The Contribution of History to Engineering Education

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Abstract *– This paper intends to bring out the experience of introducing a discipline of History of Science and Technology in an Undergraduate Course of Engineering and a proposal of transforming it so as to help future engineers deal with the challenges posed by the present moment of capitalism, usually called globalization. The discipline was lectured at the Department of Nautical Engineering in the Federal University of Rio de Janeiro between 1996 and 1997. The proposal is a product of some reflections that rose out from this experience.*

1) Introductory Comments

Before we get into the subject of this paper, I would like to make a few comments. It may sound strange to bring reflections from and about a discipline such as History to this Conference on Engineering Education, in a moment when the demands of a global market seem so oppressive to professionals whose job by definition pushes towards permanent competition. The wise attitude in this context, at least in which it concerns the undergraduate education given to future engineers, should point the other way round, in the direction of a more specialized approach to science and technology. Yet, I believe this is not the only possible direction. More than that, I am convinced that this is not necessarily the easiest nor the best way to achieve what we all expect here: prepare our students to deal with the enormous challenges they will have to face after University. If this paper is able to show why I have this opinion, and what exactly I mean by History applied to Engineering Education, then it will have reached its aim. One last comment: it is never useless to note that many professors and scholars in our universities share the same view, and although still isolated in one and another Engineering Departments, they are trying to put these ideas in action. Some of them have helped me with their criticism and suggestions, and I would like to say how much I am grateful to their contribution.

2) History applied to Engineering Education

This paper is the result of a short experience on teaching a discipline of History of Science in an undergraduate course of Nautical Engineering at The Federal University of Rio de Janeiro. In this sense, it will bring simultaneously a description of some initiatives that actually took place and a proposal of others that never have. Despite the name of the discipline and because of the loose nature of its pattern, it was divided in two parts, the first one properly dedicated to the History of Science and the second to the History of Technology. Briefly, it must be said that there has been a general and unfortunate asymmetry in the burden given to the History of Science and to the History of Technology, partly explained by the richer literature available for the former.[1] Although we shall come back to this issue, I would like to remark that I consider it essential to make an effort to reverse this bias, even if I was not able to do it utterly.

2.1) History of Science

The point of departure to shape the first half of the discipline were the many complaints from both students and teachers about the great difficulty faced by beginners to understand some basic scientific concepts from Physics. Because we were within a Nautical Engineering course, these concepts were mostly restricted to the domain of Mechanics, but obviously this should not be the case in a discipline lectured at the Electrical Engineering Department, for instance. The method devised to help students deal with those difficulties was a certain kind of historical perspective, bringing into light some objections raised at the time the concepts were first presented, as well as the arguments that scientists eventually used to support their ideas. Finally, the approach chosen was derived from the practice of social sciences undergraduate courses, with their specific techniques. We will see now each one of these topics with more details.

2.1.1) The Concepts

First, the concepts. I think it is not necessary to justify in this forum the choice of some concepts from Mechanics, such as force, motion, matter, space and time. Newton himself had pointed to their central role in his explanation of the world system, in the third book of Principia Mathematica. Nevertheless, he was the first one to admit that they were not at all easy to understand, not only because of the mathematics involved, but also because of the prejudices inherited both from the past and from common sense. Common sense, as the French historian Alexandre Koyré noted, is above all Aristotelian.[2] Although I do not totally agree with him, this statement was read as a clue to disclose the difficulty with which some students, even those who come from the best schools, leave the world of their day-by-day experience and enter the abstract world of Physics. Accordingly, one alternative to solve this problem was found in History, by making explicit different forms of intelligibility through the controversies they led to in Newton's time.

I do not intend to spend too much time giving examples, but maybe one or two could help. The modern concept of motion, for instance, which looks so obvious today. Motion, as defined by Newton, is the transportation of a body from one place to another, and of course it can be relative or absolute, depending on what we call the referential. In fact, a whole part of Mechanics is dedicated only to its study. But this definition is not at all obvious, and this is so much true that it was only presented almost two thousand years after the emergence of some of the greatest geniuses of humanity. We can find many reasons for that huge gap, including the most widespread – the darkness of religion –, and historians all over the world are still looking for more. But I am interested here in just pointing the definition of motion that was fully accepted until the seventeenth century when Newton and Galileo began to undermine it. Briefly, although it fitted some interests of the Catholic Church, not without ad-hoc adjustments, we owe this definition to the Greeks, particularly to Aristotle.

In his works, Aristotle tried to assemble knowledge on everything in the world. As a consequence, his Physics was strongly modeled on Biology, and that's why, for him, all natural motions also had a developmental and teleological character. In other words, when a stone moves, this movement should not be restricted to a displacement, because in the meanwhile the stone also transforms itself towards a definite end. In a certain sense, this process is similar to the change of the acorn into an oak, and it is possible to state that a stone gets more real when it approaches its proper place in the world, that is, the center of the earth.

We can always say that this view is simply ridiculous, and remember the fact that, despite of any superficial resemblance, a stone is not a nut, the latter being a living object but not the former. We shall talk about that in a moment. But first, I would like to bring here a critical distinction in Aristotelian thought, between natural motions, where objects are able to move in the direction of their proper place without the action of any external force, and what he called violent motions, where a force is required to move the object against its natural tendency.

This takes us to another basic concept in Physics: the concept of force. Surprisingly, here Newton was not as straightforward as we could have expected. According to his definition, force is any external action that makes a body not exactly move, but change its movement. But at the same time force is also the action that attracts a body to the center of the earth. As we can see, Newton was trying to demolish some distinctions established by Aristotle, like the distinction between natural and violent motions that we mentioned above, or between motions in Heavens and on Earth, and so place force at the core of all sorts of motions that can actually be found in the universe. A proof of his extraordinary talent is the fact that he has succeeded better than any other modern philosopher before him in explaining at least two issues never completely surpassed by Aristotle and his followers: the path of the arrow on earth and that of the planets in the sky. But this should not hide from us the looseness in his definition of force nor the blank in his so called "laws". Newton himself advised in his book that he was only interested in giving a mathematical notion of force, gravitational force in special, without considering its physical cause: "I feign no hypotheses", he proclaimed.

It is then no surprise that many students can hardly deal with the physical understanding of the symbols and formulas they manipulate. In the case of the modern concepts of motion and force, as we can see, they were meant to be above all geometrical and mathematical since their birth. Actually, the recognition of a superiority in mathematics was not new in the seventeenth century. It is a well known fact that modern philosophers in those years had turned to the Greeks to legitimate their practice, quoting Plato's dictum that "the world was written in mathematical letters". What was really new was their attempt to bring the precision of mathematics to the world of artifacts, and when we read Newton's words in the Introduction of Principia Mathematica, his awareness of the practical possibilities of Mechanics sounds amazing.

2.1.2) The Objections

But the praise for mathematics had other consequences, and raised many objections at that time. For instance, in the definition of motion first proposed by Galileo, although we may not be aware of the fact, there is a condition for it to happen. The space around the body that moves has to be absolutely infinite and void, just like the abstract space of geometry. Only in this kind of space can one conceive a movement as a translation, that is, a movement that does not affect the body, no matter where it goes, because only in the absolute infinite and void there is no center, no up, no down. We all know the resistance of Aristotelians against the notion of infinite, which is not at all until today a simple idea out of the world of geometry. The notion of void is not simple either. By now, the important thing to note is that those complexities can help us to understand why it is so intuitive for some students to answer that a heavier stone falls faster than a lighter one, even in a frictionless environment. We all live in a world where stones are passive objects, with no purpose in their movements, and educated people learn at school that stones fall only because they are subject to the same external force, named gravitation. But the very idea that each free fall is a unique movement, of a piece of matter to a center, is sometimes stronger than anything else.

For the people who lived in the seventeenth century, that mathematical conception of space had posed another kind of problem. I shall not mention here all the steps covered since Copernicus before our world could get rid of its physical borders. Instead, I prefer to remember the importance of Boyle's experiments with his air-pump, when he was able to show the possibility of existence in nature not exactly of an absolute void, but of an operative vaccum. Newton had referred to these experiments, and was grateful to the efforts of his colleague in the Royal Society. In fact, on the shoulders of Boyle and other giants like Galileo and Copernicus, Newton has been the first one to picture without hesitation an infinite and void universe, where earth and humanity should be nothing but dust. This was a challenge for Aristotelians, with their belief in a finite and earth-centered Cosmos. But it was also a challenge for some of the so-called modern philosophers, like many followers of Descartes, whose corpuscular theory was widely accepted in the Continent at that time. They argued that with his definition of gravitation as a force that could attract distant bodies through the void of the universe, with no consistent physical explanation, Newton was in fact reintroducing a sort of "active power" in non-living objects. For these mechanical philosophers, within their material account of all phenomena, the interaction of bodies without the mediation of anything was simply unintelligible.

In order to understand that kind of objection raised against the Newtonian concept of force implied in gravitational attraction, the American historian Steven Shapin, in a recent book, refers to the metaphor mostly used by modern philosophers in general, including both Boyle and Descartes, to describe nature in contrast with the traditional Aristotelian vision: the clock.[3] This artifact, a relative novelty in the seventeenth century, very popular indeed, was seen as a complex system that although inanimate, could perform the intentions it borrowed from its designer. Furthermore, the movement of its components had the advantage of being an example of uniformity and regularity. These characteristics made the clock completely intelligible and predictable, just like nature should be. God had created a machine-like world, so agreed the mechanical philosophers, and even if it was not yet possible to explain in a conclusive way a certain phenomenon, one should require no other resources than matter and motion to give an appropriate account of it.

2.2) History of Technology

This machine-like vision of nature was chosen as the point of departure for the second half of the discipline, dedicated to the History of Technology. Actually, there is a strong consensus among different contemporary authors that the seventeenth century scientific revolution represented a fundamental step in the extraordinary development of technology in Western societies, even if there still remains much divergence in defining which of its features has been the most decisive. In this sense, I would like to bring here some reflections about technology in modern societies that could be useful for engineering students. Our concern in this part of the discipline was the unawareness shown by some beginners about the main object of their professional choice, and our method, once again, was found in History.

2.2.1) The Origins of Technology

A conviction of the imperative of using knowledge to control nature was present very early in the seventeenth century, in Francis Bacon's works, and in the writings of many modern philosophers that followed him. Surprisingly for us today, it was often justified in a religious way, with the biblical idea that humanity had lost this power through the fall from grace in the Garden of Eden, and the belief that mechanical philosophy had been assigned the role of reversing this situation. Nevertheless, when those men prescribed that knowledge should be put under human mundane interests, they were simultaneously taking this responsibility from the Catholic Church, who claimed that monopoly until then, and leaving a door open for the aristocracy's and the kings' patronage. In fact, until his death, Galileo had financial support from the Medici family, who also contributed to the creation of the Accademia del Cimento, while the Royal Society, to which Newton was attached during his whole life, received some protection from the Stuarts.

Despite Bacon's initial optimism and all efforts they made, those early scientists did not offer much more than prestige to their patrons. In the seventeenth century, significant technical advances that could have demanded some knowledge of Mechanics took place in two domains, the military art and the maritime voyages. But these advances were produced by an increasing community of craftsmen. Anyway, the first important conclusion we can get from this is that on the one hand, since its very beginning there is no such thing as a "pure and disinterested science". Bacon, Galileo, Descartes, Newton, Pascal were all equally concerned with the uses of their theories. On the other hand, there can be a distance between scientists' rhetoric and its translation into reality. As we know, the emergence of a military and/or industrial scientific system is a nineteenth century accomplishment.

2.2.2) The Development of Technology

The impulse needed to put scientists' practical intentions into action was an economic one: the development of capitalism. I have already mentioned here that the literature in the History of Technology is not as rich as in the History of Science. It is time to add that the best literature available today focuses on an economic analysis, certainly reflecting the role of capitalist economic forces in the shaping of technology.[4] Accordingly, engineers, more than anyone else, are aware of the fact that any serious approach to the history of capitalism in the last two centuries, and specially in our century, has to deal with technological progress. Without losing this interdependence from view, I believe it would help to establish a few conceptual distinctions. One of our guides in this direction could be Marx himself, a rather old-fashioned author these days, but who was very sharp in understanding in all its depth the revolution going on around him, which we now know was only beginning.[5]

The first distinction brings us back to the seventeenth century, where the roots of scientific knowledge lay. In this sense, many historians had pointed to exactitude as the particular feature of mechanical philosophy that made the potential link between science and technology possible. As a consequence, in this kind of definition, technology was born definitely apart from the very similar technique (from the Greek *techné*). When read with economical letters, this difference takes us to the history of production through the development of capitalism, and the huge gap between a tool and a machine, manufacture and modern industry. In an industry, the tool operator is not a man anymore, as he was in manufacture, but a machine – just like in a clock the gears are responsible for moving the hands. Furthermore, a machine is a complex system able to simultaneously put in action many tools. The issue here is not at all the energy source, but the uniformity and the regularity with which goods can be made, since from this perspective, even the most skillful craftsman can never be compared with a so-called "self-acting" machine.

The second distinction is between the similar concepts of invention and innovation, and in this case some traditional historians have contributed to a misunderstanding, giving a scientific appearance to one of the most widespread myths in the history of technological progress. I am thinking of the lonely inventor, whose very existence is an oversimplification, with no correspondence in reality, even in the early nineteenth century. James Watt and Thomas Edison, for instance, had developed their projects in partnership with industrials, and were mainly worried about the economic viability of their inventions. One key word here is diffusion, and the number of inventions left neglected in patent offices all over the world can confirm its importance. Actually, there is an increasing attention among contemporary authors towards technological diffusion, sometimes through what is called the "threshold model", that is, the search for later improvements or environmental changes that could explain the adoption of a new technology. Another account of a successful technology was suggested by the American historian Thomas Hughes, through the concept of "reverse salient".[6] For him, who studied particularly the development of an electrical system in the United States, technological progress in modern societies has been above all the result of the concentrated efforts of scientists and engineers to overcome these inefficient or uneconomical components found in previous technologies. In Edison's famous words: "invention is 99 percent perspiration and 1 percent inspiration".

To assume that considerations about costs and profits play a decisive role in scientists' and engineers' choices does not imply that economics is the only factor in the direction of technological progress. In an already classical paper, Langdon Winner argued that artifacts are not neutral, as our common sense tells us today.[7] In fact, we know that a technology can cause welfare or damage, but we are convinced that these consequences are due to the people who decided about its uses, not to the objects in themselves. Nevertheless, Winner showed that sometimes technological innovations may be determined by political and social considerations in a flexible manner – for instance, the development of a new machine can either increase production or just weaken a strike, as Marx reminds us. But in other instances, technological innovations may have inherent political and social qualities, which cannot be easily changed in a different context. The well-known example he gives is the atom bomb, with its lethal properties, and, less obvious, the example of nuclear power plants, which can only be built within a strongly centralized political system. We could think of many others in the history of technology. The conclusion I would like to bring here is rather a paradox. Technologies shape society, today more than ever, in the military-industrial-scientific network we live in. But this does not mean technological determinism, that is, the belief that technological progress is the result of any sort of internal dynamics. And in this sense, the most important thing for future engineers is to be aware of their power when shaping new technologies.

3) Approaching the Engineering Students

There is one last comment I would like to make before ending this paper. I mentioned here that the approach for the History of Science and Technology should be derived from social sciences undergraduate courses. Now I would like to be more clear and at the same time justify myself. In social sciences in general, besides the professor's lectures, it is common to assign readings for students, in the specific case of History, both of secondary literature and of what we call primary sources, frequently followed by discussions in the classroom. Although within an Engineering course, a discipline of History of Science could keep that practice, adapted to its scope among the other disciplines of the program. In a very similar way to what happens in exact sciences, where learning means to be able to solve practical problems, in social sciences understanding means above all to become a critical participant in this world.

4) References

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