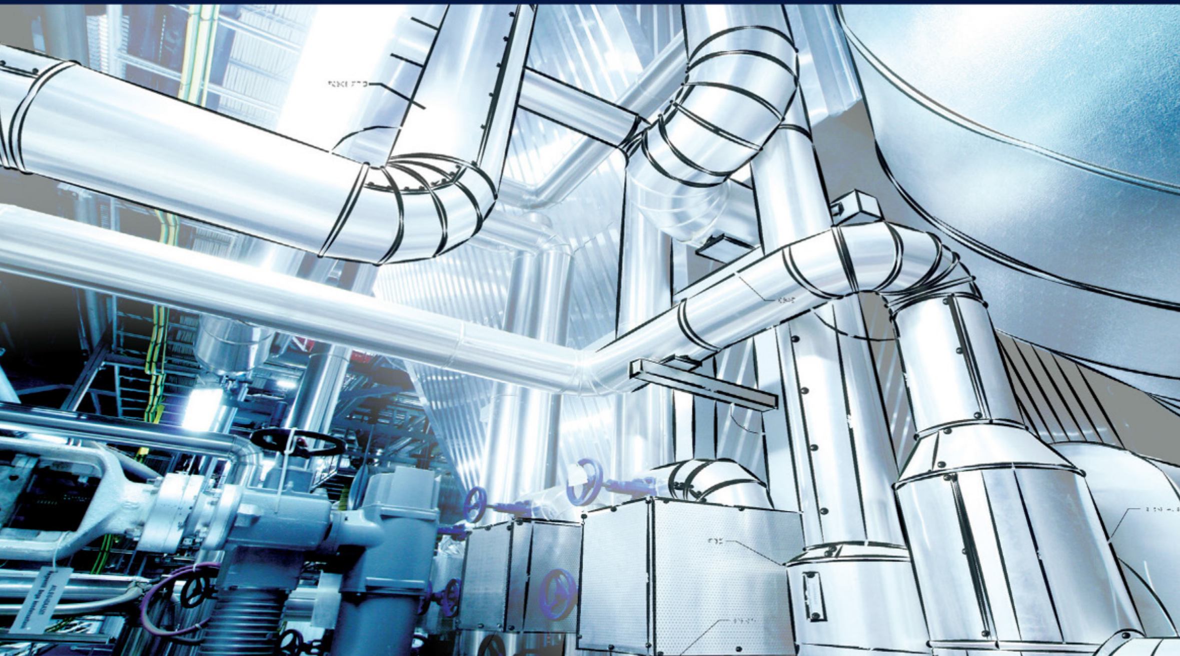
CHEMICAL ENGINEERING SERIES

Process Engineering Renewal 1

Background and Training

Éric Schaer and Jean-Claude André



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Jean-Charles Pomerol

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Contents

Foreword

This is a book that was eagerly awaited at a time when many manufacturing processes were being challenged in the name of the precautionary principle and/or ecology. Indeed, we have to move from a time when we manufactured without worrying too much about the quantity of raw materials, water or energy we used, to production that is economical and respectful of the environment.

To address this subject and make the shift to sustainable development in a timely manner, two process engineering specialists share their knowledge. Jean-Claude André – the pioneer of additive manufacturing, otherwise known as 3D printing – has followed all the developments in engineering research from the laboratory to the CNRS in Paris, for almost 50 years. Éric Schaer, a professor and researcher, is one of the members of the faculty and management of ENSIC (which largely hosts the LRGP – a joint research unit between the CNRS and the University of Lorraine – their home laboratory). Together, they share with us their vision of process engineering, and then help us to approach the future by mapping out highly relevant perspectives in both training and research.

The first volume of their book is devoted to a historical overview of the emergence of the discipline, from the chemical engineering of yesteryear to the process engineering of today. This retrospective is also a reasoned criticism of the *status quo*. Indeed, in view of the challenges facing our planet and the urgency of finally controlling development, it is time for process engineering to be renewed in its aims and in the development of new concepts. This volume is mainly devoted to training, it is an opportunity to advocate for more creativity, multidisciplinarity, and attentive listening to unconventional voices from the grassroots. This release of energies must not be stifled by adversarial risk management, which is unfortunately too often the case. This is an opportunity for our two authors to advocate for a liberated and liberating education and to provide good ideas to achieve this goal. They scan the history of process engineering education and even engineering science, as it was, as it is, and as it should be: much more multidisciplinary and/or interdisciplinary, and close to research. It is time to think about how to facilitate and develop lessons that encourage innovation and disruptive thinking; this first volume encourages us to do so.

Volume 2 is devoted, more specifically, to process engineering research and laboratories. Beyond this discipline, our two authors engage in a profound reflection on the nature of engineering research. What are the necessary qualities, what is the role of creativity, and how do we organize its teaching? The more general question of innovation and "disruption" is discussed at length, in connection with interdisciplinarity and the dynamic management of research units. The two authors, with the benefit of much experience, open up a number of new avenues. They show that what is lacking in innovative research, into the transformation of matter and energy, is the emergence of tectonic temporalities between traditional, quality research and creative processes (rather immaterial at first) for which disruptive phenomena may create (or may not create) enormous effects… as long as they are allowed to emerge and are supported (with support for risk-taking).

If, by creating differentiating factors, the disruption desired by Éric Schaer and Jean-Claude André is able to change current standards in process engineering research (which is necessary, if only to anticipate the industrial needs of tomorrow), Volume 3 deepens the debate. Indeed, many organisations have not yet understood that they will be subject to sabotage, unless, at a minimum, they "get on the bandwagon" with a renewed vision of the future and the goals (so it is not a question of pretending). However, the trained professionals have generally been taught on a stable and traditional basis; the same is true for most decision-makers, far removed from the reality on the ground, yet still committed to strategic and short-term planning. The planet is becoming increasingly complex, with shocks related to digital, high-tech, sustainable development, cultural diversity, globalization and the emergence in the West of new attitudes towards its own achievement (increasing individualism, distance from work, the value of the work in question, casualization of labor etc.). All of this happening in Europe, where the safe-haven States believe they are thinking about the place of citizens, who expect the means and solutions to be set in stone. Don't we have the right ingredients to be late to the party! This situation thus explains their desire to break away from perpetuated habits – a new form of inability – to take control of their future.

However we cannot think about "innovation" in process engineering without considering the future of the planet, the future shortage of certain raw materials and the economics of water and energy. Many pages are devoted to these absolutely crucial questions and several very relevant "for tomorrow" scenarios are developed and discussed.

All in all, in an extremely free style, both scholarly and sometimes impertinent, our two authors offer us, beyond process engineering, a profound reflection on the role of technology and engineering research in society. We cannot talk about research without mentioning the question of the difference between “functionalized” research – at best incremental – and breakthrough innovation, the need for which is becoming more and more apparent on a daily basis. This is why the first volume, devoted to training, the second to research, and the last chapter of Volume 3, to the profession of engineer and scenarios of the future, must absolutely be read and reflected upon.

If we add that the work of our authors is based on impressive scholarship, is enriched with numerous citations and is accompanied by a more than extensive Reference section, it is understandable that this book, in three complementary volumes, should be appreciated by all those who are interested in engineering sciences and their place in the future of our planet.

Jean-Charles POMEROL
President of the AGORANOV incubator
and of ISTE’s scientific council

Preface

Like most of those who study history, he [Napoleon III] learned from the mistakes of the past how to make new ones. (Taylor 1963)

Intuition for the writer is what experiment is for the learned, with the difference that in the case of the learned the work of the intelligence precedes and in the case of the writer it follows. That which we have not been forced to decipher, to clarify by our own personal effort, that which was made clear before, is not ours. Only that issues from ourselves which we ourselves extract from the darkness within ourselves and which is unknown to others. (Proust 2016)

The most beautiful thing we can experience is the mysterious. It is the source of all true art and science. (Einstein 2018)

To have to play for ten years to become a passable musician, what a miserable thing for man. (De Musset 2003)

Among all the techniques, there is a technique of discipline, and it cannot be satisfied with the old obedience obtained, worth as much as it is by empirical processes, and which should have been said to be less discipline than moderate indiscipline. The technique will at some point claim to train collaborators committed to its principle, that is, they will accept without unnecessary discussion its conception of order, of life, of its reasons for living. In a world dedicated to efficiency, to performance, does it not matter that every citizen, from birth, is dedicated to the same gods? The technique cannot be

> discussed, as the solutions it imposes are by definition the most practical. (Bernanos 2015)
>
> The creator is an archer who shoots in the dark. (Mahler 2018)
>
> Machinism depends on the goals that man gives it and therefore it must recognize that the machine – apparatus, regulations, state – is a means, not an end, in the service of a reality that surpasses it: the personal life of man. (Ellul 2017)
>
> All models are fake, some are useful. (Box, quoted by (Berthert 2018))
>
> Epistemologists call ‘disposition term’ a word that refers not to a property of a physical system that would be directly observable [...], but rather the disposition of a system to manifest such and such a reaction P° under specified circumstances P’. (Hempel 1956)
>
> We must therefore resolve, that the original of all great and lasting societies consisted not in the mutual good will men had towards each other, but in the mutual fear they had of each other. (Hobbes 2007)
>
> They [English intelligentsia] have also become infected with the inherently mechanistic Marxist notion that if you make the necessary technical advance the moral advance will follow of itself (Orwell 2017).
>
> The network, obviously, became tighter and more capacious with each technical improvement. (McNeill and McNeill 2003)
>
> Routine is the god of every social system. (Whitehead 1967)
>
> We have thrown overboard all conventions, our sole guiding principle is that of consequent logic; we are sailing without ethical ballast. (Koestler 1974)
>
> Morality is opposed to the formation of new and better morals: it stupefies. (Nietzsche 1911)

There’s nothing worse than the *status quo*!

“You have a promising sector here, don’t hesitate to get involved, you will be actors in these great transformations. You will have a job that is exciting. If you go into industry, it is a sector of almost full employment, with wages higher than the national average.” This is what the president of the IESF (*Ingénieurs et scientifiques de France*) said during the JNI (*20e Journées Nationales d’Infectiologie*) (Ventre 2019). Further, “The training of French engineers promotes the capacity for innovation and creativity, much more than other systems elsewhere in the world.” So then, why ask questions and write a book about major changes to be made? For the IESF, creativity does not seem to be the priority. Examining engineering training courses, including those in process engineering (see Appendix 1), reveals the lessons are essentially focused on needs related to the second industrial revolution – the fourth is explored in André (2019) – requiring operators capable of “demonstrating imitation, identical production in the era of mechanical reproduction. The adjoining programs focus on literacy and numeracy as basic skills” (Frau-Meigs 2019). Creativity that is often claimed, but ultimately poorly taught and poorly supported, is relegated to the rank of non-conformism.

However, Serieyx (2014) writes that we have “enormous and expensive education systems that are exhausting themselves in making more and more poorly filled heads, less and less prepared to face the uncertainty of time”. Between a structuring ideology, based on specialization and therefore on compartmentalization, designed to effectively manage stability, in a world that moves too fast in relation to possible incremental transformations, the resilience of the production system is necessarily questioned. What should we think of an organization (of which I am a member) that does not question the essence of its functioning, that is not really clear (in its words) on current and future problems, but that is justified (again with good reason in our country) by the development of a feeling of belonging to a conditioned, even dogmatized community?

At the same time, a country in a constrained situation like Israel has more agile and visibly more effective ways of creating startups (*Challenges* 2019) because the idea is to bring creations from laboratories to the industrial world *via* startups (see Technion in Haifa which has enabled the creation of 800 companies). If Israel has one startup for every 1,450 inhabitants, it is because behind it, there are choices, decisions and financing (4.5% of GDP) that allow this dynamic. Israel’s example is not unique. So, what should we do? In the field of processes, with fairly traditional technologies
in basic chemistry, can we be satisfied with a *status quo* or should we revise our copy? The challenge of this work is to try to position oneself in relation to this question.

Bauman (2006), Cohen (2012) and Serieyx (2014) describe a planet that involves more and more complexity with shocks linked to digital technology, the increase in cultural diversity, globalization and the emergence, in France, of new attitudes towards its own accomplishments (relationship to work, growing individualism, distance from work, the notion of the value of work questioned, casualization of labor, etc.), all in a context where the refuge state must think of the place of citizens who expect resources. Don't we have the right ingredients to be late to the party!

The liberal economy, supported by decision-makers in most developed countries, has introduced a stabilized, ideological framework, assimilated into rapid technological movements that do not adequately take into account major trends such as global warming, depleted reserves or social criteria. According to *The Beam* (2019), the environment appears to be an exogenous externality in most economic models. "The misconception arose at the dawn of the industrial revolution, a time when Western civilization first believed humankind, through the power of technology, could subdue the rough edges of the natural world."

The production systems of products, consumer goods and energy have undergone some historical revolutions, from artisanal methods and the direct use of what nature produced and not artificial stocks of coal and oil, to production optimized in terms of financial value, linked to the exploitation of the disposable principle. Engineering sciences have enabled such radical transformations by introducing rationality and efficient models. The process engineering that is included in this context is no exception to this observation. For years (and this is probably not the end), these sciences have enabled considerable technological advances that have obviously led to material well-being and life expectancy inconceivable two centuries ago. So, with the ever-present success of technology, why move away from its beliefs, which are shaped by an education that goes to the heart of the matter and is translated into application facts? But, without considering the value of exploring other possibilities, is there not a risk of sclerosing the actors of industrial production, engaged in forms of single thought?

Livio (2013), in his book, "Brilliant Blunders", reminds us of cognitive dissonance (Festinger 1957). When engineers receive external information through different media that is not compatible with their initial training, what do they do? What does their company do? In a form of mental storytelling, our cognitive system must build a coherent representation of its environment, which, for Berthet (2018) and Silver (2013), is a heuristic agreement between reality and what we perceive, with the consequence of what, in a reductive way, makes sense (illusion of validity). Livio (2013) writes:

> To relieve cognitive dissonance, in many cases, instead of acknowledging an error in judgment, people tend to reformulate their views in a new way that justifies their old opinions.

But when the system cracks, how can a *status quo be* maintained?

Can we easily use traditional training and proven scientific research in the field of matter and energy transformation to meet the needs of a new world; exploiting impoverished reserves, digital performance, the complexity or use of the powerful citizen of ecological behavior? Today's skills are fundamnetally beyond our understanding and our ability to fully integrate this near future. We are left to our own devices, especially if we respect the words of Von Förster and Piaget (2000):

> The environment does not send us any information, we are the ones who go after it. We are the ones who build them from our perceptions of phenomena. Our world tells us nothing, we are the ones who create questions and answers from our experiences in relation to the world.

After the Second World War, the establishment, of a national chemical engineering research activity – in France – in leading engineering schools resulted from the postdoctoral stay of a few young French researchers in the United States. The latter, supported in their mission by the national economic partners in a country under reconstruction, were able to create structured teams of international, scientific quality, with new training courses at the time, and which continue to bear fruit. However, the coexistence between traditional disciplinary components and engineering sciences has not been so simple; it fades as the notion of engineer becomes more blurred, but persists in some ideologies.

Today, chemical engineering, which has become process engineering, is defined on the basis of an approach – both scientific and technological – with synergies between disciplines that contribute to its development, openings to the industrial sector and openings to society. It has taken several decades to stabilize this scientific component, in a highly hierarchical national research system (and this achievement may not be totally sustainable) and in training courses, which, on the contrary, are (probably excessively) stabilized in a few well established engineering schools.

Traditionally, "Pasteur's Quadrant" (Stokes 1996) can be summarized in the table below.

	Scientific depth	**Consideration of possible applications**
Pursuit of fundamental principles	Pure basic research (I)	Use-inspired basic research (II)
Non-continuation of principles, but their use	–	"Pure applied" research aimed at achievements (III)

Table P.1. *Pasteur's Quadrant*

Should we not consider process engineering sciences as governed, both by the quest for the discovery of fundamental principles on the one hand and by systemic research that promotes the creation of economic and social value on the other? If this is the case, these sciences must have singular characteristics: openness for some, deepening for others.

In terms of scientific deepening, "bottom-up" research – a common approach within other scientific fields – can be at work. Yet, to allow the eventual emergence of technological solutions with a potential market, it is necessary to engage in reflection and prospective monitoring: in operational choices, in the mastery of applicable methods, etc. Time bases may not be quantifiable in a bottom-up deepening approach. On the other hand, it must be different in the context of problem-solving (top-down), based on systemic scientific tools and more stable knowledge.

There is therefore no possibility of presenting, without a significant scaling back, process engineering sciences as black or white, but rather as a specific culture of integrator, assembler, creator of in-depth scientific knowledge and original methods (system approach) of action, allowing within it, a confrontation and enrichment of ways of thinking and acting. It is therefore not only just about scientific technique, it is a matter of doing so in an economic and social context. We no longer build settlements against the inhabitants, we do it with them, which broadens the situation. The legitimacy of process engineering must be built de facto by the dynamic and recursive sharing of scientific knowledge for an end whose origin comes from the scientific component or that of the applicators, or from a request from decision-makers. It is a science of action: "It is a dynamic in progress [...] by its transformative, manipulative, constructivist power…" (Hottois 1992).

Undoubtedly, in light of these comments, we must try to begin to optimize process engineering around revisited foundations. For example, the era of fossil fuels and carbon chemistry that has led to technological advances (and this is probably not yet over) has introduced standardized forms of reasoning and the establishment of costly infrastructures that reinforce and shift cognitive dissonances to other fields. But where will we be tomorrow? In fact, in agreement with Raymond Boudon (2006), the mass capture of collective phenomena that transform disinterest, even rejection, into something accepted, or even desirable, are only the result of accumulated weak signals, of more or less individual origin. They are formatted as great ideas of the moment, a form of integration of common "values", by synchronizing emotions (Chazel 1974; Virilio 2010), sometimes based on verifiable data. Ideologies with their "fake-news" reign, placing technology in an ambiguous situation to meet new requirements. Virilio writes: "The great ecological fear combines these three types of pollution: pollution of substances, distances, and pollution of knowledge."

According to Matthew Hornsey (2019), a researcher at the University of Queensland in the USA:

> "We grew up in an era when it was just presumed that reason and evidence were the ways to understand important issues; not fear, vested interests, tradition or faith […] But the rise of climate skepticism and the anti-vaccination movement made us realize that these enlightenment values are under attack."

What is to be noted, however, in the increase in uncertainty is, paradoxically, the place of individuals who are increasingly separated from the collective, but who must integrate consistent thinking. It is undoubtedly for this reason that the communication industry is, for Jean-Claude Michéa (2008), the second largest item of expenditure in the world (after armaments). This situation leads Huxley (2016) to state: "But when applied to the problems of human society, the process of simplification is, inevitably, a process of restriction and regimentation, of diminution of freedom and denial of individual rights." Manipulation and propaganda are old methods as the world has shown in campaigns, especially digital campaigns, of strategic manipulation, with the intention of influencing political processes in the broad sense (EP 2019). Lobbying is at work.

Several scenarios are possible, and it is difficult to know which is the most credible (see, for example, the often-irrational debates between fossil fuels, nuclear and renewable energy on the one hand and energy consumption and transport on the other). To progress, there is not only the pressure that forces the movement, there is the need to take ownership of the issues in order to control them; and above all the organization of a collective imagination allowing innovation for engineering sciences in the broad sense and process engineering for this particular work, a certain promise of pleasure associated with the development of this imagination (and a certain assurance in the activity to be conducted). On this basis, we need to recharge our batteries to redefine, for a time, a new "nervous system" of the economy, essentially developed on a new culture and education to force us to leave our current comfort zones, perpetuated habits and therefore the status quo.

The success of the upcoming transition is likely to require integrated solutions that should reorganize economic activity in matter and energy transformation to maximize the strengths and minimize the weaknesses and tensions that are increasingly emerging. This will make more dopamine from the ventral tegmental area and the accumbens nucleus of the brain (Fiorino *et al*. 1997) of process engineering (PE) researchers and trainers for their happiness (and if possible, that of society and the planet). Moreover, Einstein, quoted by Bernstein (1991), wrote: “Never regard study as a duty but as an enviable opportunity to learn to know the liberating influence of beauty in the realm of the spirit for your own personal joy and to the profit of the community to which your later works belong.”

However, in principle, in the field of process engineering, as in other engineering disciplines, great scientific adventures should increasingly escape normality, the “all foreseeable”. Indeed, recent developments have revealed numerous and complex couplings between systems, going well beyond the disciplines. For researchers in the field, there is undoubtedly a need to “look outside” their discipline, which should be reflected in educational actions. “Interdisciplinarity seems to be the order of the day. Though some people worry that the dilution of specialization may lead to a decline in the standards of intellectual rigor, the insights that one field of thought can bring to another cannot be ignored” (Sokal and Brichmont 1998).

A central paradox of process engineering is the diversity that lies behind an apparent unity or at least a proposed coherence, a real portmanteau term. If we take, for example, a leading review in the field such as AIChE J (*American Institute of Chemical Engineering Journal*), it is possible to highlight the diversity of the field, with in-depth articles and original boundary objects that exploit stabilized know-how in process engineering. When trying to compare scientific articles with each other, it is not always easy to consider them as strictly belonging to the same scientific field. Moreover, the lack of consensus on the part of the scientific world on a definition of PE and the irreducible diversity of practices covered by this engineering science, which is a little over a century old in the USA and the United Kingdom, are symptoms of its particular epistemological status. And this is both the demonstration of a strength, inclusion in a community of thought, and at the same time a weakness by transfer (another form of delegation) to current objects that need the support of PE knowledge. This breadth is essential, because of the opportunities it allows, with the chance of becoming a science that serves social areas with greater potential. But the field of process engineering undoubtedly needs scientific and technical controversies and new enigmas to stimulate its imagination in order to evolve; the rich vascularization between its private preserve and its natural partners (and sometimes complicated in relationships) is an asset for its healing. This situation is in fact a considerable asset when one considers the difficulty of inventing such collective spaces in interdisciplinary operations. These links, with the associated boundary objects, will therefore be logically mentioned in the book.

NOTE.– While in English, the term Chemical Engineering is used preferentially, in France, initially the term Chemical Engineering was used, then some proposed the term Process Engineering, probably to better distance themselves from chemistry?

In the text, process engineering and its abbreviation PE are generally used by convention.

"But since the object has been decomposed and its constituent elements distributed and hierarchized by, and because of these intellectual constructions that are the disciplines, the question then arises of the subsequent convocation of those portions of the object which, at first, were not considered naturally suitable to constitute the subject of scientific investigation" (Alvarez-Pereyre 2003). Thus, in order to avoid confining the researcher and/or teacher-researcher to his or her discipline, in which he or she exercises freedom (autonomy) and activity that allows him or her to go beyond the limits of knowledge, it is probably necessary to find ways of "transgressing" that must authorize and support new cultural couplings that combine divergence and creativity. These must allow the promotion of appropriate synergies, allowing the creation of new concepts or artefacts that are useful to society. This is what the (happy?) idea of coupling science and technology expresses. By supporting creativity at the interfaces, by developing creative hybridization, it is therefore a question of going beyond other frontiers of knowledge, but undoubtedly on the basis of new or revised methods, by placing "research and researchers in the context of the life of the city" (Pompidou 2004). This view is supported by Araujo-Jorge's (2001) position, which emphasizes that it is now necessary to "integrate the knowledge acquired at a higher level to understand the global functioning of nature in order to truly understand its complexity". However, if these visions are supported by most scientists, in reality, the situation is less simple.

Thus, from these various comments emerge a set of questions allowing a better understanding of how a research unit in process engineering, how a school of engineering specialized in process engineering, positions itself in the academic world in relation to society and companies in the field. But, in addition, the world is moving around us, which implies a reflection on a certain internal dynamic of changes in terms of concepts, value creation and applications. The prospective, presented in a reductive way in this book, will also help us to consider these possible changes.

This positive vision with voluntary resourcing, as we know, will compete with conservatism, which requires less energy and effort than the search for the new social utility which breaks with certain forms of social blindness (Kerven 2007; Simone 2012), especially if we follow René Descartes (2018) with comfortable inertia: "Reason wants us to choose the path that is usually the most secure." These conservatisms, or these barriers to change from various origins, on the part of principals, scientists (Barreau 2007) or pedagogues, sometimes from those who demand it (but rather for others), have led the authors to sometimes, but voluntarily, take large leaps rather than the conventional small steps. So how did we get to the writing of this book?

First of all, the two authors come from (but not at the same time) the same engineering school. However, this initial common culture does not correspond to a desire to belong to a community, nor to a desire to exist separately. We have remained free of our convictions, of our dreams for their implementation with our knowledge and our vision of the physical and intellectual means that seem to us to be at our disposal. The freedom claimed by everyone, for everyone, has obviously not prevented exchanges or debates – debates that are merged into this co-authored material.

Rather, I am engaged in research on light-matter interactions (including additive manufacturing (André 2018, 2019) and, in this context, nothing predestined me to write about process engineering that is just familiar to me. But, with a long career (begun in 1966), following the initial (conservative) path was not always envisioned, which has led to detours towards research management (in engineering sciences at the CNRS or in the private sector as scientific director of an insurance company, involved in occupational risk prevention) and finally to a return to (engineering) science. In this journey, it is possible to examine needs, ways of thinking, the need for teleological approaches, the difficulties of successfully implementing interdisciplinarity in innovation, etc. In all these areas of uncertainty, reality (at least the perceived one) is complex and effective solutions for one time are simplistic, considered effective, but only for a while. As Sevilla (2000) writes, this is the temporary victory of the fleeting over the permanent, more or less unattainable, especially if, independently of regulation (or the anticipation of its evolutions), the "socially correct" monitors us. Should we then be satisfied with the least bad proposals possible?

Back at the CNRS in Nancy, my office is almost opposite that of Éric Schaer, Director of Studies at the ENSIC (as he was at the time), a true specialist in process engineering, as a young man and, apart from his basic research in PE – see his thesis (Schaer 1997) – concerned with pedagogy and moreover involved in a European network called Iteach[1] (under the responsibility of Professor Jarka Glassey from the University of Newcastle – Glassey *et al.* 2016). The goal is to develop a framework that will support the evaluation of teaching effectiveness not only in terms of basic knowledge of chemical and process engineering but also in terms of basic employability skills in a range of geographical and educational contexts. This framework for activity is summarized in the figure below from Glassey *et al.* (2016).

1 http://sup.univ-lorraine.fr/files/2017/02/iTeach.pdf and www.iteach-chemeng.eu.

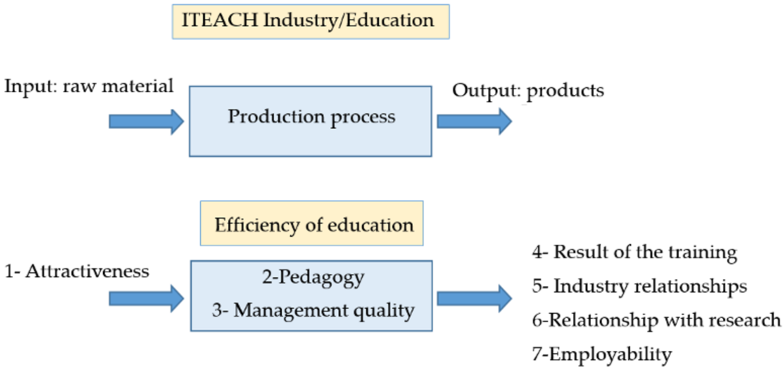

Figure P.1. *Iteach's framework of activities*

In our friendly relations, Eric tells me of his strong involvement in this European comparison operation based on a measurable existing one, and associates myself with it. So, when we started playing together, we started making a common dopamine, when one is a specialist in process engineering pedagogy, the other more involved in disruption and a holistic vision based on foresight, we had to succeed in transforming discussions, desires for change into a written document; here it is.

In fact, we are ambitious for the field in the hope that, in our modest skills and at our low level, we can contribute our little bit to process engineering (which deserves it) by trying to follow, under the same conditions, these words by Gaston Bachelard (2007):

> Reality is never what you might believe, but it is always what you should have thought. Empirical thinking is clear, after the fact, when the apparatus of reason has been put to the test. By looking back at a past of mistakes, we find the truth in true intellectual repentance. In fact, we know against previous knowledge, by destroying mistaken knowledge.

But for the authors, there is, in any case, no desire to seek to separate or even oppose process engineering from scientific activities that are essentially cognitive, theoretical, symbolic and observational of the world. On the contrary, in current scientific developments, several cultures and visions can and should coexist and enrich each other. This is one of the aims of this book, which is also based on Callon's (1998) reflection:

> The infinite frontier of basic research, funded as an end in itself and with the distant expectation of practical results, is replaced by a model

> of 'infinite transition' in which basic research is linked to its use through a series of intermediate processes.

The same is true for us for PE training.

The difficulty of improving and developing elite training and scientific research structures is not new in any field. The change must be explained according to criteria of various origins, whose robustness is sometimes questionable, with many obstacles to overcome, which leads to modest final added values, because sometimes they are based on foundations that are far from rational. Indeed, the value of the quality of instant efficiency training and the importance of research activity are probably undeniable for the future, because the objectives of science and technological development themselves are also undeniable. What stems from this are demonstration difficulties that are potentially problematic, but that have stimulated us in this work. Mahé (2002) considers, for example, that "the conservatism of science is not so much a rejection of change, as this need for consensual norms without which science could not be achieved". Is this also true for training?

Reading this book, which obviously remains insufficient to get to the bottom of (in view of the large number of scientific and technical works, scientific publications, etc.) a subject that is part of an uncertain future and that must evolve, you will realize that we have tried to open a project, to make people think, but not to shut down the adventure which can be fascinating for many. In fact, in agreement with Latour (2007a), process engineering has found its place in the technical (and scientific) society by delegation from other local partners. On this transfer, which was profitable, PE was able, in return, to explore other paths, other areas of action, other ontologies, while sharing the same fate as its traditional associates in chemistry, products, materials and certain forms of energy. The questions raised in this book make it possible to examine, in essence, with a deeply disturbed environment, how the legitimacy of this confident transfer, involving the pooling of interests, is maintained, deployed, amplified or, if on the contrary, the status quo linked to the stationarity of methods risks leading to a loss of scientific and technological credibility (for example, because of the unprecedented development of artificial intelligence) and, subsequently, to a rapid senescence. By advocating openness to others, it is not, obviously, up to the authors of this book to define the good for the domain.

So that's something which will share with us all a little more dopamine or, less pleasantly, maybe a little more stress, with cortisol production? This book, which does not close any doors, wishes to give time to time, while things can still be changed in a thoughtful framework of social utility, with the risk of thinking that we will see tomorrow, or later, when it will be necessary, that is, when it will probably be too late, because there are, in any system, inertia and delays. Indeed, under time pressure, the associated emotions (stress, anxiety, etc.) are not always taken into account, and these emotions (the body tries to monopolize all its faculties to dominate the situation or, conversely, to flee it (Santé Magazine 2018)) induce difficulties in thinking rightly, thinking broadly and in proportion to the intensity felt.

This is one of the reasons why we have devoted a chapter to PE-oriented foresight with the definition of several scenarios. As a result, we indicate trends, take sides in some options, sometimes give an opinion, but it will not be up to us to do so. Our aim is elsewhere, to make you think about the place of an important engineering science which, like most scientific and technological disciplines, faces an uncertain future. We are just convinced that it is necessary to change position, ways of thinking and acting in this science that is chemical and/or process engineering.

A certain laziness in thinking about the future, forms of carelessness or even passive incompetence on the part of some leaders, far too much conformity with a restricted freedom and initiatives, are forms of expression of a good old principle of inertia. We just want to participate in a positive questioning of the stationarity of goals and methods to achieve them, in a system that protects our world too much from any changes that break with perpetuated habits. To move forward, we need all of you to prove wrong the second sequence of D'Olivera Martins' (2007) writing: "After the first symptoms, it becomes clear that the global economy is sick – and the crisis can be conducive to the adoption of new solutions. But there is also the risk of the temptation of selfishness and solutions that turn communities and economic spaces inward."

> From Science comes foresight; from foresight action: this is the very simple formula that expresses in an exact way the general relationship between science and art. (Comte 1998)

> Technology doesn't work, it organizes need. (Jünger 2018)

> The chief, if not only spur to human industry and action is uneasiness. (Locke in Leibniz 1996)

> Results are achieved by exploiting opportunities, not by solving problems. (Drucker 2006)

> The design, manufacture and use of the machine are inscribed, even in their dreamlike deliriums, at the heart of dramas involving dreams, love, temptation, despair and even madness, accompanied by all the

vertigo that can lead to a quest for intoxicating discoveries. (Brun 1992)

Respect for ordinary life is not a good program. (Ellul in (Latouche 2013))

Those who advance research are in very small numbers compared to those who repeat or replay things they have found elsewhere; the largest number publish banalities that do not advance anyone. (Rovere 2019)

Science and technology are what socializes non-humans in such a way that they have an impact on human relationships. (Latour 2007a)

We need impertinents, deviants, the shifted, the marginal. We need people who have new ideas and dare to implement them, who dare to break the implicit rules established. (Baransky 2014)

"Science" is limited to studying the events whose regularity can be discovered. (Friedman 2018)

To train minds without conforming them, to enrich them without indoctrinating them, to arm them without enlisting them, to give them a strength from which they can build their strength. (Rostand 1959)

"Science" cannot be defined independently of its counterpart, independently of an environment accepting as an image of itself all the judgments that are organized around the qualifier of non-scientific. (Stengers 2006)

If the idea of a France in peril is so vivid, while it brings together so many talents, it is undoubtedly because, at last, awareness is growing that in France, more than elsewhere, our rules of the game and our collective modes of operation sterilize all the intelligence, all these creative capacities, all these potentialities. (Serieyx 2014)

There is a fatal deficiency in contemporary knowledge based on compartmentalized, quantified, unidirectional, bureaucratized knowledge. (Keynes 1996)

At every moment, therefore, the present is full of several possible futures. And man becomes an actor "of" history, capable of acting, either by weighing at the critical point or by working on the propagation medium. The first mode of intervention explains the role of minorities (or even the individual) in history; the second depends on the responsibility of all. (Passet 2011)

The very idea of satisfying needs no longer makes sense because they are barely satisfied by a new object and are reactivated by another, newer one, which relegates its predecessor to the status of waste. (Bauman 2009)

The slower you pedal, the slower you move. (Poulidor, quoted by (Serieyx 2014))

Because, without knowing what is written up above, none of us knows what we want or what we are doing, and we follow our whims which we call reason, or our reason which is often nothing but a dangerous whim which sometimes turns out well, sometimes badly. (Diderot 2000)

In cultural terms, no company is built on dreams alone and no company is built outside of them. Successful action is by necessity the result of practical considerations. But the purpose of any action is explicitly defined by the deep nature of the human being, his dreams, his vision of life, his culture. The dynamics of life, the challenge of risk and uncertainty require a new effort of creativity that will lead us to the reconstruction of the notion of progress, the one that philosophers, the ideologues of certainty, have damaged and almost destroyed. (Giarini and Stahel 1990)

We too often forget that specialists are produced from amateurs, just as the military is produced from civilians. (Latour 2007b)

In a physical environment of interaction, [places] add meaning to exchanges. They locate and contextualize them. They guide behavior and speaking skills. (Berthet 2018)

In France, strangely enough, it is not these regulars of the high seas, these specialists of the concrete that are asked for advice to guide the flagship, but the members of a caste who remain in port and have, for the most part, only a very theoretical knowledge of the sea. (Beigbeder 2012)

The technique has taken on a new dimension and organization. I am looking here for its specific structure, and I have realized that it exists as a system, that is, as an organized whole. (Ellul 2004)

Those in the organization who have ideas for doing things differently or better are divided into two categories: those who do not dare and those who dare. Those who do not dare understand the stakes and the importance of new ideas, but they are paralyzed by risk-taking and fear of displeasure. Having never tried anything, they have not failed and are therefore unharmed by reproaches [...], they are renouncers. Those who dare, innovators, move forward by disturbing agreed ideas, organizations and sometimes procedures. They raise fears and misunderstandings and are strongly criticized... (Philippe 2012)

Andersen's paradox: "Everyone in the working classes can see that the king is naked; but everything is done, consciously or unconsciously, to make everyone believe that they are the only ones to see him." (Michéa 2008)

If [...] a society is in favor of high energy consumption, then it will necessarily be dominated in its structure by technocracy and [...] it will become [...] intolerable. (Illich 2004)

A discipline is by definition an encounter with constraints. (Miller 2014)

In fact, flexibility is often more apparent than real, and the impression of freedom may only be apparent or compensated for by a great loss of time. (Simondon 2018)

All things considered, neither the mind nor the world are, after all, partitioned and compartmentalized. Relationships between the various areas of reflection must therefore exist. All you have to do is detect them. (D'Espagnat 2015)

Because there are generally several responses to a structural demand and some innovations do not meet any demand. (Boudon 1984)

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Introduction

Technology […] is much more than tools and artifacts, machines and processes. It deals with *humanity's efforts* in satisfying our desires through human action on physical objects. (Keransberg and Purcell 1967)

It took us a long time to realize that the power of a technology is proportional to its inherent out-of-controlness, its inherent ability to surprise and be generative. In fact, unless we can worry about a technology, it is not revolutionary enough. (Dupuy 2013)

Our era is devoted to the "speed" demon, and that is why we forget ourselves so easily. However, I prefer to invert this statement and say: our era is obsessed by a desire to forget and, in order to satisfy this desire, we devote ourselves to the speed demon; we accelerate the pace because we want to teach ourselves that we no longer want to be remembered, that we are tired of ourselves, are sick of ourselves, that we want to blow the small trembling flame of memory. (Kundera 2005)

Collective behavior is the typical form of action for people in a hurry. This impatience exacerbates conflicts and engages actors in ways that move away from the goals they have set for themselves. (Bourricaud 1977)

The more individual people are, the more necessary it is for them to share beliefs in unique values. (Dubet 1994)

The deepest nature of relationships between people is at the surface of their skin, it is the skin of others. (Goffman 1974)

The increasing cost of research has thus led to the promotion of certain programs by concentrating efforts and prioritising the potential devoted to them, to the detriment of subjects that are considered as less important – which will not raise the question of researchers' freedom of action and spirit with, beyond the personal aspect, an overall risk of conformity and the impoverishment of scientific practice. (Esterlé and Schaeffer 1994)

Where public education once had to arm the enlightened citizen, fuzzy school first makes you an employable person. (Lecointre 2005, pp. 126–127)

[…] Capitalist economy is not and cannot be stationary. Nor is it merely expanding in a steady manner. It is incessantly being revolutionized *from within* by new enterprise, i.e., by the intrusion of new commodities or new methods of production or new commercial opportunities into the industrial […]. (Schumpeter 1946/1976)

The company must face a paradox: to demand more and more from people and to transfer work to the machine using increasingly complex processes and methods. Social relations must grease the wheels of a system that operates to the maximum of its potential. (D'Alençon 1994)

The size of the global economy is almost five times larger than it was half a century ago. If it continues to grow at this rate, the figure will be 80 in 2100… (Viveret 2013)

Efficiency is the principle of selection that distinguishes good from bad technical initiatives. Efficiency is a quantity that can be calculated, and the technique seems to embrace two virtues that are generally the prerogative of scientific rationality: necessity and universality. (Feenberg 2014)

A scientific work cannot create a rupture that cancels out the path that made it possible; it is, therefore, both oriented towards the past it inherits and towards the future it proposes. (Prigogine and Stengers 1988)

Diversity, complexity, imperfection, vulnerability, here is strength of Ulysses, the force of Man. Ulysses is not seeking to steal the divinity from the gods; he opposes them with his humanity, which is the key of his freedom. Before the progress of science, it is not morality that

> must limit technology, it is reason. The world is built to be more human, but most importantly to survive, must be inspired by the teachings of Homer. (Léonetti 2010)

After the French Revolution, political power was based on the legitimacy of scientific knowledge (Thoenig 1987). But over the past several centuries, with the development of technology, the world has changed profoundly with a better and measurable material life. In this context, engineers first of all participated in the accelerated evolution towards "all-round" technological progress, which for a long time made it possible to free humanity from many material constraints. In this context, the pace of implementation of research results has changed considerably and become more complex, thanks to an increasingly frequent back and forth between "production" and research and thanks to the hybridization of technologies. Thanks in particular to engineers, these were rationalized, technicist contributions, where the social impact of the effects of emerging technologies, from material revolution to new technological era, was not the first priority. In this "historical" present using the culture, memory, and practices of the past, to put it simply, the engineer, during his/her career, was led to progress in a generally incremental way, with relatively stable knowledge.

According to Wikipedia (2018) (see also (Gaglio 2011; Koutani 2012)):

> An engineer is a professional who designs projects, if possible, by innovative means, and directs the realization and implementation of the whole: products, systems or services involving the solution of complex technical problems. He/she creates, designs and innovates in several fields while taking into account social, environmental and economic factors. This requires not only technical knowledge, but also economic, social, environmental and human knowledge based on a solid scientific and general culture.

According to ABET (2018):

> Engineering can be defined as the profession in which a knowledge of mathematics and the natural sciences, acquired through study, experience and practice, is applied with discernment to developing ways of economically using the materials and forces of nature for the benefit of humanity.

They are therefore "five-legged sheep", because according to Lane (2016), engineers must possess various skills to do well in their careers: learning to learn, reading, writing, mathematics, communication: listening, verbalization, creative thinking, problem solving, self-esteem, personal development, interpersonal relationships, negotiation, teamwork, operational effectiveness, leadership, and shared leadership (Laurini 2013). However, for a long time, as shown in Figure I.1, it was possible to consider families of engineering schools with distinct missions, which today tend to change.

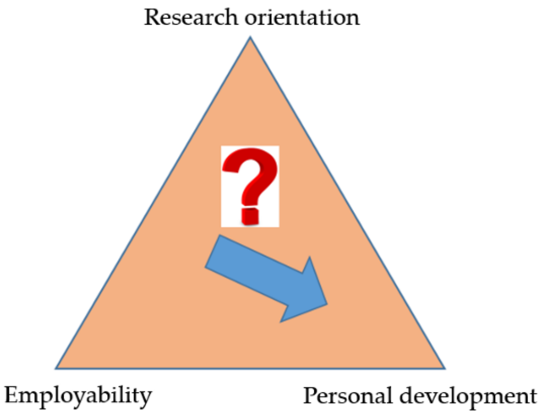

Figure I.1. *Different types of targets in traditional formations*

Work in many engineering schools is often linked to a certain form of self, with specific premises (Veltz 2007; Roby 2017); they develop a sense of exception:

> Based on the traditional and socially elitist model of the *Ancien Régime*, the entire organization of schools always aims to create a space of sociability for students, which keeps them in a closed universe, spatially and mentally, so that they can best integrate the values they are taught. (Roby 2017; see also (Picon 1992; Corbières 2003; Lemaître 2007))

And in addition, in the current complexity of the world, the speed of its evolution, the role of these key technological figures, is changing: indeed, in order to work in a more partnership-based way with the new knowledge economy, there is now a need to think more carefully about creativity, innovation (Alter 2002), and the societal impact of scientific and technological activities in a society confronted with many paradoxical injunctions (hence the notion of social responsibility), which has led us to try to review in depth the roles of engineers and executives in society. Increasingly, globalization and the effects of technological progress must be taken into account: the expansion of information technologies (including artificial intelligence); the reduction of barriers to trade and finance; the interdependence of markets, products, and services; the homogenization of behavior; the enhancement of competitiveness; the reduction of political power; the reduction of labor costs; the depletion of resources; but also the increase in pollution, global warming, etc. Anders (1999) reminds us that: “Between our manufacturing capacity and our representation capacity, a gap has opened up, which is widening day by day.” The debate therefore opens with this link to be examined between available, renewable material goods, and society.

Over the last two centuries, market needs and expectations for manufactured parts, products and materials, and energy (in short, everyday consumer products), have changed significantly with a considerable qualitative and quantitative increase in the number of objects/products manufactured and radical changes in production methods (Rufer 2014). Industrial revolutions and world wars are the triggers for the gradual transition from artisanal to mass production. The first is based on a qualified workforce, using general-purpose machines to make the product requested by the customer individually with the available materials. In contrast, mass production meets demand in excess of supply. It is based on the production of a limited range of products, manufactured at high volume, by dedicated production means. Henry Ford and Louis Renault are, respectively in the United States and France, the first to apply this type of production to the automotive industry (Marty and Linares 1999).

The period of economic crisis that followed The Glorious Thirty (meaning 1945–1975 in France) saw the gradual emergence of mass personalization, which responded to the context of a supply that was this time greater than demand (Kumar *et al*. 2007). To support the market, it is becoming necessary to offer products that are likely to better meet the different expectations of customers:

> This multiplication of models will be achieved by developing “optional” products that allow the customer to choose the combination that best suits him/her. Such an approach allows companies to maintain massive production, no longer at the product level, but at the component level. However, it requires a review of the product industrialization cycle approach. (Rufer 2014)

In fact, the following sentence by Meda (2013) makes the assumption that there are always solutions to the situations created by technological progress. “And that as worthy successors of Ulysses and Prometheus, we will be able to combine cunning with ingenuity to find solutions when the time is right.” This is a mission, one that is undoubtedly to be updated for the engineers of tomorrow (or even already today).

Engineering sciences cover a very wide field, ranging from the design, manufacture, and development of materials and devices to management disciplines. These are based on the integration of many fields, including specialties close to the hard sciences (chemical and/or process engineering (PE), materials). These are engineering sciences developed by academic research in the laboratories of *grandes écoles* (French higher education establishments) and technological universities, or large industrial groups, and in their industrial implementation and in everyday life. In engineering education, there is a dual aspect of research and application, which is less marked in the so-called pure sciences (which by definition pay little or no attention to the second aspect) (Vincinti 1990; Schmidt 1992, 1997; Auyang 2004, 2005a, 2005b; Leonelli 2007; Guy 2012; Frezza *et al*. 2013; Ratcliff 2013; Lahtinen and Stenvall 2017). Its development, which has become "obligatory" in today's society, forces the productive imagination towards a given social ideal, a position that cannot follow the simple logic of initial rational training (otherwise, apart from the necessary know-how, it would in principle be possible to integrate it into a computer memory). There is therefore a difficulty between rupture and continuity, one preventing the other from developing or, on the contrary, giving it support to move forward.

It is in this spirit of evolution of the representations of the training of the professions of material production managers that this book was written – not on a subject too vast for two people concerning the whole engineering profession, but on a target that is certainly broad, but is limited to the science of process engineering (chemical and/or process engineering). Chemical and/or process engineering (PE) can be defined as an engineering science associated with the study of the transformation of matter and energy, for application or finalized purposes. It is based on the acquisition of scientific knowledge to describe these transformations by integrating all multi-scale and multi-physical phenomena and processes, as well as their couplings (André *et al.* 2013). Following this definition, several remarks can be made; they are summarized in Box I.1:

> Process engineering has therefore evolved considerably in a very short period of time. However, unlike chemistry and physics, which are relatively mature sciences, process engineering still promises significant upheavals if we are to believe the professionals in the field. (Latieule 2017)

It is a science: science is what we know because we have learned it, what we consider to be true, the set of knowledge, studies of universal value characterized by an object (domain) and a determined method, and based on verifiable objective relationships.

It is a discipline: a discipline refers to knowledge developed by a community of specialists adhering to the same research practices. It naturally tends towards autonomy, through the definition of its boundaries, the language it is constituted in, the techniques and theories it is led to develop and use.

It is an engineering science: the science of artifacts, the science of objects and systems where knowledge of nature is combined with the intervention of human engineering to solve, by abstract or concrete means, problems that arise indirectly and remotely from functional concerns…

Matter is what makes up any body with a tangible reality. This is a huge area.

Energy is the ability of a system to produce work, a transformation of matter or energy. It is also very broad…

Linked to scientific deepening and applications, this definition contributes to technoscience, which underlines the concrete solidarity between material technological developments and theoretical knowledge, in the form of constant interactions and positive feedback between scientific discoveries and technical inventions (with the risk of subordination to applicative and self-interested purposes and external management of research, without net knowledge creation).

But according to Poincaré (1911):

"The scientist must not focus on achieving practical ends. He/she will probably get them, but he/she must also get them. He/she must never forget that the special object they are studying is only one part of this great whole which must be the only spring of his/her activity… Science has had wonderful applications, but science that would only have applications in mind would no longer be science, it would only be cooking…"

Modeling makes it possible to go further and faster. It is a mental construction in which reality is simplified, even reduced to its main influencing variables (at least those that have been perceived), which may raise questions about providing robust solutions to the complexity of the world around us (Tönnies 1977). The computer replaces the experience to rediscover the old dream of some people to "theorize thought", or even palpable reality.

To avoid limiting the researcher to his or her discipline, in which he or she exercises freedom (autonomy) and activity that allows him or her to go beyond the limits of knowledge, should we not find ways of "transgressing" that would allow and support new cultural couplings? How can we enrich ourselves with others? To foresee the societal demand that may be made to him in his field, must one only engage, alone or with others, in a prospective reflection, only on visions of potential applications or should one engage in a more complex way, on new concepts?

How to get out of everyday life by developing a little creativity: it corresponds to an ability to easily change the perception of things, the ability to move from one model to another. Asking someone for creativity means encouraging them to "get out of the box" (Numa 2018). Today, knowledge is almost immeasurable. But what is this knowledge worth? Concepts help us to step back to "think better". It may be necessary to learn how to learn, and to organize information around knowledge.

Here are a few questions, many of which go beyond the "simple" PE, a concept that is difficult to understand in a positive way for an unprepared audience (as if there were note-reading competitions instead of operas!), even if the domain has its popes, gurus, academic recognition, newspapers and learned societies, etc. Apart from this essential aspect of readability (and therefore of recognition), isn't there a risk that daily activity risk will remain, in a "between oneself", a ritual with dogmatic models instituted by a knowledge and by practices, collectively shared, with models that are staged and represented, or are confirmed by the self-representation and self-interpretation of the order of a community?

Box I.1. *Chemical and/or process engineering: science or "simple" technical method?*

Can we then apply to process engineering a "standard" epistemological critical approach that we apply to all sciences (forming hypotheses, conducting experiments, and comparing the results of experiments with the predictions of hypotheses)? While some fields of process engineering sciences can indeed be interested in the basic laws of nature (and then almost identify with the pure sciences), as in some fields of materials (nanotechnologies, superconductors, semiconductors, etc.), the objects to which chemical and/or process engineering relates are generally more complicated than the elementary objects of chemistry or physics, because they are partly "anthropized" (design, manufacture and use by/for humans) (Guy 2012).

Thus, the devices and installations created by the engineer are partly unknown objects on which a specific scientific investigation must be carried out. One of the reasons for this particular positioning is the existence of uncertainties in scientific disciplinary knowledge, in the ability to know and exploit the interplay of their links, their common methodologies and more precisely on their "convergence" or integration for operational purposes. The historical approach taken will remind the reader that this is a young science that is in a stabilization phase, while other disciplines were emerging at the same time and more established disciplines were renewing themselves sufficiently to challenge their own epistemological foundations. The management of interdependencies between these disciplines that contribute to the development of PE must therefore be taken into account.

Using the example of the production of a chemical compound in a multi-step production line (see Box I.2), chemists claim to know each of them, at least at the laboratory stage. Either we operate by "trial and error" for industrial production, or we seek (or exploit) laws, of a type different from the elementary laws of chemistry or physics: they concern composite systems and variables that are often more "macroscopic" than the variables of the elementary laws (the total quantity manufactured at the end of the chain rather than the flow of a given chemical compound at a given place). The concept of "black or grey box" (often used for PE theorization, but not only) requires a scientific approach. If we do not try to open it, it becomes grey each time we can distinguish between what we can control (the nature, size, and arrangement of the elementary parts found there) and what we cannot control (the physical laws).

Regardless of these considerations, Figure I.2 illustrates the scientific strength of the field. This figure represents the number of annual publications calculated from the two key words: "Chemical Engineering" (total of more than 2,400,000 publications).

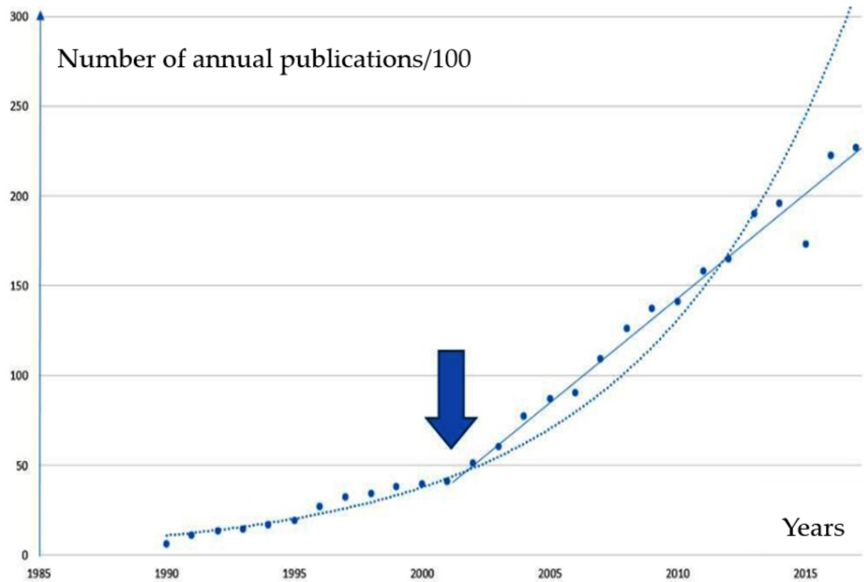

Figure I.2. *Growth rate of scientific production in PE (according to data provided by the University of Lorraine's academic library)*

Figure I.2 shows a significantly exponential growth until about 2000, followed by a linear increase since then. It visualizes a "good health" of the field, structured in France since the creation of the CNRS engineering sciences department with the stabilization around many learned societies. With a total of more than 2.5 million scientific articles over the period 1990–2017, proof of the existence of a large community, reproducing common cultural codes in scientific depth, no longer has to be demonstrated.

Mr. Berthelot, who was at the forefront of Chemistry in France in the second half of the 19th Century, wrote, according to Moscovici (1999): “Chemistry creates its object”, so this is a remarkable difference in relation to the sciences of chemical and process engineering that appears in this simple sentence (although, PE can also create its object as shown in (André 2017)).

Chemistry is involved in the manufacture of products for our daily lives, but also in the manufacture of products for industry, construction, agriculture, health, etc. It produces both raw materials in large quantities (basic chemistry) and very elaborate substances (fine chemistry), in connection with the materials that are often derived from them (Les métiers de la chimie 2015). According to the same source, “the chemical industry in France recorded a growth of 0.9% in volume in 2015 (after +2.8%). Its production is now almost 6% higher than its pre-crisis average level in 2007. The trade balance stands at €7.3 billion in 2015 (after €7.4 billion in 2014) due to an increase in exports from all zones combined to €55.6 billion, offset by a slight increase in imports to €48.3 billion.

According to UIC (2017): “The chemical industry has a significant influence on the national labor market. It employs more than 156,600 people (economic scope: chemical production activities, head offices and R&D), 201,500 employees under the collective agreement for the chemical industries and about 500,000 employees including indirect jobs. It is the fourth largest industrial sector in terms of workforce behind metallurgy. It represents about 1% of total employment in France and 6.8% of employment in industry [...]. In ten years, all the business lines of the sector have gained in skills and qualifications. Chemistry is one of the industries with the highest management ratio. In twenty years, the proportion of engineers and managers in the sector has more than doubled while the proportion of workers has significantly decreased. To date, 29.5% of employees are workers/employees, 39.7% are technicians and supervisors and 30.8% are managers who represent the face of a high-tech industry. Recruitment is focused on increasingly specialized and technical trades that require a higher level of qualification. 11,900 employees work in R&D.” For MESRI (2017), R&D in sectors in which PE has a significant share is more than 20% of total manufacturing (see also ReportLinker 2018).

Table I.1, extracted in part from DGE (2017), shows in several European countries the importance of the different branches of manufacturing industry with the role of PE in these industrial sectors. The classification of PE is represented by pluses (from 1 to 4), question marks or minuses, depending on the importance that this engineering science may have in the fields.

Box I.2. *The chemical market (in the broad sense)*

Sector of activity	France (%)	Germany (%)	Italy (%)	UK (%)	Importance of PE
Food processing industries	19.8	6.9	11.3	16.0	+++
Capital goods	13.9	28.5	22.9	14.9	?
Repair, installation, manufactured products	13.8	19.1	9	9.7	+
Chemical and pharmaceutical industries	12.9	11.1	8.3	14.0	++++
Transport equipment	12.5	21.4	7.8	14.4	?
Metallurgy and metal products	11.3	12.3	15.3	12.1	++++
Plastics, rubber and non-metallic mineral products	8.3	7.3	9.0	7.4	++++
Wood, paper and printing	5.2	4.1	5.7	7.0	+++
Textile, clothing, leather and shoes	2.2	1.3	9.7	3.6	+
Coking and refining	0.0	0.6	6.9	1	+++

Table I.1. *Relative influence of manufacturing branches in EU countries*

COMMENT ON TABLE I.1.– *What we see from this summary table is the importance of the discipline in industrial activity, hence the importance of focusing on its future, enabling it to maintain its key role in the material and energy processing industries (see also (DGCIS 2012; World Economic Forum 2018c)). The pharmaceutical market is estimated at around €100 billion per year (Kesic 2009).*

However, as shown in Figure I.3 (Virlouvet 2015), industry is not the largest consumer of energy to date, nor the one responsible for the largest amount of greenhouse gases produced.

This author refers to the POPE Law of July 13, 2005, which, in France, aims to reduce greenhouse gas emissions by a factor of 4 in 2050 compared to 1990 emissions. There is no doubt that if this programming is followed, process industries will be significantly affected. This could be the case because the cost of renewable energy and the cost of storage continue to decline, as they already beat the price of natural gas in many American markets (Hill 2019).

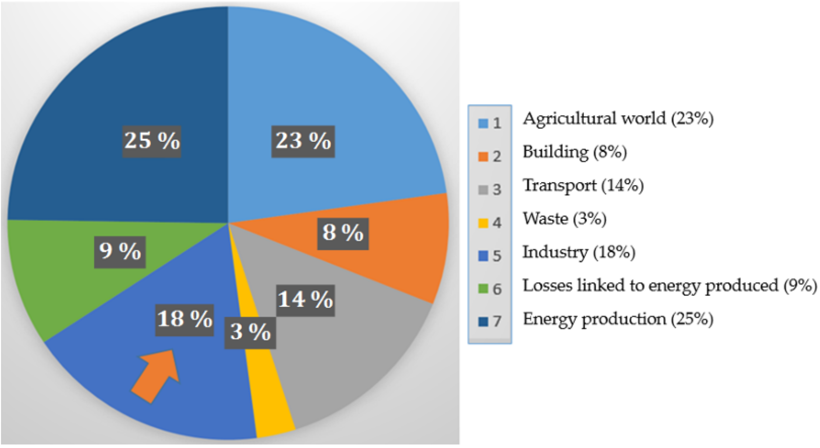

Figure I.3. *Quantities of greenhouse gases produced by sector (world). For a color version of this figure, see www.iste.co.uk/schaer/process1.zip*

In this context, the PE engineer is required to master new variables, new laws, for new scales of complexity. If it is useful to take a specific validation approach for these new domains, it is because new properties are emerging for them, although the underlying elementary level is known. Thus, there is probably more information in the production protocols of a chemical substance or material than in the thermodynamic properties of the compounds involved:

> Synthesis is "creative" in the sense that all this knowledge and technology does not combine on its own. There are countless possible combinations. It is the values, the vision, the culture, the project that will serve as a crystallizer for the synthesis that will be carried out by creators, directors and entrepreneurs at the heart of society. (Giget 2010)

In practicing PE sciences, it is necessary to study laws of behavior while inserting them into a function of social utility (teleology). We are then, not in the register of knowledge and the search for "pure" truth, but in that of optimized action in relation to an objective (economic, environmental, etc.). PE is thus at the crossroads of epistemology (validation of science) and certain forms of ethics (validation of the application of science).

Whether or not we welcome the success of the emergence of process engineering in the engineering sciences, the multiplicity of research on increasingly disciplined areas may raise questions, because of the possible disjunction of the knowledge created, about the target of this science-object. There is indeed a multiplicity of paradigms, methods, and approaches that risk turning it into a fragmented science, without the initial happy and creative idea, a real modern response to the needs of the material and energy processing industries, which have constituted the legitimacy of chemical engineering or processes.

Indeed, since its emergence, it seems interesting to examine the historical aspects that explain these changes in the conduct of researchers and trainers in the field, perhaps too individualized. The strength of the CE, now PE, has been to address practical issues whose rational solutions, a real common matrix, have enabled (and continue to support) technological progress in material transformation (see Figure I.1). To this general question related to the development of sciences leading to exploration through interdisciplinarity for convergence towards an operational end (Theureau 2009), new questions related to new needs, ideas of decline (Latouche 2013) with a certain bankruptcy of the promise of happiness of essentially technical origin, the problems of reserves, globalization, etc. are being raised in a world that is changing more and more rapidly, all in a scientific and technological environment strongly disrupted by the operational emergence of artificial intelligence with highly renewed academic and civic expectations (see Box I.3).

In the 1930s, the economist Nikolai Kondratieff proposed a heuristic on socio-technical structural change in terms of development cycles (Schumpeter 1939; Wilenius and Casti 2015; Silva-Morales 2017), cycles that fluctuate in 40- to 60-year waves linked to major radical technological innovations that become dominant (Dosi 1982). The last wave is associated with information and communication technologies related to smart technologies or intelligent technologies such as artificial intelligence. It is on this basis that the concept of industry 4.0 (André 2019) was developed.

The ever-increasing growth in the power of data processing by computers has a very high impact on the ability to collect and process increasingly complex digital data. “A standard tablet today has the equivalent processing power of 5,000 desktop computers from 30 years ago. The cost of storing the information produced by these devices is close to zero. For example, storing 1 GB costs on average less than \$0.03 per year today, compared to more than \$10,000 20 years ago. This has completely flattened the costs of information processing” (World Economic Forum 2018b). This global change is a very important part of what is generally referred to as industry 4.0, or the fourth technological revolution.

Table I.2, which is based on the same reference, examines the priorities expressed in this synthesis report and makes it possible to represent points of questioning (with 1 to 4 pluses) or with minuses, the importance that these technological trends can have, either that PE appears as a proactive stakeholder, or that it is a user of the knowledge created.

Box I.3. *Industry 4.0 (World Economic Forum 2018b)*

Priority	Comments on the report	Inclusion of PE	Use of knowledge
Additive manufacturing	Additive manufacturing techniques used to create three-dimensional objects based on the "printing" of successive layers of materials	+++	+++
High-tech materials	Production of materials with significantly improved or completely new functionalities (nanomaterials, biological or hybrid materials)	+++	+++
Artificial Intelligence (AI)	Computer learning algorithms to perform tasks that normally require human intelligence and beyond (for example, visual perception, speech recognition, and decision-making)	+	+++
Robotics	Electromechanical, biological, and hybrid AI-activated machines that automate, increase or assist human activities, either autonomously or according to specific instructions	++	+++
UAVs and autonomous vehicles	Stand-alone or remote-control operation	?	+
Biotechnologies	Including bioengineering, biomedical engineering, genomics, gene publishing and proteomics, bio-mimicry, and synthetic biology, a set of technologies with applications in fields such as energy, materials, chemistry, agriculture and medicine	++++	++++
Energy	Energy capture, storage and transmission. New energy technologies ranging from advanced battery technologies to smart virtual grids, organic solar cells, spray solar systems, liquid biofuels for power generation and transmission, and nuclear fusion	++++	++++

Blockchain	Cryptographic software algorithms to record and confirm transactions and/or immutable assets with reliability and anonymity; intelligent contracts (France Stratégie 2018)	–	?
Geo-engineering	Deliberate large-scale interventions in the Earth's natural systems to, for example, modify precipitation patterns, create artificial sunlight or modify biospheres	+	+
Internet of Things (IoT)	A network of advanced sensors and actuators with software, network connectivity and computing capacity, which allows data to be collected and exchanged over the Internet and automated solutions to several problems	+	+++
Neuro-technologies	Technologies to influence consciousness and thought by decoding what humans think in detail through new chemicals that influence decisions for better functionality and enable interaction with the world in new ways	+	?
New computer technologies	Quantum computing, DNA-based SSD hard disks, Big Data, Cloud; IoT, advanced sensor platforms	?	?
Advanced detection system platforms	Advanced fixed and mobile physical, chemical and biological sensors for direct and indirect (remote) detection of a myriad of environmental, natural and biological variables from fixed locations or autonomous or semi-autonomous vehicles in land, machinery, air, oceans and space	+	++
Virtual reality, augmented and/or mixed	Computer-generated simulation of a three-dimensional space superimposed on the physical world (AR) or a complete environment (VR)	=	+++

Table I.2. *Place of PE in the fourth Industrial Revolution*

As Table I.2 shows, it is clear that there is a prominent place for the field of processes in ongoing technological developments. However, since the PE domain emerged, our environment has changed considerably: in negative, a dazzling transition to a new world, “new public management”, quantitative evaluation methods, contract management, but also convergence, Internet, network organization, hyper-mobility, tertiary, silver-economy, sustainable development and new forms of production, the relationship to life, the factory of the future, industry 4.0, etc. As evidence (if necessary), Figure I.4, taken from the World Energy Council (2019), highlights a breakthrough, that of the cost per ton of CO_2, which was relatively stable until 2017 but has seen its price “soar” since. Continuing this trend leads to process changes to keep solutions that are economically acceptable.

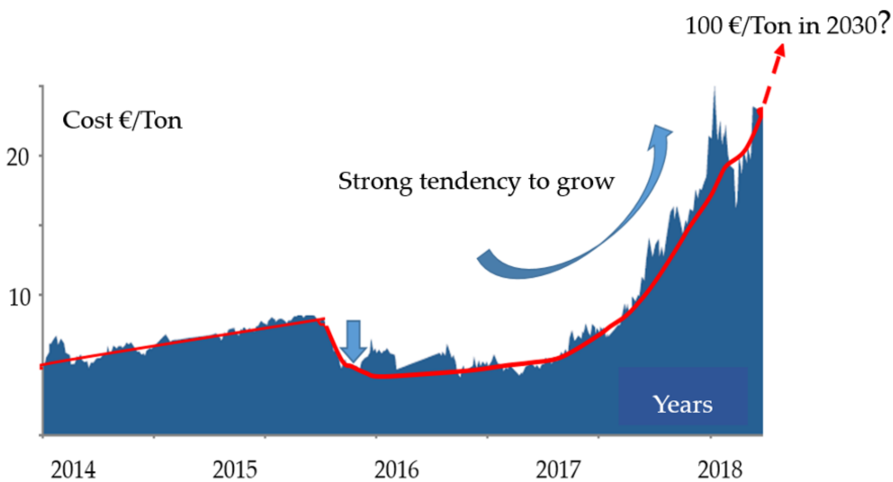

Figure I.4. *Changes in the estimated cost per ton of CO_2. For a color version of this figure, see www.iste.co.uk/schaer/process1.zip*

NOTE.– Ambiguity in absolute terms: the price of CO_2 on the EU-ETS market collapsed to 2 €/ton (25 € in 2008/2009) before rising to around 7–8 €/ton and falling back to around 6 €. This price results only from the regulation imposed by the European Commission (CO2 Account 2018). However, there is agreement on a significant evolution towards an increasingly high cost (the price of carbon dioxide is expected to reach 100 €/ton in 2030).

On this basis, the use of hydrogen for chemistry, energy, is beginning to be of interest. New possibilities then emerge, such as some presented in order to illustrate the point made in Figure I.5, also from the World Energy Council (2019). The changes and associated processes are “on our doorstep” (see also (EASE 2019))!

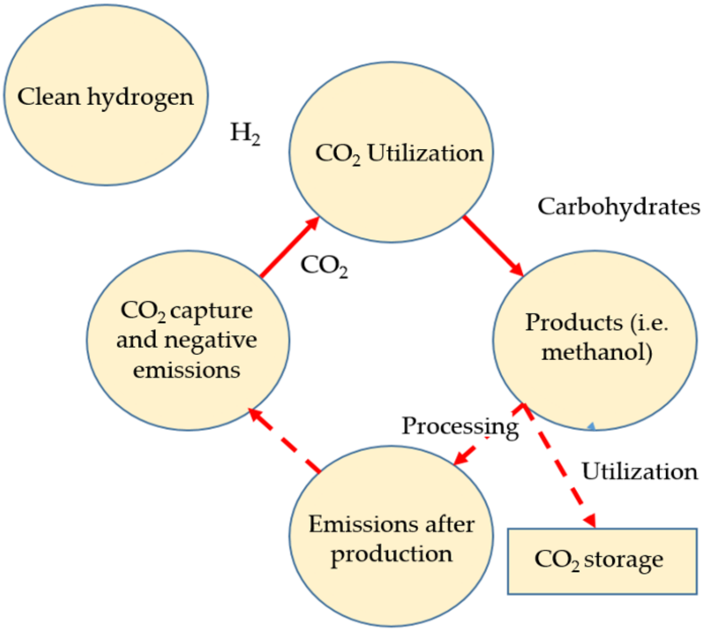

Figure I.5. *New processes induced by environmental constraints*

NOTE.– Recent political developments must be integrated into the development of forward-looking scenarios that will have an impact on human research and training. Exploratory scenarios provide a possible vision of the future, taking into account various trends. They are necessary elements of reflection (which will be explored because they impact the PE field) for professions that must be sustainable in a context where it is known that it is no longer possible to rely on a linear projection of the past to achieve this objective (see, for example, (Hajkowicz *et al.* 2016)). Their goals are not to predict the future, but to show how these forces or trends can influence it. This knowledge of constraints and opportunities must precede strategic choices: technological, economic, political, and social, based on values that can be transformed for a time into standards of action.

These different scenarios can occur simultaneously in different regions, industries, age cohorts, or socio-economic groups, adding uncertainties to the forecasts (World Economic Forum 2018a). However, trend analysis provides the most robust basis for the development of strategy proposals to take advantage of emerging opportunities – from scientific and technological aspects, to the ways in which knowledge is now too disconnected to the promotion of new forms of entrepreneurship and the development of new business models. Political frameworks, with the emergence of new ideologies (Crédit Suisse 2018) will be taken into consideration in order to allow future generations to be adapted as best as possible to satisfy future needs involving PE in a framework that will attempt to minimize the effects of technology on the future of our planet (independently of various lobbying activities – see for example (Weatherall *et al.* 2018)). In short, our world of certainties is full of temporalities that are being reduced to innovate and be easily considered as actors of authentic public utility. There is therefore an urgent need to reflect on the future of research and training in our field of expertise.

If society today is always asking for new things (for different reasons), artefact producers rely on commercial objects that get bought by many clients, without anyone, upon purchase, remembering not only that it took a great deal of direct intelligence to create these objects, but that they were created indirectly too, from materials and/or energy systems of chemical origin (Dubois 2013). Falsely lagged intelligence is normally called upon to meet demand, unless manufacturers are able to find the substances and materials needed for their "off the shelf" innovation. Thirdly, the person who designs the processes is also obviously called upon to meet the demands of producers of materials and chemical substances with the same problems as in the second place. The headlong rush characterized by frenzied innovation is not reflected in a deep crisis for this engineering science, as evidenced by the current attractiveness of industrial sectors for the hiring of PE specialists. Apart from an aspect of the often-negative image of chemistry, there is therefore no marked feeling of disenchantment with the specialty today.

Phase shift leads to both displaced and extended temporalities of PE aspects with regard to the sole transformation of the material, itself confronted with the same destiny with regard to manufacturing innovation (consumer products). It is basically this impression of duration that leads to the thematic depth described above with a certain stabilization of the training methods of PE executives and associated research. This form of timelessness is well reflected in the ease of hiring specialists in the current field in the Western world, illustrating training that corresponds to the satisfaction, at least partially, of the three classic missions: specific selection of candidates, education in the PE field, and socialization. The knowledge taught, students' attitudes, and behavioral patterns are obviously still adapted to the needs of companies.

But in other privileged, less functionalized places, we are witnessing (without much money) support for the capacity offered to thwart the frameworks of action within the fixed system, with the exploitation of its virtuosity and the desire to go beyond norms to invent singular, pioneering processes (success-oriented actions (Habermas 1986)). Does the dogmatization of a domain that has developed contribute to this inventiveness, or is it linked to a collective will to function differently with renewed practices?

A discipline that is not directly visible to human consumers (we are more interested in the performance of the cook than in the performance of their pots and pans!), with an "institutional" representation of seriousness, of stratification, potential "novices" may not fully understand the importance of the field, which is difficult to define in a short sentence, with the additional risk of juxtaposition of autonomous models, each with its own conception of the actions to promote. Moreover, as Figure I.6 (Opinionway 2017) points out, process engineering is not identified in research surveys!

The PE unit can be revealed as a simple academic convention with its aspect of a group refuge of defense against other disciplines. Everything, at heart, is a matter of beliefs in the future, because no major cloud obscures the sky above us, for the leaders who assume scientific and administrative responsibility. So why try to practice activities that are part of divergent thinking and creativity as long as there is no major obligation to change? But are the time bases for resourcing appropriate to maintain scientific and technological leadership in the field? That's the dilemma! To whom should I give credit for changes to be made? The risk of a delay has apparently not been assessed, which does not make it possible to reveal an urgency in the necessary developments and their anticipation. This work is thus undertaken in this book.

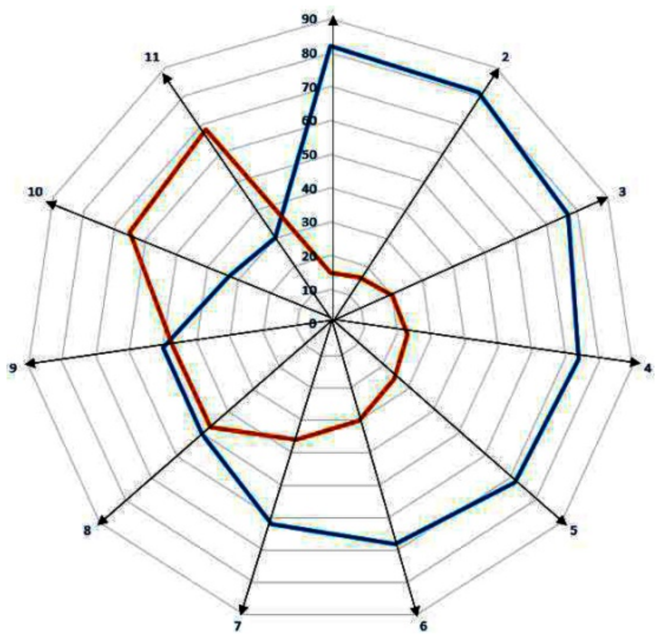

Figure I.6. *Lack of public sensitivity for PE. For a color version of this figure, see www.iste.co.uk/schaer/process1.zip*

COMMENT ON FIGURE I.6.– *The question asked is: "would you say that you are concerned about scientific research in the following areas?" The blue curve corresponds to a positive response, the red curve to a negative response. 1) Transport and mobility; 2) Health; 3) Environmental, renewable energies and pollution; 4) Space research; 5) Home automation; 6) Drugs; 7) Defense and security; 8) Robotics and Artificial Intelligence; 9) Genetics; 10) Nuclear power; 11) Food (GMOs).*

Is the PE specialist the object of a habitus, a fantasy of skills in an increasingly open production system? Or is it part of a complex holistic approach to its field, linked to socio-economic constraints? These questions refer to a necessary revisiting of PE research and training activities in an emerging context of severe disruptions, even if the pressure on the necessary change is not yet very noticeable. "Creative or innovative periods are precisely those in which, under the influence of various circumstances, people are brought closer together, in which meetings and assemblies are more frequent, relationships are more frequent, and exchanges of ideas more active." (Durkheim 1967). Clearly, the schedules, quantity, and quality of scientific productions do not reveal favored encounters that allow for constructive debate.

This does not mean, however, that there are no reflections, but they are rarely expressed in the ambient and traditional paradigmatic inertia in research and training units with an internationally recognized quality in their scientific work, to recognize the potentially emerging forces that allow evolutions, evolutions that should fit into the collective ideal. Orléan (2011) writes on this subject: "This transformation is not the product of an intellectual adherence resulting from a rational analysis of the situation, but rather that of a setting in motion of individual desire by a power greater than the individual." The sociological and organizational problem will consist in seeking, through different forms of perceived, present or future external constraints, as they are understood and shared, the different ways of resourcing that correspond to them (and in discovering the causes that have determined them).

While the specialist's role in their systemic approach has been the core of PE competence, the possible dispersion of the initial unit model leads to a multiplicity of new solutions that are not focused on the discipline, but moreso on its application objects (sustainable development, waste, etc.), avoiding obligations to innovate and invest in exploring systemic complexity. The exploitation of traditional know-how on emerging themes with real success may suggest that the general model is becoming obsolete or at best can only be considered as a particular vision. There is therefore a need to a step back from this phenomenon of fragmentation, of the creation of increasingly separate cultural identities, if only to understand it (with the risk of revealing the exhaustion of the traditional representation of PE). These different "manifestations" of external tensions should therefore be shared to create a sense of common action and a shared sense of common purpose among members of the PE scientific community. The intelligible representations from all stakeholders require a minimum of trust between them so that they can interact in order to build a shared vision of their field of scientific activity.

This transformation presupposes that it will be possible to achieve full support from “statutory” teacher-researchers, members of a conservative system that sets them specific training with goals to be achieved, who must then direct their pedagogical skills towards the development of the profession(s) in the field, which is really put to the test of continuous interpretation of the mission with real risk taking, currently poorly supported by “New System Management”. By adopting society’s expectations, it is necessary to identify an acceptable position for the body of trainers (and researchers), probably difficult to find, between contradictory subjective aspects (associated with the vision of the profession) and objectives (associated with the imposed program) (Derouet 1992). It is with this relationship of trust between stabilized knowledge and creativity, and openness to others, that one envisages relying on revisited values to create a common narrative, history, and legitimate commitment around the field of this particular engineering.

On the openness side, companies no longer assume the management of their innovations alone. These are increasingly based on a contribution, sometimes simultaneous and sometimes sequential, from clients, suppliers, and academic research (“open innovation” according to (Chesbrough 2003; West 2014)). Ayerbe and Chanal (2011) cited by Mignon and Laperche (2018) recall the characteristics of the two standard ideals of innovation strategies:

> The first is for firms to seek to build a competitive advantage based solely on internal resources and to defend the pioneer’s rents through defensive intellectual property strategies (barriers to entry). The second allows them to consider that resources can be captured both outside organizational boundaries (Inside-out) and that resources that are not internally valued can find opportunities for valorization outside the borders (patent sales, licensing, spin-off, etc.) (Outside-in).

The current situation, with a form of downstream management of academic research, nevertheless leads to a more “Darwinian” life for researchers (Drucker 2006), linked to the survival of the most able to cope in the emerging normative universe linked to changes in the institutional research environment, thanks to a good perception of the new rules, explicit and especially implicit, of function. By introducing mutations, the conservative body (at least in its discipline) of many researchers is led to modify its ways of acting, which can be beneficial. Indeed, in the absence of stimulation, an instinct is formed to resurrect the old order (Freudian automatisms of repetition). Specialization is probably a necessary evil in science, but how can we avoid premature silos and inappropriate programs that risk "ossifying" specialists, confined in their systems of thought and unable to recharge their batteries (Elgozy 1966)?

Innovation is a phenomenon whose complexity, due to its socio-technical, creative, emerging, collective, interactive, and multi-trade dimensions, is now widely recognized by all its stakeholders: socio-economic actors (companies, federations, clusters, associations, etc.), institutional (State, communities, funders, etc.), and the various scientific communities that are interested (engineering sciences, design, industrial engineering, management, sociology, psychology, etc.).

The change in the global landscape, with the rise of the BRIC (Brazil, Russia, India, China) and major changes in supply and demand, are the two major trends that will structure the creative, research and innovation activities of tomorrow (France Stratégie 2014). In addition, the challenges (as well as the opportunities) associated with intensifying the consideration of sustainable development will lead to an amplification of changes and adaptations necessary for all individuals and organizations.

Sustainable development, the current leitmotiv, is based on three interdependent axes: the environmental sphere, the sphere linked to production in a liberal economic context, and the social sphere, involving for some the development of collective intelligence in a so-called knowledge-based economy, and the absence of rejection for others. While it is unrealistic in today's society of technological progress to consider technological setbacks, the approach has so far largely consisted in reusing metallic materials and the energy carried by other materials. For the authors, the challenge is quite different, since it aims to explore the possibilities of rethinking functional product choices and associated processes for easier reuse. This new "paradigm" must rebuild industrial chemistry and associated process engineering (responsible eco-processes) in order to propose innovations that take into account reality: economic constraints, technical constraints, human and possible constraints: regulatory developments, social agreements, etc.

Today, there is a double challenge which consists of:

– promoting industrial innovation which can result in the development of new processes/products, services, organizations, business models, etc. in order to develop the competitiveness of companies (Alter 2002);

– supporting the transformation of all innovation stakeholders (companies, institutions, research, companies, citizens, etc.) towards responsible innovation, which consists in finding a balance between economic development, reducing environmental impacts, and respecting societal and ethical values, avoiding conflicts between tradition and economic project (Durand 2012).

But, to achieve these objectives, the engineer as well as the individual worker and/or the "simple" citizen must be considered as a being who experiences, perceives, experiments and evaluates space based on their body, feelings, senses, and affects. Subjective experiences are a dynamic process by which the individual adds their own empirical knowledge to the identity and collective memory of places and processes to give them meaning and to create his/her own vision of their environment. Thus, a new paradigm based on the place that should be given to subjectivity and individual experiences in the conception allowed by process engineering would offer an anthropological and philosophical break that should be explored.

To return to this civilizational basis implies more and more that one should consider processes as complex and continuous, combining different knowledge, cultures, and technologies that must be taken into account (the average of the averages is not the average). This paragon of a system is in continuous evolution, in perpetual transition, and sustainable, even resilient, and would put the act of being, the individual, experience at the heart of the future application of process engineering sciences.

Thus, in practice, it seems difficult today to define the PE community by a united and functional cultural homogeneity; the actors can no longer be considered as reducible to a single logic, to a controlled, even "programmable" role. A central question asked in this book is whether it is possible, and at what cost, to leave the traditional representations of the field (while keeping a reverence towards the founding fathers), with the risk of losing the memory of its cultural roots, of its initial centration. But to do what? How can we then dynamically combine talents to bring together heterogeneous behaviors in order to maintain the attractiveness of PE in its crucial role in the field of optimal transformation of matter and energy with the many current environmental constraints?

Only flexible, open, minimum or variable determination, or low identity "systems", that is, systems that themselves contain a significant dose of uncertainty and undecidability, are adaptable and can claim relative effectiveness. In other words, vague categories of reasoning are needed to be able to think of or act on conditions that have become uncertain, temperamental, or paradoxical. These few sentences clearly come out of the discourse where everything must be (still) programmable!

Such a conception of an action strategy, which avoids agreed and ineffective discourses, has the particularity of giving a place to contingency against the programmed, to transience against permanence, to "becoming unknown against providence", in order to face a singular moment when PE will be subjected to a "chaos" of events, whose course it may not be able to control, or very little. The need will then arise to try to answer the following question, adapted to research and training: how to represent what is uncertain or subjective? Is it better (for oneself, for the community, for science in general) to use a certain reassuring model, but one that represents reality from too far away, or a vaguer model that would represent it a little better? Or who would better adapt to the situation?

The idea of prioritizing knowledge and the supremacy, or even exclusivity, of some of them is replaced by the idea that a plurality of rational or different "interpretative systems" capable, on the basis of distinctive rules of the game, of recognizing the share of reality, as well as the value of the insights projected on it. A "fuzzy" thought must be a thought that is free from the practice of orthodoxy that gives common sense and creativity every opportunity to develop, to express their specific potentialities of investigation, prospective and creation. This thinking should be characterized by an intertwining between the theoretical and the practical, that is, by confronting the concrete as it emerges and not with fixed plans, reductive forecasts, or even pre-established scenarios, in order not only to find solutions, but also to understand and ask the right questions.

Pierre-Henri Simon de Laplace's deterministic ideal should be shaken and the scientific strategy of PE should feel allowed to emerge from a reducing fatalism awaiting the next call for projects from national, European, or international principals, from a cozy conservatism in which it could tend to see the criterion of excellence satisfied (Hirsch 2005). The consideration by engineering sciences of the processes of notions of ruptures, new temporalities, irreversibility, creative disorder, or interaction must make it possible to no longer ignore the forced involvement of enlightened observers, disruptive actors with "fuzzy and/or complex thinking". The emergence of this thought should characterize a world of fluidity, of mutual trust where the researcher, the teacher, and the engineer can be located in between, between two worlds, between two cultures, in the middle of a redefinition of transcendence and immanence that deprives the thought of imperative reference points and only allows relative orientations. This certainly leads to responsibility, to possible mistakes from which we must learn, but it is a means of relativizing what we say and, above all, of finding original scientific and technological paths that will bring us to the future.

These various complex and interdependent exercises, which will be addressed in this book, raise the question of the roles and cultural diversity of students, trainers, and associate researchers (including, of course, teacher-researchers) who can construct their personal vision of the field based on the various elements of their professional lives (initial training, curiosity, research work, etc.). Today, these personnel, in relation to the previous unitary dynamics (emergence of PE), when they are proactive, allow a certain amount of time (Dubet 1994) and distance themselves from the system in which they are supposed to exercise their talents, with sometimes modest adherences.

The findings show that it will be necessary to address the concept of anticipatory merit, which presupposes that an assessment, taking into account the complexity, diversity, as well as the scarcity of talent, can be carried out with accuracy and relevance for a "body" of several tens of thousands of researchers and teacher-researchers in the public and private domains around the world. A first area of reflection will be to know if it is possible to have a small elite team of "scouts" and how we can judge the societal impact for tomorrow of their creativity, their unreasonable imaginativeness of the distant, and their associated scientific depth of view, provided that we give them consistency (what will be/is then the legitimacy of the evaluator?); a second axis of reflection will be to examine the influence of the "virtuous followers", wise, learned, but compliant. As producers of stabilized knowledge, they represent the necessary backbone of a research and/or training unit that needs to be based on common and effectively shared values; a third, which is not opposable to the first, plays on the development of links, both internal and external, disciplinary and/or interdisciplinary. They represent another form of intellectual mobility.

Between secure positions, the merit of scouts or ushers can only develop if a draught is possible, if it only exists for a certain amount of time, a space for action, and human and financial support to explore the uncertain with its real risk taking. There is therefore probably not a single merit, a single "excellence", but diversity, the harmony of skills (not only scientific) must constitute the richness of a field, provided that symbolic balances, non-aggressions, the opaque reality of certain local practices are overcome and that tensions between these tendencies are serenely managed, with empathy, sometimes under the paradoxical injunction to be "readable", "credible", "a motor", in short excellent. It is this governance that must strengthen a collective imagination to have a space of freedom and solidarity, freeing itself, as much as possible, from a "superior" administrative technocracy that thinks it can steer research/training to meet the needs of society (as it imagines them) and that continues to apply principles of "meritocracy" adapted to everyone and perhaps to nothing. But it may be the price to pay to continue to do business, if you know who you are and where you want to go (and how).

But the deeper question we are trying to explore in as much detail as possible is what the new scientific and pedagogical realities should be: which disciplines or "indisciplines" should be promoted by and for PE? What desirable state of the world do we want to reach and to what extent with "sustainable" specialists? On what (cultural) bases should we try to map out the paths that will allow us to consider achieving this objective? With whom? How to change (without destroying them) identity "beliefs"; get out of reassuring subjectivities and positively debate real concerted disruptive piloting on and around the domain (see European Union 2018), collective approaches, functioning on objects (teleology)? How to change the posture of actors; learn to create an environment conducive to creativity and exchange; explore new ways of working (especially through digital technology); etc.? These different concerns are summarized in Figure I.7.

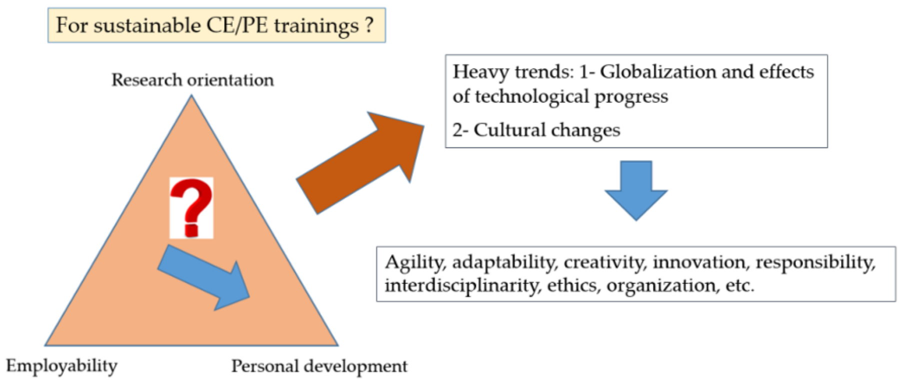

Figure I.7. *The need to develop training in a constantly changing world*

Moreover, at the end of the last century, one of the most extraordinary phenomena was the globalization of trade at all levels, with the notion of a sovereign State, covering its needs in consumer goods, becoming increasingly vague, if not just diluted in the electoral jargon of politics. Without having to take into consideration the concept of a post-industrial society (Bell 1976; Ingelhart 1987), as the production of goods using materials, energy and materials continues to grow worldwide, this internationalization of trade significantly changes the role of engineers facing new challenges: maintaining low-cost, but large-tonnage production on national soil, with an apparent modest intellectual added value, participating through individual or group creativity in innovation ahead of countries engaged in international competition and performance (Ehrenberg 1991). This kind of disarticulation and disintegration must thus reach the cultural foundations of PE confronted with new paradoxical spatio-temporal injunctions, in particular through the existence of formations that are still national (but with international openings to be reinforced or anticipated) for work to be carried out in an increasingly globalized framework, emergencies at the same time as a rational management of past productions (even if, as shown by JRC (2018), the current development in quantitative terms of engineering work continues to progress).

These different considerations are aimed at a common goal, that of the least bad possible action in a world of changing desires. Each, based on different scenarios that will be presented in this book, is built around an objective based on revisited values, problems to be solved, political and cultural constraints, etc. “We must not build a simpler model of society, we must accept it as more complex. We must not design a more solid system, we must imagine it more flexible. We must not organize a model, we must encourage diversity and movement” (Léonetti 2010). By treating, undoubtedly insufficiently and partially, or even biasedly, the future nature of our society, “new” paradigms of action to achieve new goals must be integrated, without leaving the present rational foundations, into engineering science training and research applied to the field of transformation of matter and energy. It is on the basis of a prospective work, with different scenarios to be presented, that it will be envisaged to define new goals for PE with new “typifications”. This “game” is possible with a necessarily flexible programming (a strategy?), leaving areas of uncertainty open to creativity (Amabile 1997; Christensen 2011; Crozier and Friedberg 2014).

In defining possible paths, we should not hide our faces. Knowledge of the real and the possible will be necessary to “optimize” paths of rebound from the slump and qualitative decline observed for a long time (despite some beautiful “replasterings” that limit the impression of a certain loss of readability), which will raise the willpower of decision-makers and will urge for the acceptance of real risk taking, part of the long-term process to make this important field of engineering sciences evolve positively. Indeed, it will be necessary to convince all partners and the configurations of actors involved before new disruptive cognitive models (normally provisional) are accepted and supported individually (essential appropriation mechanisms).

This reflection will require an analysis of the cognitive, emotional, affective (acceptability), epistemological, ethical, pragmatic, organizational, interdisciplinary, automatic activation of associations (e.g. stimuli linked to a past context) (Berthet 2018), the consequences of increasing information flows and their uses on paths proposed in “creative sciences to do”, etc. We should bear in mind that according to Sloterdijk (2006): “In a civilization saturated by technology, there is no longer any adventure, there is only the risk of being late.”

It seems that the debate is there, requiring us to move away from conformism elevated to the rank of ethics by many to an entrepreneurial culture resulting from a revitalized science with “sustainable” training more adapted to the world that is being created or transformed rapidly. Indeed, it seems natural to think of PE training and research in an open and dynamic framework that is dependent on and even anticipates transformations and representations on the part of the social body. “[There are] very deep doubts about the path of science, which shows less and less dialectical paths between them, with a kind of prevarication of the winning model [...]. In short, I don’t like a world of tacit blackmail. At this point, a debate should be opened on what it means to feel better and, above all, on the cost that others must pay so that we can feel better.” (Cantafora and Duboux 2002). In any case, for Sen (1984), market products and materials must always satisfy the classic criteria of novelty, utility, and development (image, ideology, values).

It is against this reflection, which is expected to generate discussions and controversies in the standard way, as the ins and outs are so numerous with their interdependencies (a fine example of an approach to complexity!) that it will be possible to measure its social utility in favor of the debate on redeployment that it supports, if not that it should generate. In attempting to proactively reconcile the active characteristics of the PE/CE elites with the systemic nature of the domains ("property of common integration of values" (Chazel 1974)) in which they exercise and will intentionally exercise their talents for a long time, the main idea is to move beyond the initial constraints as developed in this book in order to internalize them, appropriate them and, as much as possible, experience freedom as part of a constructive dynamic.

Thus, this introduction aims at a triple angle of attack of vertigo and questioning, of the scale of the issues and finally of a joint rebuilding of an essential field but which, by changing, must also better communicate its importance in technological developments for the "new" society.

> An engineer who loves his job must be convinced that he will be a perpetual student. He must always maintain the desire to expand his knowledge at the current rate of scientific progress. The one who does not budge from the notions he learned at the School will quickly be lost. (Le Goff 1987)

> If we think of innovation as a state of exception, it ends with proportional means: it is by redefining the fabric of the world, the beings that compose it and its regularities, and by also redefining the technical forms that the state of technological exception closes. After the technical coup, science is called upon to continue its work of describing beings in order to absorb the exception, to maintain a society where technology is neutralized, and to restore the liberal system to its fullness and coherence. (Fressoz 2012)

> Yet the forms of society, its works, the types of individual that arise in history do not belong on a list, be it an infinite one, of posited and positive possibilities. They are *creations*, starting from which new possibilities, hitherto inexistent ones, because heretofore meaningless – appear. (Castoriadis 1996)

> Results are achieved by exploiting opportunities, not by solving problems. (Drucker 2006)

> The procedure comes to take precedence over the objective, the mission is forgotten in favor of the rule. Our societies disembody in this way, and the reality of social and political work, as well as the spirit and values that guide it, are masked in favor of the method. (Beigbeder 2012)

This type of politics is nourished by a form of eternal present, its retrospective practice is of a pastoral nature. The duty of prospective to which a person is bound naturally escapes them; they lend themself only to it in a succession of modernist attitudes or expressions which make it possible to confuse the time of their person with an eternal time which exonerates them, forever, from all the consequences of their failures. (Rouger 2013)

Research [...] is a victim of motorway toll syndrome. This paradigm describes situations in which an ancillary device to improve the function of the system is so costly that it absorbs the majority of resources. (Ségalat 2009)

In academic terms, technical culture is, shall we say, a scientific field that includes philosophy, history, sociology, economics, information and communication sciences, to name just a few of the disciplines concerned. This leads to a more complex recognition of this field, because this interdisciplinary approach runs counter to the disciplinary approach of the National Council of Universities (CNU) at the research level. (Chouteau *et al.* 2015)

Any attempt to challenge prophecies by criticizing a particular technical device immediately raises the spectre of obscurantism, reaction and barbarism. (Jarrige 2014)

The technique can allow survival, through the sophistication of models or systems that are not optimal. In other words, it could, in the future, prevent latent epistemological revolutions. I would call this defect of the technical vision of the world “Ptolemy’s computer syndrome”. It concerns much more than the production of knowledge. (Malrieu 2011)

It may well be that modern society’s relentless drive for constant innovation and dynamism is the cause that undermines its ability for essential innovation and creative adoption. In this sense, a very solid form of sclerosis and blockage could appear behind the hyper-dynamic surface of late modern societies. (Rosa 2012)

The inventiveness and creativity of younger scholars is discouraged from going into interdisciplinary work, slowing down this work, making it intellectually and practically less attractive, and so on. (Sperber 2010)

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