
From “Autonomous” Research to Societal Solutions

[...] a complete work was not necessarily finished, and a finished work not necessarily complete. (Baudelaire, cited by Merleau-Ponty *et al.* 1993)

Researching is inventing the world; it is setting new rules of functioning for an ephemeral world. Not like the tyrants who also invent a new world for themselves, but impose it upon others. The researcher does not recreate the world, but rather unravels it to make it. They imagine one, then compare it with the real world to clarify it and not to exhaust it. Researching is an endless quest. The more we move forward and the less we know, the more we understand and the more we measure complexity. The more you empty the barrel, the less you reach the bottom. (Rose 2001)

No consumer today has even an approximate knowledge of the production technique of the goods he uses every day and most of the time he does not even know how they are made or by which industry they are produced. (Weber 1965)

Future factory designs and their footprints will likely favor modularization, with micro factories capable of mass customization using such technologies as 3D printing as well as digital manufacturing technologies. (Frost and Sullivan 2017)

In the modern factory, flexible manufacturing technologies facilitate the efficient transition from ideas to finished products. In addition, factories are increasingly communicating more closely with external

organizations and receiving manufacturing instructions from collaborating companies. In the industrial goods sector, global production networks take precedence over hierarchical supply chains. (Henn 2017)

Through the holistic application of new design principles and digital technologies, leading manufacturers can intelligently coordinate all aspects of their plant operations and integrate the value chain that runs from suppliers to end customers. The first manufacturers to succeed in transitioning to full-scale adoption will usher in a new era of industrial activity. (Küpper *et al.* 2017)

All meaning falls back on excellence. The only socially recognized meaning is to use one's life to become the best in one's field [...]. There is no meaning available for losers. The meaning of life is supposed to be in innovation, not in repetition. (De Conninck 2001)

Our societies seem to be developing a kind of 'fear addiction' in an aseptic world. The search for thrills becomes the rule for an intensification of the relationship with the world or for self-assertion. (Da Lage *et al.* 2008)

[The context and purpose of the study] represent a definite risk, because the understanding of individuals' attitudes and their impact on behavior is only partial. The attitude may be distorted or falsified because people can control their discourse, especially in the case of socially desirable behaviors such as eco-citizen behavior. (Hetet *et al.* 2013)

According to a survey conducted in 2010 by the European Chemical Industry Council, France is thus with Sweden, the country of the European Union where the image of chemistry, like that of chemicals, is the most negative. (Ferey 2013)

Because it essentially consists of transforming, modifying and synthesizing elements, chemistry is considered fundamentally anti-natural, associated with an aseptic and 'dehumanized' imaginary. (UIC 2018)

The notion is hybrid, the term equivocal, the risk is not a defined object or the stabilized product of a calculation, it is eminently relational. (Coanus *et al.* 2007)

For many years, the Glorious Thirties – the methodological development resulting from chemistry, extended to all processes of transformation of matter and energy – has constituted a collective basis for the development of research, open to other disciplines. The creation of a generic methodology has been the success of the process engineering (PE) approach, which is now being transformed into a world where traditional processes are either stabilized or outsourced, without research providing a more decisive contribution (André *et al.* 2013).

1.1. Positioning of process engineering

Process engineering has built its territory by becoming a recognized discipline in both industry and public research. But, as is often the case, nothing is ever stabilized because what is tangible is the product, its quality, the material and its performance, etc. It is the chemist who, through his mastery of the relationship between active compounds, provides for the transformation of matter. But, the hidden art of PE, by choosing the processes, by adapting them, by calculating them, honors in a hidden way, the mission of its own optimization so that the transformations are carried out with safety and efficiency, as required. It is difficult to explain to the layman who has just understood by buying a product that “it works”, that it is not only the practice constituted just by the juxtaposition of empirical experiences, but that there is scientific support for this “it works”, illustrating an irreversible emancipation of the sciences of teleology. But how can we explain it simply? We will certainly not go so far as to support Charpak and Broch (2002) who wrote: “Two things are infinite, the universe and human stupidity. But I’m not sure of my affirmation when it comes to the universe...”

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).

PE is not a static data, from which the question of what scientific knowledge represents could be asked, but a convergence of integrated knowledge, with the particular meaning of dimensionless numbers, to satisfy certain needs of society. To achieve this objective, there is an alliance between regularity research models and experimentation, the only current way to control these needs. However, this stabilized form of access to the intelligibility of new knowledge must not eliminate a power of invention to explore less usual phenomena, even those currently considered exotic or of no interest. However, this creativity must respect the arrow of time, the symmetry break between before and after, with a permanent reminder of the second principle of thermodynamics, to entropy and irreversible processes (Clausius), synonymous with forms of impotence in the fight against degradation processes.

The transformation of matter, the phenomena of transport, with an entropy production that is associated with exchanges, correspond to increasing entropies and do not correspond to reversible processes. In these dynamic processes there are differences between the past and the present, the application control of which constitutes the core of PE know-how, where we learn to fight in an optimal way against disorder by creating useful sources of coherence. But what does order or disorder mean if it is only a somewhat abstract convention invented by humankind to conceal/embrace certain concepts of repetitiveness, regularity and redundancy on the one hand, and variety, improbability and complexity on the other?

Today, with the mastery of balance equations and material and energy flows, the company's call to PE skills has been acquired. But the near future that is taking shape (before reaching thermal death in a very distant future) leads us to move away from the principle of sufficient reason and to reflect on the deterministic sequence of causes and effects that is the consequence. For example, dynamic instabilities (attractors) may correspond to a given initial state. The consequence can then be a probability distribution as can be observed in areas of complexity. Will we have to get out from above in PE of the calculable and reproducible phenomena currently under control? Or, in open systems, consider the possibility of the emergence of complexity, to create order from forms of disorder (von Foerster), to work on non-linear dynamic systems or to consider long-range correlations? So what then is it to understand the world of material and energy transformation in order to successfully apply it in the industrial world?

In any case, with its fundamentally historical culture of efficiency, PE, with its power to integrate knowledge, must retain its inventive character between humankind and the rational world of phenomena. The latter, as far as our discipline is concerned, must take into account contingencies, social constraints and acquired knowledge, but...

Box 1.1. *Positioning of PE*

Moreover, what the comments presented in the previous paragraph show is the existence of social demand, which is an important condition for the use of optimized knowledge for practical purposes. This situation gives rise to an old debate on what some call "applied science", while others are borderline, drawing their essence from more fundamental disciplines that need to be brought together for joint action. On these points, PE would only be a large interdisciplinary project without conceptual autonomy, having only application achievements. It does not seem easy to situate PE in a space of total autonomy and submission to demand (especially if it is strong, making it vulnerable (Bourdieu 2001)), it is for the authors a futile debate, since "it works". But vigilance must be maintained, not for a dialectical or dogmatic approach, but to verify whether the support for autonomy of independent thought, dear to Bourdieu (1992), is real.

Moreover, in an attempt to convince oneself of the need for a strategic approach, based on those that are forward-looking, it is interesting to examine, in the West, the development of the tertiary sector in favor of tangible or intangible production: productivity in 50 years has increased significantly by a factor of 10 thanks to automation, collective production processes and new technologies. The population has increased slightly (about 20%) and working time has decreased significantly (-15%). Apart from the production of superfluous or disposable goods (increasingly outsourced), can we not think that the uncontrolled complexity of production systems is one of the origins of the development of the tertiary sector? In this context, would the definition of new processes not have benefited from a more cooperative approach? What subsidiary role should PE play then? Organize interdisciplinarity and project management, develop, in consultation with partners, forward-looking approaches to foster innovation?

In recent decades, there has been a shift – felt strongly by the social body – towards the reduction of national production of goods in favor of services. This corresponds to a civilizational revolution that is reflected in a certain stagnation of competitiveness (often defined in terms of the increase in the average income of citizens).

It should be recalled that in the production economy, the impact of PE was threefold:

- progress in the mastery of new environmental and energy materials;
- processes allowing “efficient” production;
- products allowing mass production at the lowest cost.

Today, thanks to technological advances (IT, automation, electronics, etc.), production is carried out at a lower cost and in a more flexible way, integrated into the research areas of many PE units in the academic world. Thus, we are witnessing a new phenomenon, that of the decrease in the cost of production (reinforced by globalization) and the increase in the cost of design. There is a shift in value added, that is wealth creation, within the “supply chain”: from factories to laboratories and test centers; from production to distributors and communication companies. And it is in this integrative issue that these units are involved.

Thus, wealth creation must take into account the specific need or rather the demand of the public, which may be attracted by novelty, and the accumulation of consumer goods, and/or which is part of a new societal dimension (renewable energies, sustainable development (Da Lage *et al.* 2008), clean processes, pollution control, global warming, etc.). However, the object cannot be reduced to its sole functions for which it was designed; it is clear that every object recounts a posture, a way of seeing the world, a personal re-culturation. This important observation

illustrates the fact that we remain in the same culture, without any clear break since the object is permeated by it. So, to satisfy future applications through science, it is necessary to anticipate and get closer to society, in order to better perceive its future needs (in the same cultural context or in an adapted evolutionary framework). Perhaps it is a question of thinking of PE research as a technological and social process and thinking of the organization of research as a learning support. This is an original founding principle that serves as a basis for other principles. All of the following would be insufficient if we continued to work in the spirit of a top-down knowledge chain, because PE research is built within a network of actors whose quality determines the effectiveness of the research and development process.

In fact, by making it easier and easier to acquire “objects”, by reducing their useful life, by exploiting available reserves too quickly at low cost, consumer society knows that it is in danger of being destroyed; there is therefore both a desire for the new and for conscious forms of repentance. According to Girard (1982), “like any sacrificial mechanism, this society needs to reinvent itself from time to time”. To survive, it must reinvent ever-new gadgets. This form of sacrificial remedy is deployed in “fashionable” technological frameworks with their somewhat magical keywords: nanotechnologies, ambient intelligence, sustainable development, etc., which make it possible to set aside disturbances of the conscience for a time. In its driving role, PE can constitute a reference base for the development – in consultation with the socio-economy – of acceptable innovative processes, taking into account particularly the associated risks and the ways of dealing with them.

Regardless of this ambivalent but important aspect of attraction/pleasure for certain social groups, the anxieties fed by the citizen (perhaps by social groups) for their health, safety, freedom, are potentially blocking factors (the case of GMOs in France, nanotechnologies for example (Retzbach *et al.* 2011; Pillai and Bezbaruah 2017), because the possible added value is not felt, at least by militant individuals). This is how aspects of acceptability emerge, that in a factual way disrupt the course of events (pollution and risks to health, for example; see also Godfray *et al.* (2019)), but which define a need expressed by active groups and then by the Company and which must be addressed as such. “For information to be accepted, it is practically necessary that it be in advance in adequacy with what the receiver thinks, with his own vision of the world,” says Claude Thiaudère (1993), thus highlighting the phenomenon of cognitive resonance described by Daniel Bougnoux (1995).

The worlds, as a whole, form a system of references supposedly common in the communication process. Through this referral system, participants establish factors on the basis of which a general agreement is made possible. By agreeing on something mutually, the global relationship established by communication stakeholders is not only the relationship to the objective world suggested by the dominant

pre-communication model in empiricism. What the participants are referring to is in no way limited to something that takes place, can happen or can be generated in the objective world, but also to something in the social world or in the subjective world. (Habermas 1995)

“According to a survey carried out in 2010 by the European Chemical Industry Council, France is, together with Sweden, the country in the European Union where the image of chemistry, like that of chemicals, is the most negative” (Ferey 2013). There are then challenges for PE, which is a natural ally, to overcome. In this environment, the demand-driven approach, which can/should be worked on responsibly with representatives of bodies other than those of PE, must lead to a revisiting of scientific activities (objectives and distant goals) and, in particular, to a change in cultural basis. Optimization is no longer achieved on cost or energy, but on the quality of service, which changes many things, if only by strengthening interdisciplinary research processes, innovation and respect for deadlines.

This situation requires prospective reflection and/or integrated monitoring of trends in evolution and social perception, in order to deduce scientific activities to promote original research with a view to the marketing of new products, material or otherwise, or processes that are appropriate for strengthening the “well-being” of citizens. The contingent and strategic approach introduces a new element, that of controlling vulnerabilities, temporalities, space through cooperation (relational optimization) and knowledge of the cultural elements of the recipients of the services that could be put in place. In this sense, as desired by many managers, it is indeed a question of moving closer – in a risk-assessed activity, taking into account the real and possible – to the current operating methods of many companies, while at the same time guaranteeing the development of disciplinary achievements. The world around the researcher is working on new bases, so why not be a contributing factor in this innovative human adventure? How can it be transformed from a supply-side role to an anticipation of social demand? And social need? How can we control the relationships we have, that we will have with objects, knowing that they contribute at least as much as their properties, their functions, to give them an identity, contingent on the context in which they operate?

This apparently dual position, of a cultural paradigm shift – in an organizational and educational context still strongly controlled by Auguste Comte – led the Engineering Sciences, and then “successors” to try to fight, with the same weapons (in fact, those that were available), on the disciplinary field. This research, of good scientific quality, is certainly favorable to the development of healthy competition and sharp lucidity (this is desirable), but, due to the partial weakness of recognition, this has led to the emergence of somewhat pathological, defensive and introspective

situations (see research on a scientific paradigm applicable to process engineering, aimed at the emergence of a new discipline).

Is PE's ambition today, for the research work, to take up Lévy-Leblond's sentence: "Everyone knows or should know, that most of the time is devoted to trying to overcome the obstacles of thought and action"? The notion of challenge is therefore brought into play, which can potentially be expressed through a conceptual approach and/or on the basis of experience. In this sense, there is no opposition between fundamental and applied for PE since the basis is based on the notion of overcoming (and failing – let us remember Mulliez's provocation (2017): "Miss again; miss again; but miss better!"). In this context, we know through research against prior knowledge.

For PE, it is naturally necessary to have a vision and the scientific and technical capacity to take action, support from the hierarchy, time management, with a flexible and agile internal organization. The art of "combining" skills is an important factor for the success of a PE research operation, often interdisciplinary, in that it allows for creativity, the premise of which is always very fragile and fleeting. In addition, it is important to remember that the more uncertain and turbulent – i.e. risky – the more autonomous the project team must be in terms of process, organization and objectives and therefore supported by its supervision. This "normal" situation which invests the complexity of the systems to be studied and/or created, requires teams from various origins (present in PE for a large part) to allow an exchange of points of view and experimentation, going, whenever possible, to the demonstrator, the only one likely to allow, through feedback, measurable progress and the emergence of scientific obstacles.

The Gartner Institute (2017) has published a report on emerging technologies that increasingly involve artificial intelligence and digital technology. The hype circle they generally use is shown in Figure 1.1.

Gartner believes that the combined effects of these technologies will provide unparalleled intelligence, profoundly new experiences and platforms that will enable organizations to connect to new business ecosystems. For example, in the field of artificial intelligence, Gartner expects deep learning, the technology based on artificial neural networks, to become a crucial component of data analysis and guidance. However, as Figure 1.1 shows, it is new functionalities that are the focus for the authors of this analysis; hidden aspects such as the transformation of matter and energy, and the engineering associated with it, are completely absent (with the exception of additive manufacturing, one of the elements of the concept of Industry 4.0).

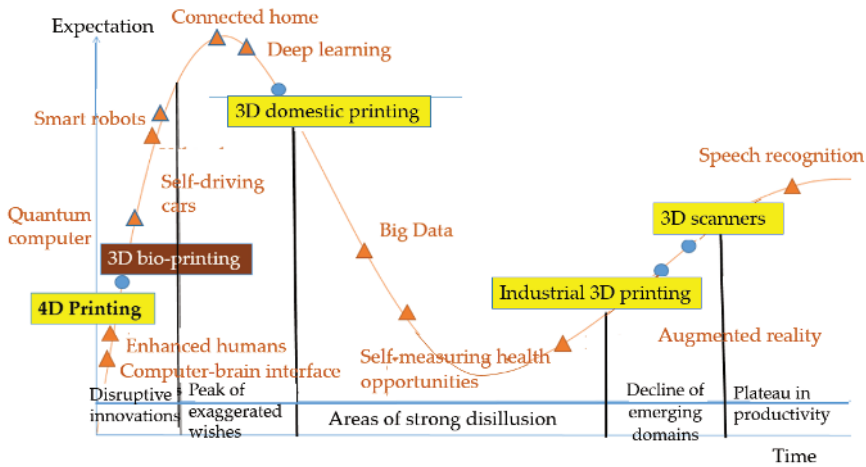


Figure 1.1. *Emerging technologies (with a specific focus on additive manufacturing). For a color version of this figure, see www.iste.co.uk/schaer/process2.zip*

On the other hand, augmented reality (AR) and virtual reality (VR) – because of their ability to blur the boundaries between the physical and digital worlds – are immersive technologies. They are expected to facilitate access to new types of content and profoundly transform the interaction experience of both customers and employees. There is therefore a global point of “fixation” on what is called artificial intelligence (AI), which is making extraordinary progress with its entrepreneurial field in manufacturing defined by the “Industry 4.0” label (AT 2017).

1.2. A forced transition

André (2019a), in his book on this theme, does not highlight the transformation aspects of matter and energy in the priorities associated with the development of the concept of “Industry 4.0” (see Figure 1.2). The energy, materials and chemistry behind it are “off the shelf”, which means that only the digital industries are of concern. However, what is shown is that the lack of control over the material processes of the future is and will be an increasingly constraining problem for the development of digital technology (for example, in 2050, about 50% of the world’s energy could be used by digital against the current 3–4%, the “readily” available rare earth elements will already be disposed of in waste, etc.). But today, in placing the user-designer client, “the current reference to a need for innovation multiplied at the level of each manager, combined with the egotistical tendencies of the nomadic hyper-consumer, who may also be unemployed and a victim of his/her own choices, is the precursor of a world that is complicated because conceptually and practically

now unbreakable: the object/subject distinction is disappearing” (Le Méhauté *et al.*, 2007).

Apart from the positive image aspect for digital, the polluter and the dirty aspect for the transformation of matter, the definition of new objectives is essential, if only to integrate sustainable aspects in the PE domain. However, it was shown in the introduction to this book that the PE field was alive and well with ever-increasing numbers of publications, numerous industrial links, etc.

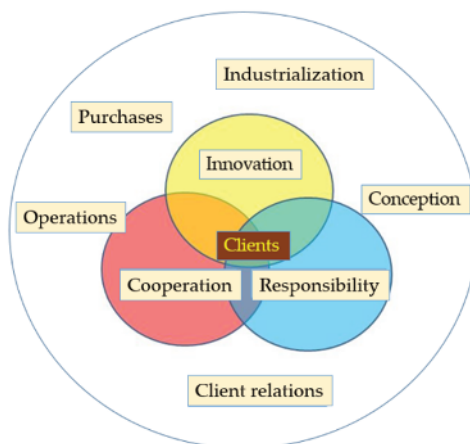


Figure 1.2. Industry 4.0 (source: Audéoud 2017). For a color version of this figure, see www.iste.co.uk/schaer/process2.zip

But is that satisfactory? On the one hand, the success of the field, finally recognized in academic structures, has made it possible to establish a dogma (paradigm according to Kuhn 1983) that guarantees the legitimacy of a field that must be interdisciplinary, while maintaining an engineering (or engineering science) culture, which is only very rarely a factor for creative development. On the other hand, with the display and exemplary success of digital technology, the best brains interested in science are turning towards the cutting-edge fields, those of which we are talking, those that allow scientific and technological breakthroughs. There are therefore, for PE, questions of attractiveness to be resolved (which are beyond the scope of this reflection).

Nevertheless, there are some studies concerning the expected developments in the chemical industry in the near future (Charpentier and McKenna 2004; Molzahn 2004; Chen 2006; Wickramasingha *et al.* 2007; Favre *et al.* 2008; Diaz 2010; KPMG 2010; A.T. Kearney 2012; IChemE 2012; Darkow and von der Gracht 2013; Morawietz and Gottpagar 2013; Valencia 2013; CEFIC 2014;

IChemE 2014; Deloitte 2015; Gosh 2015; NAP 2015; Parkinson 2015; Polytechnique Montréal 2015, etc.).

Figure 1.3 from Chen (2006) illustrates the changes envisaged for the future (nanotechnologies, biomass, etc.), Figures 1.4 and 1.5 present possible options for the future in the field of the chemical industries (respectively Darkow and von der Gracht 2013; Gosh 2015).

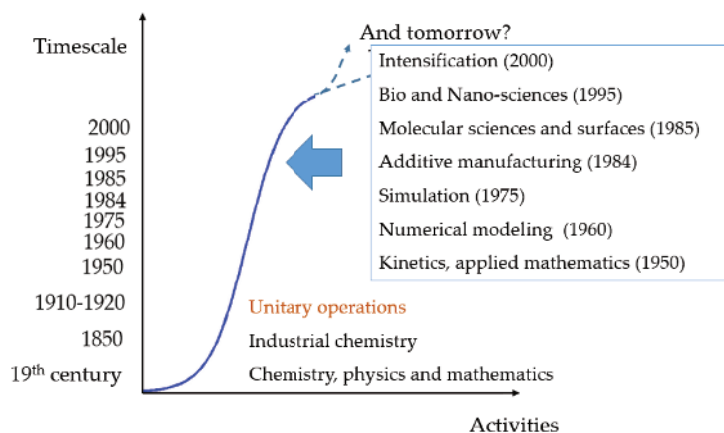


Figure 1.3. Evolution of the themes addressed by PE according to Chen (2006)

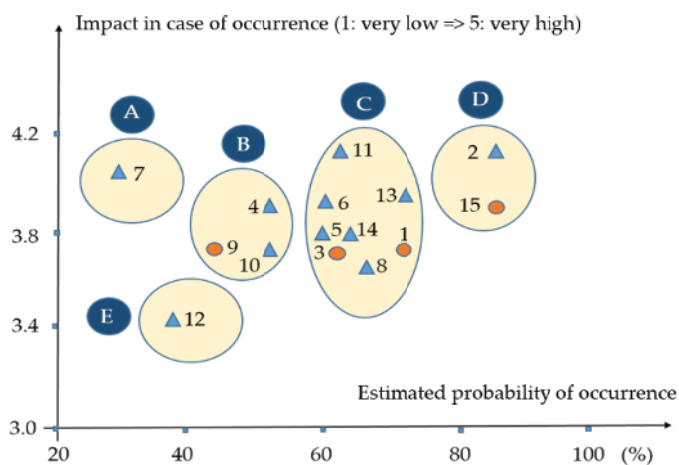


Figure 1.4. Possible disruptions in the chemical industries in the near future

COMMENT ON FIGURE 1.4.– A) *high-impact disruption*; B) *high-impact contingency*; C) *high-impact expectations*; D) *high-impact perspectives*; E) *medium-impact disruption*; 1) *uncertainty*; 2) *regulation and legislation*; 3) *new value chains*; 4) *industry attractiveness*; 5) *radical innovations*; 6) *dependence on oil*; 7) *change in production*; 8) *credibility of the brand image*; 9) *use of synthetic materials*; 10) *recycled materials*; 11) *competent personnel*; 12) *world hunger*; 13) *change in the composition of raw materials*; 14) *organic products*; 15) *importance of a sustainable commitment*. Triangles: *total disagreement by experts*; records: *consensus*.

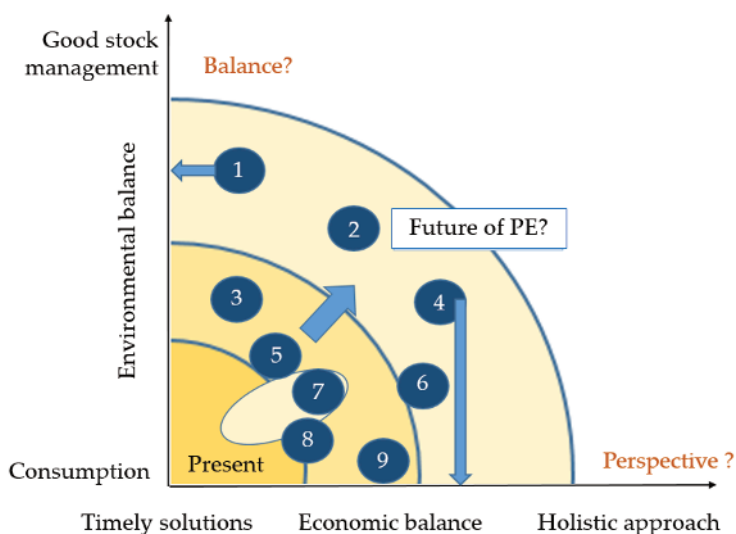


Figure 1.5. Positioning of economic and ecological activities in the future of process engineering activities with two strategic directions. For a color version of this figure, see www.iste.co.uk/schaer/process2.zip

COMMENT ON FIGURE 1.5.– 1) *carbon-free energy system*; 2) *systems approach for energy and transport management*; 3) *new chemistry for motor vehicles*; 4) *waste recycling*; 5) *recycling*; 6) *plant-based chemical industry*; 7) *lighter products*; 8) *functional improvement*; 9) *intensive processes*.

Cayuela Valencia (2013) offers a more continuous vision, with (non-radical) developments in the relocation of production sites, orientations towards new products, etc. (see Figure 1.6). This figure corresponds to a weakening of the European Union's position relative to the United States, China and India.

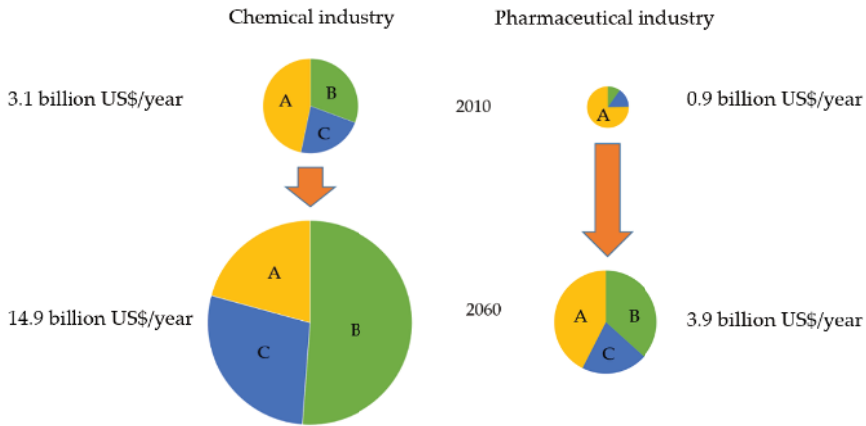


Figure 1.6. *Expected developments in chemical industry production.*
 For a color version of this figure, see www.iste.co.uk/schaer/process2.zip

However, whether it is PE or other scientific fields, there are very good reasons not to go too far off the beaten track of academic science, reasons that must be fought against but which are real. So, before discussing the aspects of the research, it seemed important to the authors to recall some of the facts of daily life, presented in a summarized form below (Larrivée 2017):

- the almost absolute sacralization of the quantitative in disregard of qualitative appreciation raises the question of the relevance of the reference (a fashionable and peer-recognized subject will be read more than a subject that is too innovative);

- as a corollary, a creative researcher deciphering unknown, unexplored or unfashionable tracks will have little chance of having their work published, of being read and even less of being quoted. An overly quantitative evaluation system is not used to take an ambitious or risky scientific position;

- for Phelps (as cited by Wolf 2014), the desire and ability to innovate would be less and this would also affect the traditionally creative sectors;

- “wage growth in advanced economies is disappointing, discouraging the invention and use of labor-saving innovations” (LNE 2017);

- the triumph of bibliometrics leads to a probably uncontrollable inflation of production: “unlike *Fahrenheit 451*, totalitarianism will prevail not by burning books, but by drowning the reader in over-information” (Durand 2009);

- to be recognized by their peers, it is a question of increasing their chances of being cited, hence the division of scientific work with a dilution of the knowledge acquired in the mass of biased information;

- regular self-citation in a series of scientific studies may become a rule to increase its so-called digital impact factor;
- the difficulty of a substantive assessment due to the time needed, possible competition, fear of liability;
- calls for tenders in engineering fields require a significant investment in terms of time and money with modest success rates;
- “Laboratory managers are increasingly dependent on sponsors from whom they must systematically apply for funding. Such a policy undeniably encourages the development of precarious employment and we are indeed witnessing a multiplication of fixed-term contracts linked to these projects” (Fossey 2004);
- the researcher is, because of this lack of support, doomed to reproduce what has already been successful, hence forms of continuity in innovative activity;
- weak support for risk-taking, etc.

A fundamentalist scientist behaves like a capitalist: everything happens as if his objective were to maximize his credibility capital. Indeed, what does a scientist do? First clue, he only talks about credits. In the morning, he talks about credit-credibility: is my hypothesis credible? How secure is my data? At lunchtime, he talks about credit-recognition: has anyone read me? Was I quoted in a good position? Is my poster well placed? Am I first among the thanks? And in the evening, he talks about credit-money: did I win this call for tenders? Have I been given this new research position? These signs [...] actually reflect part of the work and circulation of scientific capital. The basic operation of scientific capitalism is to convert one form of credit into another. (Latour 2001)

But now that we know that everything is moving in the direction of the gradient, can we remain in a wait-and-see position where others will take the first step to open up new research spaces that are useful for society? This is what one is tempted to do, knowing that the proposals are provisional, probably biased by our own culture and experience. But you have to take the plunge. When practicing PE sciences, it will always be necessary to study laws of behavior, while inserting them into a function of social and/or economic utility (teleology) (see for example, Letcher 2008; Towler and Sinnott 2013). As before, we will be placed, 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 must thus remain at the crossroads of epistemology (validation of science) and certain forms of ethics (validation of the application of science). For Amartya (2004), this should lead to the promotion of freedom, and therefore the values of autonomy, the lowering of inequalities, “to

bring fraternity to life and allow access for all to the applications of technological advances; objectifying the march towards a more just and enlightened society, guaranteeing access to rights in a vision that promotes the human being by establishing ‘capabilities’” (Hervé 2018). However, in the forward-looking section of a dedicated chapter, we will show that the constraints of reserve management can have significant effects on the freedom of citizens.

PE is not a static data from which the question of what scientific knowledge represents could be asked, but a convergence of integrated knowledge. To achieve this objective, there is an alliance between regularity research models and experimentation, the only current way to control these needs. However, this stabilized form of access to the intelligibility of new knowledge must not eliminate a power of invention to explore less usual phenomena, even those considered today as exotic or, for some, of no interest. However, this creativity must respect the arrow of time, the breaking of symmetry between before and after, with a constant reminder of the second principle of thermodynamics, entropy and irreversible processes (Clausius), synonymous with forms of impotence in the fight against degradation processes. It is part of a set of skills, as defined by MERN (2017) and shown in Figure 1.7.

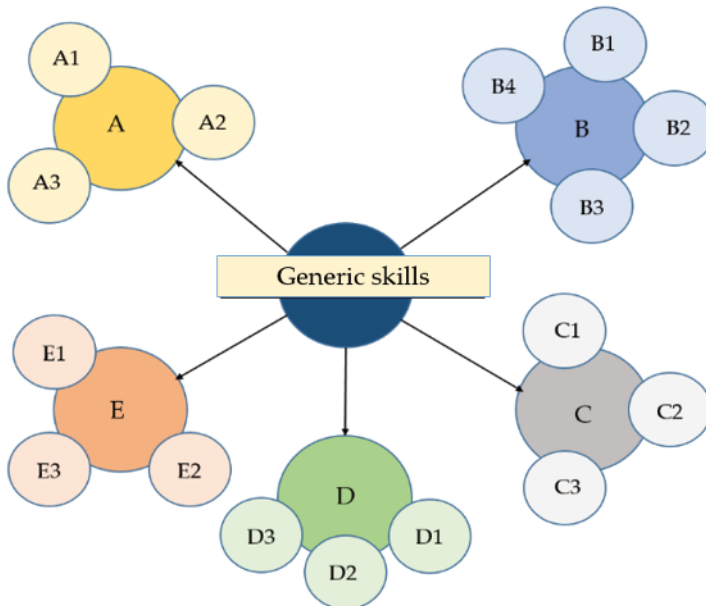


Figure 1.7. Skills required for research open to society

COMMENT ON FIGURE 1.7.– *A) social and emotional skills; A1) openness; A2) self-discipline; A3) perseverance; B) critical thinking; B1) ethical reflection; B2) digital competence; B3) truth seeking; B4) creative problem-solving; C) civic sense; C1) multicultural awareness; C2) social responsibility; C3) democratic principles; D) cooperation and communication skills; D1) entrepreneurship; D2) presentation skills; D3) group work; E) self-reflective attitude; E1) maturity; E2) personal development; E3) general knowledge.*

The transformation of matter, the phenomena of transport, with an entropy production that is associated with exchanges, correspond to increasing dissipation and do not correspond to reversible processes. There are differences between the past and the present in these dynamic processes, the application control of which must continue to constitute the core of PE know-how, where we learn to fight disorder in an optimal way by creating useful sources of coherence. But what does order or disorder mean if it is only a somewhat abstract convention invented by humankind to conceal/embrace certain concepts of repetitiveness, regularity and redundancy on the one hand, and variety, improbability and complexity on the other?

Today, with the mastery of balance equations and material and energy flows, the company's call to PE skills is acquired. To put it simply, it is based largely on the so-called onion model, presented in Figure 1.8 (Foo and Chong 2017), which defines a structure of thought that starts from the material transformation reactor. But the near future that is taking shape (before reaching thermal death in a more distant future) leads us to move away from the principle of sufficient reason and to reflect on the deterministic sequence of causes and effects that is the consequence. For example, dynamic instabilities (attractors) may correspond to a given initial state. The consequence can then be a probability distribution as can be observed in areas of complexity.

Will it be necessary to take the, currently controlled, calculable and reproducible phenomena out from PE? Or, in open systems, consider the possibility of the emergence of complexity, to create order from forms of disorder (von Foerster), to work on non-linear dynamic systems or to consider long-range correlations? So what is there to understand in the world of material and energy transformation in order to successfully apply it in the industrial world?

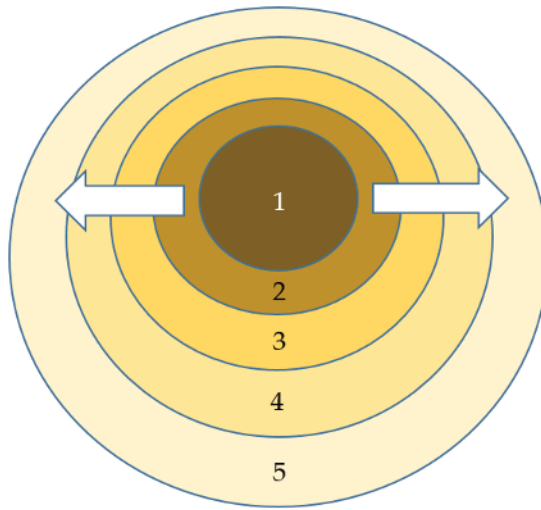


Figure 1.8. *The onion model in process engineering. For a color version of this figure, see www.iste.co.uk/schaer/process2.zip*

COMMENT ON FIGURE 1.8.– 1) *Reactor*; 2) *Separation and recycling systems*; 3) *Heat recovery system*; 4) *Energy system*; 5) *Waste treatment*.

In any case, with its fundamentally historical culture of efficiency, PE, with its power to integrate knowledge, must retain its inventive character between humans and the rational world of phenomena. The latter, as far as our discipline is concerned, must take into account contingencies, social constraints and acquired knowledge, but...

In our thinking, several interdependent situations may be at work. The first, of internal origin to the PE community, may target original activities that go beyond paradigmatic habits established over several decades; the second is to examine how external inputs (such as the artificial intelligence used to introduce this chapter or automation already widely used in companies, as illustrated in Figure 1.9 from WB (2017) – see also Appendix 2 of this book) can stimulate the field; the third uses knowledge of the chemical engineering sciences to integrate actions corresponding to finding solutions to the major problems of the moment (sustainable development, renewable energies, waste management and recycling, substitution, frugality, etc.). Depending on the approach, the facets of the research range from disciplinary deepening to the most complete interdisciplinarity (Guérin, Bouquet and Morvant-Roux 2016); from causal to systemic approaches, from bottom-up to top-down; the space is therefore very wide. With regard to demand-driven steering, it

seemed necessary in another chapter to return to a prospective study to identify possible courses of action that could be of interest for the future. This vision is shown in Figure 1.10.

NOTE.— From an industrial point of view, the breakthrough often develops in an almost subliminal way. But for different reasons (access to knowledge, conservatism, return on investment of recently acquired equipment, acceptance, etc.), the progression of the use of the new one follows a non-linear but time-consuming path! (Silverzahn 2017) – see also Appendix 1.

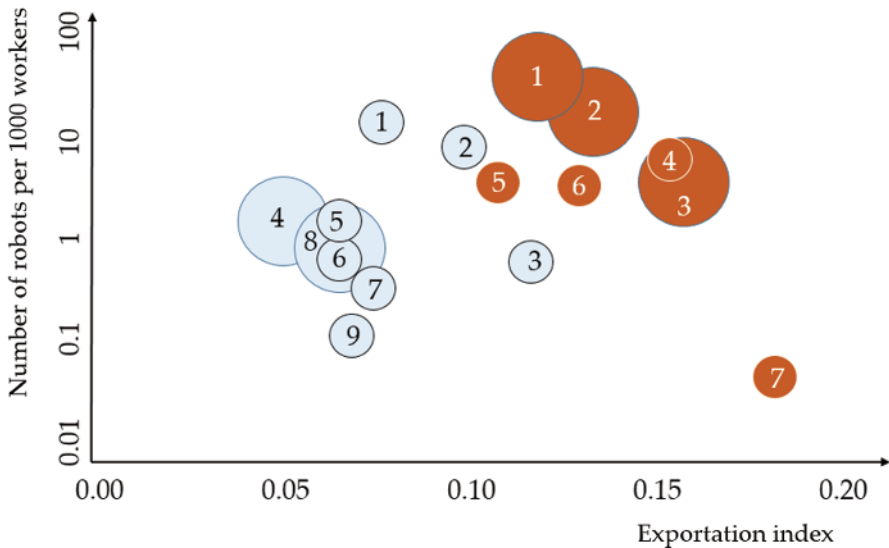


Figure 1.9. Example of PE association with automation-robotization.
For a color version of this figure, see www.iste.co.uk/schaer/process2.zip

COMMENT ON FIGURE 1.9.— In brick red: highly exporting sector: 1) transport equipment; 2) electronic, computer and optical equipment; 3) pharmaceuticals; 4) manufacturing and supplies; 5) electrical machinery and equipment; 6) machinery and equipment; 7) textiles and clothing. In light blue: low-export domain: 1) glues and plastics; 2) processed metals; 3) other non-metallic products; 4) food; 5) base metals; 6) wool and other textiles and natural materials; 7) paper and cardboard; 8) coke and oil; 9) chemicals.

However, as Varma and Grossmann (2014) point out, process engineering knowledge is found in many activities. It will therefore be useful to consider whether research should be directed towards generic activities, adapted to the

majority of application domains or, on the contrary, to the satisfaction of specific productions (see Figure 1.11), on possibilities for incremental innovations or towards real breakthroughs.

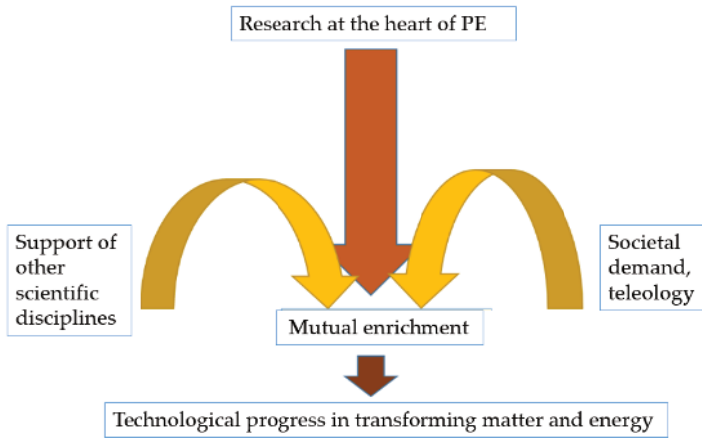


Figure 1.10. *Evocation of some of the major movements to be carried out in process engineering*

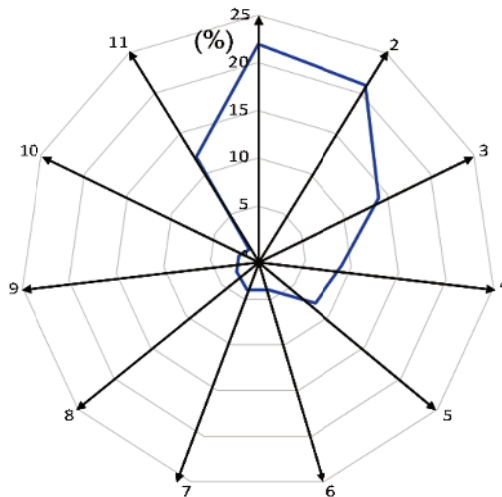


Figure 1.11. *Reminder of the areas of employment of process engineering specialists*

COMMENT ON FIGURE 1.11.– 1) Chemical sector (22%); 2) Petroleum sector (21%); 3) PE engineering and construction (14%); 4) Biotechnology and pharmaceuticals (9%); 5) Food and household consumer products (8%); 6) PE and environment (4%); 7) Materials (4%); 8) Electronics and information technology (2%); 9) Commercial services (2%); 10) Pulp and paper/paperboard (1%); 11) Miscellaneous (12%).

According to Ghosh (2006), all the capabilities/missions of process engineers are very important in terms of the specialties to be promoted and openings to other disciplines, as shown in Figure 1.12.

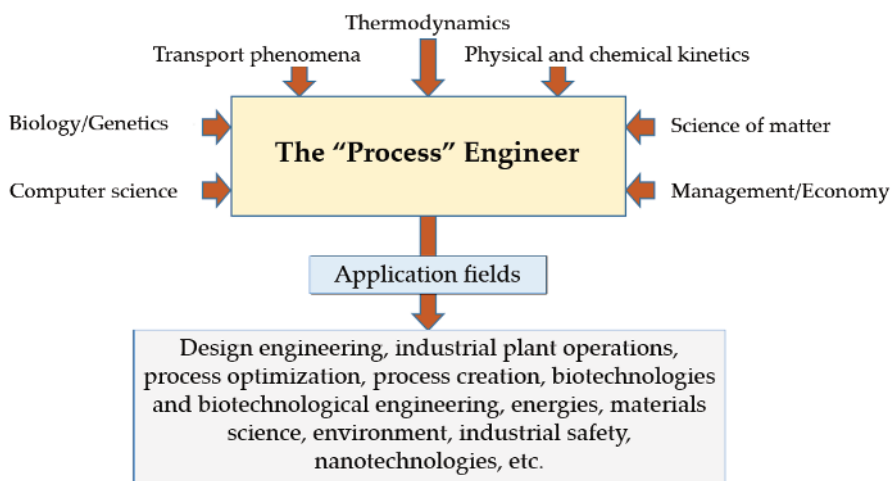


Figure 1.12. Key positioning of PE

The elements presented in this framework, related to the development of process engineering, will be the subject of specific insights in the following four chapters: Chapter 2: highly “autonomous” research; Chapter 3: externally stimulated research; Chapter 4: research in response to societal questions; Chapter 5: list of possible actions in process engineering (not exhaustive). However, these elements, presented in broad strokes, have consequences for action in the field, which constitute the concluding chapter; Chapter 6: consequences and an attempt at an operative conclusion.

NOTE.– Given the interdependencies between the areas explored in these six chapters, the references for these five chapters were compiled at the end of the last chapter to avoid duplication.