentiated goals.

Certain scientists work as engineers, and vice versa. The transfer between these two professional groups is not usually difficult due to the in-depth training undertaken by both parties, but when exercising one activity or the other, goals and canons become radically different.

Feedback and Norbert Wiener

As an illustration with a specific example of that stated above, this section is devoted to the concept, widely known to engineers, of feedback, and to one of the names frequently associated with its study, Norbert Wiener. It is acknowledged that feedback is one of the great concepts that has emerged from modern engineering, and has extended further afield to be found in domains as diverse as the biological and social sciences.

Certain artefacts have exhibited feedback since the beginnings of civilization (the clepsydra, the windmill, and, more recently, the steam engine, among many others) and during the nineteenth century numerous studies were devoted to analyzing the stability problems of the steam engine. However, the systematic study of feedback systems did not began until the electrical engineer Harold Black (1898–1983) devised, in 1927, the humble electronic amplifier with negative feedback, which has since then transcended the specific application that motivated its initial creation. This amplifier was the result of the ingenuity of Black and his co-workers, who applied a rigor to the circuit comparable to that of scientists trying to unlock the fundamental secrets of nature. Moreover, the conception of the influential circuit was not grounded on a previous theory, but resulted from the outstanding creativity of an engineer while he was solving a specific problem and searching for utility.

The mathematician Norbert Wiener (1894–1964) joined the Massachusetts Institute of Technology in 1919, after a broad education that included a doctorate from Harvard at the age of 17. During the Second World War, while studying the control of anti-aircraft guns, he became involved with feedback, a concept that turned out to be crucial to him for the rest of his life. In collaboration with the engineer Julian Bigelow (1913–2003), Wiener proposed improvements to the effectiveness of these guns by using information regarding the past trajectory of the target aircraft in order to predict the future trajectory. To this end, he provided feedback with original and innovative stochastic treatment.

Despite the mathematical brilliance of Wiener's proposal, Bigelow soon realized that it would not work in practice, and the military administration that financed them rejected the proposal [2, 8]. A scientist, such as Wiener, may have a wonderful idea, but it takes an engineer with the appropriate background to estimate the practical relevance of an abstract theory. This is what happened to the engineer Bigelow and the mathematical solution proposed by Wiener, a mathematician who adopted the role of a scientist.

The actual solution to the problem differed from Wiener's. He had displayed a naive faith in an ideal analytical solution, as often happens with scientists who concentrate on internal aspects of their theories, the elegance of their formulations, and other considerations that deviate from the specifically practical goals of the study. This illustrates the complex relationship between theoretical approaches, typical of a mathematician, however sound they may appear, and the elusive practice of engineering, which is rarely based on a single theoretical framework. Scientific theories seldom fully cover the specialized problems of engineering; on the other hand, the science philosopher Karl Hempel proposed that this always occurs in science, see Hempel's covering law [3].

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Although Wiener failed to provide an operative solution to the problem of the anti-aircraft guns, he did achieve remarkable mathematical results for feedback systems, which had a great impact on the subsequent development of control engineering. In fact, in feedback control, Wiener found a fertile field to apply his skills as a theorizer. By applying mathematics to information and control, and in parallel with Andréi Kolmogórov (1903–1987), Wiener extended the rigor and precision of science to a domain that had hitherto been little explored with stochastic mathematical resources.

The case of Wiener refutes the putative dogma that science necessarily precedes modern technology and that the latter is the daughter of the former. According to this dogma, scientific genius (in the form of a mathematician in this case) generates original ideas for technology, leaving to adjuncts, usually engineers, the minor task of applying these ideas to make useful artefacts. This did not occur in the field of control feedback systems: rather, the opposite took place. The use of feedback to solve problems of automatic control was derived from previous engineering attainments and it triggered scientific and intellectual speculations of great relevance [4].

Feedback clearly illustrates the various contrasting priorities of engineers and scientists. Engineers sought utility when they incorporated feedback into their designs and the universal relevance of feedback was, for them, subsidiary. The mathematical theory developed by Wiener, although impractical in the specific case that originally inspired him, later found varied applications in engineering, in the hands of engineers.

Engineering and Science

It seems a contradiction that in our time of specialization and fervor for biological and cultural diversity, a movement in the opposite direction strives to dilute engineering in the vague *totum revolutum* called "science and technology." The weakening of identity is likely to be disastrous, both for engineering and for science, since it threatens to distort the distinctive characteristics of each player. It is not the same to be a good engineer as to be a good scientist; society neither demands nor expects the same from these professionals. Their separation is needed to meet the goals that defined them in the past and that will be demanded by society in the future. These different goals led to the traditional division of engineering and science degrees in universities worldwide.

In short, it can be stated that engineers conceive their innovations by employing *all* available knowledge (from the complex forms of production, to the most advanced knowledge of properties of natural things and of mathematical methods), and by adding their peculiar inventiveness and experience to imagine and make artifices in order to cover practical issues. It would be ridiculous to assume that engineers start from zero when carrying out each of their achievements. They design and produce using stored knowledge, wherein a scientific view usually occupies a prominent place. However, scientific knowledge most of the time is not sufficient. In the search for utility, it is always necessary to add the imaginative conception of something that previously did not exist. This rarely results directly from theoretical knowledge. Science can open new ways to engineering, but it is always engineers who have the last word in all the products with which they contribute to the manmade world. Although engineering in our time is filled with scientific knowledge, the specificity of the engineer's own mode of action remains undiluted. This is something engineers must never lose sight of.

In any case, engineers, searching for utility, are able to make useful seemingly useless scientific knowledge.

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Author Information

Javier Aracil is Professor Emeritus at the University of Seville, Spain. During his active working life he was a member of the Department of Systems and Control Engineering of the University of Seville. E-mail: jaracil@us.es.

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