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What Technology Should We Use?

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ABSTRACT

Given the choice and the resources, most countries will choose to educate their labor force to take advantage of modern technology. Downgrading technology to match the degree of education found among the population of a country is not a desirable path to industrialization because it reinforces the under-development of the country's industry and its technological base. The path of education, however, is daunting as much as it is self-rewarding. It takes large economic resources to educate people, but even worst, it takes a long time.
It takes almost as much technological sophistication to buy technology that to develop it on your own. Thus, educating chemical engineers to simply run chemical plants, condemns these professionals to rely on the good will of the vendors to acquire modern technology.
In ideal settings, the role of universities will consist on preparing engineers to satisfy the needs of industry and to become a pressure focus for change. In addition, there is an obvious role of government institutions on fostering development and supporting education to attain a sustainable process of assimilation of technology for Latin American countries.

Keywords: Education, basic engineering.

1. INTRODUCTION

This paper is written from the perspective of an educator. I am not an economist, nor an industrial planner or manager. I taught chemical engineering for 35 years under different settings and, while I was a professor in my home country, Argentina, I participated on research and development activities for the chemical and nuclear industries.

The premise of this paper is that education of engineers and scientists must be aimed at the highest level. This sounds like a no-brainer. Yet in practice and in many cases not even by design, this is a visible goal.

I will explain first, what do I mean by the highest level. I could try to qualify and state instead: the highest possible level but this qualifier would only weaken my proposal. Second, I will explain why engineers educated at the highest possible level are important in the development of a country's industry and how they will become agents of change and help the country absorb the pains of globalization. In my talks with my bright colleagues from UAM-Ixtapalapa, I marveled at their attitude that chemical engineers had two professional functions: (1) the classic one of functioning productively in an industrial setting, and (2) being the agents of change in a society that abhors change. Their point of view was that few professionals were as well equipped as young engineers to fight for social justice. Their graduates were smart, respected, and they had an obligation to contribute to society both in terms of their normal professional activities but also in terms of their superior intellectual skills as applied to social and political problems.

2. Engineering curricula: the art of the possible.

In 1973, following the euphoria of the elections that installed, even briefly, president Campora in Argentina, the Dean of the Chemical Engineering School called a group of faculty to revise the chemical engineering curriculum. I was asked to be part of a rather heterogeneous group including faculty and students. To my surprise, the charge that we were given by the Dean was to define a model of country, then define the chemical engineer that was suitable for that country, and finally define what were the subjects that a chemical engineer with such characteristics will need to learn. I tried in vain to explain that the axiomatic method is good for teaching, but it does not work in defining a plan of study since there were already many givens that one could not ignore. Eventually, the committee without my participation, made a recommendation on a curriculum that was about 95 % identical with the existing one. Nobody worried about the incongruence that the model of country proposed by the Peronist Youth, was very different from the institutions existing in Argentina.

Looking back to the task, I have to admit that it was easier in 1973 to define what would be a generic chemical engineering curriculum that it would be today. The impact of biotechnology on our profession has been modest but the impact of biotechnology on teaching and research at universities has been huge and totally out of proportion with the applications. Although the changes in many cases has been cosmetic and mostly a change of the name of the department, by looking at the list of department names that include Biochemical, Biomolecular and Biomedical, one would conclude that a large percentage of our recent graduates are employed by a biotechnology-related industry, when it is really a small fraction. Most of our graduates, although not as many as 50 years ago, still work at the large petroleum and petrochemical industries.

I am not proposing that we roll back the changes that took place in chemical engineering departments, but in many cases, changes were dictated by faculty concerns and research interest rather than a demand from the marketplace. My own department has now two areas of concentration, one in Materials Engineering and the other in Biotechnology, where we use 13 credit hours, namely four courses and a laboratory to introduce students to basic material in one of these two areas. The obvious drawback is the fact that plans of study are finite and when you introduce something new you must make room by taking out something else. There are several (I am tempted to say many) chemical engineering programs that have eliminated process control, stage-wise process separations and most heat transfer applications. Very few chemical engineering departments require a course in linear algebra and close to none requires a course in partial differential equations.

Thus, we can certainly say that the introduction of biotechnology tracks has resulted in a weakening of the traditional chemical engineering curriculum. Whether or not this is a positive and justified change, we will not know for many years. But the largest casualty, in my understanding, has been the depth of mathematics and physics that can be used to teach the traditional chemical curriculum.

3. Rigorous approach to education.

Higher level of education simply follows the scientific method on its mathematical tools and logical rigor. The higher the level of the discipline being taught, the more organized its development on the basis of a few axiomatic principles. A high level of education is based on equations, not anecdotal information.

As a second-year student of chemical engineering in Santa Fe, Argentina, I was totally mesmerized when the old Italian professor of Physics II declared, as an introduction to his first class that most concepts of electricity and magnetism could be derived from the results of two experiments: Coulomb's measurement of attraction/repulsion between charges, resulting in Coulomb's Law, and the experiments of Biot and Savart and later Ampere that leads to Ampere's Law, although it should more properly be described as Biot's Law. The professor immediately explained that these "Laws" were really axioms, that is universal principles that could not be derived nor proved from higher principles. Experiments, he emphasized, were demonstrations of the axioms, not proofs.

There is a mistaken feeling that axioms are somehow related to matters that do not belong in a classroom. A colleague told me once that in a conversation with another professor at his university, while talking about the use of axioms in teaching the other person declared very seriously: "I would never use that word in a classroom". However axioms may have religious or non-scientific connotations but my Webster dictionary has three definitions that are applicable to our purpose:

1. A self-evident truth

2. A proposition assumed without proof for the sake of studying its consequences.

3. A universal principle which cannot be proved from a more general principle.

Similarly to electricity and magnetism, solid and fluid mechanics are based on few laws-axioms, just as thermodynamics and Euclidean geometry are based on a few axiomatic laws. One could say that the more organized and mature a scientific discipline, the more it can be reliably developed from a very small set of axioms. The scheme used to educate students in these disciplines is to present the axioms, explain in words the experiments that suggested the existence of such axiom, and then introduce a mathematical framework to represent in equations, the physical content of the axiom. For example, if we are teaching material balances, we introduce the axiom of conservation of mass:

Axiom of conservation of mass: The mass of a body is constant.

There are equivalent statements to this axiom, such as "mass cannot be created nor destroyed", but they all have the same mathematical statement:

(1)

There are a few primitives needed, such as the concept of density and body, and the fact that "constant" is translated into "not changing with time". Next, we introduce a purely kinematic result, the Reynolds Transport Theorem. Kinematics refers to the description of motion by purely mathematical terms. A kinematic result is valid regardless of the system under study because it just a mathematical identity. When we apply the Reynolds Transport Theorem to the mathematical expression of the axiom of conservation of mass, we get the more general expression:

(2)

where the integral now extends to a control volume that can be closed, i.e. the control volume is a body, or it can be open and moving or undergoing deformation and A is the closed surface surrounding our control volume. Since we can characterize mass fluxes as a function of the normal velocity of matter across the surrounding surface, a working expression for mass balance on an arbitrary control volume reduces to

(3)

where the surface integrals denote the flow of mass entering the control volume and the flow of mass leaving the control volume. Except for the kinematic extension from a body to a control volume, Eq. (3) contains exactly, no more and no less, the physical information contained in Eq. (1). We can use Eq. (3) to analyze batch processes, steady-state processes, and with some definitions, two dimensional systems.

A popular textbook introduces what should be the equivalent of Eq. (3), as follows:

(4)

In principle, any simple material balance could be solved on the basis of either one of the two expressions. We do not need to make a distinction between moving or deforming control volumes, because mass balances would be unaffected. One could easily justify writing the input and output terms as a function of volumetric flow rates, etc. The question then remains: Why use a rigorous approach to teaching material balances when we can get away with introducing an ad-hoc statement like Eq. (4).?

A short answer would be, paraphrasing Bertrand Russell: because shortcut statements have all the advantages (and connotations!) of cheating over honest toil! However, we can identify at least three important reasons in favor of the rigorous approach. First, using Eq. (4) is very restrictive because we not know the limitations of its use, the bounds that are contained in any assumptions made to develop it. We can use Eq. (4) in situations that are similar to the examples given in the text, but there is no way for us to really know if it can be applied to a material balance around a jet engine moving at 500 miles/hour. We cannot answer this question, because we have no information on how the equation was developed, what was the sequence of assumptions, how would these assumptions hold in a particular situation. Second, the process of learning by introducing a minimum number of laws and then building a set of applications on the basis of a mathematical framework is an important component of the process of education because it demands from the student an active participation in its development. In short, a rigorous, high-level of education develops your mathematical and logical skills at the same time that teaches the skills necessary to perform material balances. The third advantage of the axiomatic method is that you can simplify your basic set of equations to a very small number. My students in the Senior design look at me incredulous when I tell them that in order to understand any chemical engineering system they have to master the use of only three equations, (1) the macroscopic mass balance, (2) the macroscopic momentum balance, and (3) the macroscopic energy balance. Many students do not know for example that Bernouilli's equation can be derived from the momentum balance nor the difference between the macroscopic balances and equations of state.

By teaching shortcuts, we are depriving students from developing an important ability; to look at the essence of a concept, use mathematical tools to generalize the results and develop his/her own conclusions. However, the most damaging result of this approach to higher education is the assumption that concepts can be boiled down to a level where they can be learned without effort. The one in charge of thinking and deduction is not even the teaching faculty, is the person who wrote this simplified textbook. By following this approach we treat engineering students as if they are unable to think on their own. A demanding education develops intellectual discipline that could be transferred to many other activities, even if Eq. (3) could not.

Teaching at the highest level cannot be done without trade offs. The trade offs are rarely on the type of subjects or the amount of time that can be devoted to each subject, but on the amount of students that will be able to complete the course. If retention is a goal, teaching at the highest level is not the path.

4. Education, Research and Technology.

If students are used to learn by thinking and deduction and are accustomed to employ rigorous methods to develop the tools that they will subsequently use in the solution of problems, they can easily be prepared to do research. However, if the students learned most engineering subjects in a boiled-down simplified manner where the goal is to learn cookbook recipes to perform computations, before they are ready to do research, universities must put these students through graduate courses to teach them the mathematical tools and to develop the deduction skills that they should have learned at the undergraduate level.

But the effect of a watered down undergraduate education has some unexpected consequences. In developed countries with four year bachelor of engineering degrees, students are not expected to do research nor design new chemical processes. Graduate school will teach the mathematics and the rigorous approach to thinking and will eventually work on the development of the professionals that deal with innovation in industry, at the universities or in government labs. Research projects are sponsored by federal or state agencies and priority lines of research are either determined by government planning or by the pressure created by new research findings.

Less developed countries either do not have graduate programs in engineering or have only a few universities with graduate programs and not in all engineering disciplines. In a less developed country, the driving force to get a graduate degree in engineering is much smaller since it is possible to teach without a doctors degree. There is also a difference, between the more developed and the less developed countries, in the choice of research topics. Many research topics chosen by faculty is a continuation of research done during their own graduate study years or are designed to fill gaps in well-developed research areas. It is a rare occurrence to find out that research publications of universities from less developed countries, are cutting-edge subjects.

We could argue for ever about research, the role of research in developing countries, the need for an educated core of engineers that can carry research and development in industry as well as in government and universities. That is an unbounded problem and is not the purpose of this talk. The most important question, however, is who develops or buys the technology in less-developed countries, because the answer to this question is the key to development. If a multi-national company installs a plant in a less-developed country, its own engineers and scientists will decide on the type of technology, although one cannot assume that it will always be cutting-edge technology. Multi-nationals have been known for installing plants abroad that were already discarded or upgraded in their own country.

If a local private or government company buys technology for a less-developed country, it has to relay on their own engineers. If the engineers have been educated with little of no exposure to rigorous thinking, they may not be able to understand the details and consequences of the technology they are purchasing. I heard plant engineers boasting that their team was able to improve performance of a plant and as a result the plant was working at 120% of design production rates. Certainly it is very important and commendable to remove "bottlenecks" from an existing plant but in some cases the available capacity was built-in because the builders used existing equipment rather than a new one or a copy of an existing equipment rather than going through the task of designing a new one.

In the early 80's our R&D team working within INGAR a quasi-government institute in Santa Fe, Argentina, participated with a large Engineering & Construction firm of Buenos Aires in the bidding for the provision of ordered packing for a distillation tower in a petrochemical plant. The change from perforated plates to corrugated-type ordered packing was part of a revamp to improve capacity and the tower to be modified was a bottleneck to the rest of the process train. We suspected that the other bidding company has been working already with the engineers of the petrochemical plant and suggested the changes in design. However, it was obvious that none of the plant engineers knew how to evaluate the technical aspects of the offers and make a decision solely on a technical basis. Needless to say, choosing a foreign and well-known provider of technology got the local engineers of the hook.

The right technology can give you an edge in world markets but the wrong or obsolete technology can prevent you from reaching these markets. The question of developing your own technology may be an unreachable goal, but it should be clear that you must be technically competent even to buy technology in an open market. When INGAR produced the basic engineering plans for a small-production heavy water plant for the atomic energy commission of Argentina one of the engineers of a engineering firm confessed to us that he had never seen so much detail in the basic engineering of any of the plants his company bought previously. There is no need to give detailed information if you do not ask for it because you are incapable of analyzing it.

5. Conclusions and recommendations.

Conclusions are always welcomed, although I am not sure that I can sketch a conclusion, but I have one recommendation. Train your scientists and engineers with the most rigorous, scientific method. Teach them to think, to use physics, mathematics and biology in the development of engineering tools and scientific logic in their engineering design. Teach them to be unafraid of complex and difficult topics. In sum, teach them that there are not better nor worst than their counterparts in the more developed countries. The path to development is never a straight line nor it is an endeavor of guaranteed success. It is a long and difficult journey, but the education of our young scientists and engineers is certainly the first step.

Do not train your engineers to be the housekeepers of the plants installed by the multi-national companies in your country. Train them to be ready to question everything, even if it comes from the home-office and it is written in English. Give them a sense of pride for what they have learned was not a watered down version, but the "real" thing in all its complexity. They will be your agents for progress.

I spent the best years of my life in Argentina pursuing the dream of education as a vector for change, research as a way to master scientific principles and train students in rigorous thinking, and design and development to improve the standard of life of my country. I will never regret those years although I cannot say that the change that I was part, has persisted or was successful. I have been out of Argentina for over 20 years and I do not even have a clear picture of what is going on in my country of birth. In a recent international conference in Buenos Aires, I found out that the power reactor of Atucha II, bought before I left Argentina, was never started and is lying mothballed next to the oldest unit and to the heavy water plant that INGAR designed and was never completed. The industrial plant for the production of heavy water in Arroyito, Neuquen, was never completed. Nobody knew what happened nor what was the present state of the nuclear fuel re-processing plant near Eseiza and it was clear that the development of a uranium enrichment facility in Pilcaniyeu has been stalled. When I left Argentina in 1985 there was a Plan Nuclear, based on technology developed by Argentinean engineers and scientists. I have no idea what is left of it. Did Argentina go backwards in its development? Absolutely not! At least in chemical engineering, there is a number of good graduate programs and many of this programs are training some very bright students. Argentina will lose many who will emigrate more developed countries, but, even if it is a tortuous path, the movement is in the right direction.

I wish I could also give you a recipe on how to implement an educational system that will train students at the highest level. There are local conditions that cannot be ignored and the local conditions always determine the path that you could follow. However, even if you have one lonely professor teaching students intellectual discipline and challenging their intelligence, there will be students that would take the challenge and assimilate these ideas. These students would also follow many different paths, but they will always remember that they once took the challenge and won. If they were able to conquer a demanding course of studies in engineering and science, they can do anything they set their minds to do. The Conference Proceedings will be produced directly from the camera-ready manuscripts received from authors. Therefore the authors should try to produce their paper, as closely as possible to this model paper.

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