

**Self learning and “transdisciplinarity”
in industrial processes studies
or industrial surveillance at the EMAC
(Ecole des Mines Albi Carmaux)
To learn complexity,
to understand and act in complex systems**

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“The process engineer has commonly to face all problems at once without being able to isolate the contribution of each scientific field because of the feedbacks and couplings which exist between the processes involved” (J. Villermaux, 1993).

Sharing this perception, we have developed a teaching programme based on the formalization of the processes in complex systems. To prepare **the student-engineer to live and act in the uncertainty, we have chosen to make him autonomous in his training** by programming in each year **a complex study involving scientific, technical, technological and “societal” aspects** (Sablayrolles & Falempé, 2006).

We describe here a **methodology of accompaniment** of each student for the examination of a **real process in the industrial world** (comprising inputs, outputs, utilities, unit operations and the way they are linked together, economy, organization, human and environmental impacts). This is achieved with a broad survey of possible improvements and imminent processes of substitution. This **“transdisciplinary” study** is carried out alone on a process selected by the student according to his intended professional project (**as many subjects as there are students, which means over a hundred “learning system” every year**).

Today, we can say that this methodology of accompaniment has been mastered and the teaching contribution to each work (6 hrs teaching per student workload of 120 hrs minimum) is feasible and irreducible. The main factors of success mainly depend on: the definition of the concepts shared in the institution, the strict definition of the scope of the work, the “transdisciplinary” tutoring and a **strong relationship between the teacher and the student through face to face meetings** with a very precise demand of outcomes. Individual tutorials are alternated with group meetings in interactive lectures. The teachers who conduct and take part in these studies are in permanent self teaching on STTS (Science, Technique, Technology, and “societal”), in order to help students to make the decisions appropriate to the complexity of their “learning system”.

We think that the success of “transdisciplinary” self learning in process engineering has been able to develop largely thanks to information technology (the students have **total access to all human knowledge, good or bad**, available in electronic form) but it cannot be done by e-learning alone. Man is not yet naturally totally digital.

1. Context : evolution, acceleration, uncertainty

In 1992, time of the foundation of the Ecole des Mines d'Albi-Carmaux, a generalist engineering school in process engineering, it was already no longer possible for a generalist engineering school with a teaching structure based on conventional didactic techniques, to offer access to all the knowledge and competence that may become necessary for an engineer throughout his career.

Due to its constant evolution, the “business world” does not offer long-lasting career perspectives to its staff. Changing of company, of specialisation, of role inside the company, in short of job, becomes ever more necessary for the engineer.

Fields of knowledge have been enlarged, scientific competences and their applications evolve at an ever fastening pace. The engineer constantly has to update, or even to renew his “knowledge”.

In spite of this constant updating, the engineer is and will be regularly confronted to situations where he will have to make decisions with an incomplete knowledge of the parameters- the missing data being unavailable in the allotted time. **He will therefore have to take action without complete assurance on the system which he is part of as actor/ observer- this system being complex precisely since it is unintelligible at the moment of the decision making.**

2. Complexity raises questions, systemic analysis provides answers

Dealing with complexity is a natural dimension of mankind. The innate awareness of this complexity is more or less developed according to each individual. But in the case of the training of engineers, no matter the level of awareness and competence of this complexity, such a level is nowadays insufficient to meet the needs of what is required by the professional world in which decision making is an essential dimension.

The aim of this study being presented is to enhance the awareness of complexity among engineering students, and more precisely among students specialised in process engineering.

This can be achieved by avoiding the two extreme situations identified at the moment of the realisation of the complexity of a problem: the inhibition of any decision making (incapacity of making a choice when a choice has to be made) on the one hand, and on the other hand, the shirking of responsibility, (that is thinking that, **in any case**, one's decision will have a minimal effect on the evolution of the system, therefore one is not responsible)

The challenge facing our teaching programme is the following : **“How to respond to the evolution of our complex teaching programme of process engineering, to train our students to adjust to their future complex systems. What didactical means must be established?”**

Self-learning appears as a frequent answer to this question. But, in our case, is it sufficient to develop the “learning-skill” (H. Trocmé-Fabre 99) and (P. Carré 2005) “*the durable set of dispositions favourable to the act of learning in all situations*”

From our point of view, the answer is yes, self-teaching as satisfactory regarding the learning know-how. However, we consider it is insufficient as regards “understanding, apprehending, and acting”.

Similarly, **the “learning skill” guarantees the acquisition of elements, but does not**

guarantee the acquisition, at a precise moment, of an encompassing vision of the systems, nor the acquisition of the capacity to make this vision evolve.

The systemic approach is the answer at which we have progressively arrived.

3. Complexity and industrial surveillance at the EMAC : study of real industrial processes.

In their analysis of real industrial processes, students will necessarily have to vouch for their understanding of science (i.e.: why it works), of technique (i.e.: how it works), of technology (i.e.: what it works with) and of the “societal dimension” (to whom, for whom, from whom, with whom it works). These four components enable students to go beyond the stage of understanding itself, to the identification of the problems and the suggestion of potential improvements and of future processes.

The person responsible for the accompaniment methodology has to supervise the managing of these **six complexities** :

a) The complexity of the context has already been presented.

It corresponds to the complexity in which the engineer will be immersed once he has graduated, and which will require from him to take risks and make responsible thought-out decisions.

b) The topic of this study, the process is often complex

Sales and competitiveness are dominated by the end-use properties of a product as well as its quality. Structure and function, which confer its quality to the product, are determined at the nano and micro levels but are synthesized in a reactor at the mesoscale. Consequently, chemical process engineer must deal with various length and time scales (Grossmann and Westerberg, 2000). This multiscale structure as well as the non linear and non-equilibrium phenomena involved in the production units are the common nature of a complex system. These couplings are still reinforced by new operating modes and by design of multifunctional reactors, resulting from process intensification. Lastly, on the macro-scale, the process are no longer selected on economic criteria alone. The engineer must consider safety, health and the environmental impact.

c) Industrial surveillance works are complex because :

- **processes are chosen freely by the students**, at a moment when they cannot anticipate their choices in relation to the information which will have to be researched and studied (knowledge and comprehension).

- **the information handled is uncertain**. Indeed, the aim is not to make the student work on a defined and limited corpus of academic sources, but to let him in the totally unlimited current field of knowledge good or bad. Great use is made of the digital field. Thus, no result can be anticipated. This approach is totally different from traditional teaching methods, and even from the situation based on problem based learning (PBL).

- **the level expected at the end of this research** (on oral and written evaluation) is the level of a professional prospective : someone able to predict events yet unknown thanks to the elaboration of scenarios which generate anticipatory strategic options.

d) Concerning the tutoring, the implementation is complex :

First of all, each system, made of the exercise required, the student, the chosen process of the study, the environment we referred “learning system” is specific. Indeed, each student is unique, and every process is different.

Besides, the point is to allow total freedom to the “learning system” concerning the possible ways to achieve the end of the exercise. The meeting point offers the possibility to the training staff to check whether a number of elements have been acquired or not, and to intervene, through methodological advice.

e) For the student, the study is complex.

The learner intends to make as little effort as possible in the system where he is immersed. By so doing he underlines a characteristic of complex systems consisting in minimising the resort to its **homeostatic function**. He does not understand the concepts, let alone the contents, and must appropriate the objectives and the tools for success, among other things. The milestones give him limits and deadlines which remind him that reaching his objective remains uncertain and help him to regulate his commitment towards his objective (faculty of self-management of complex systems).

f) Lastly, these studies are not disconnected from the programme

In the environment close to this action there are similar topics of research, at least outwardly: that is to say the projects, PBL, and there are also different types of study: that is all the conventional teaching : lectures, tutorial, experiments. The management is difficult since if an outside observer may deem them complementary, another observer may consider them as diverging thereby creating an antinomy.

4. The accompaniment of the Real Industrial Process study

The choices have been made on proposals based on a **systemic and iterative analysis** (J.L. Lemoigne, J. Lapointe).

The deadline is made of :

a). Three lectures involving discussions and group work: the 1st lecture aims to introduce the project, to present the scope and the concepts, the diffusion of the scope of the research and the evaluation sheets to fill in before each appointment. The 2nd lecture is focused on the first collective assessment of progress. The 3rd one is dedicated to the second common assessment of the progress made by the students. These group meetings take advantage of the emulation among the students to raise all the questions which have not been treated, concerning the scope, the difficulties of the study, and the results which are expected...

b). Two individual appointments, involved within the student’s timetable. The dialogue starts with an empty sheet of paper, and develops thanks to diagrams, sketches, symbols, blueprints...(and so on) This step aims to check and clarify the coherence of the student’s reflection and of his presentation. At this stage, within a half hour, the student presents:

- at the first meeting/ 1st evaluation sheet: the topic of the study, the problematic of the production/ fabrication, the limits of the scope of the process, the inputs and outputs (material-energy-data); with the professor, the student checks that he has identified the areas to explore the S.T.T.S. (science, technique, technology, societal).

- at the second meeting/ 2nd evaluation sheet: topic, current and future problematic, and all the aspects of the process : S.T.T.S. for each of the transformation, of the material, the energy, of the information, circulation network of these three vectors, their outcome, connections between the different unit operations, feedbacks and linkages.

E-teaching is only used to answer simple queries. When the question is complex and

requires an expanded answer, the student must make an appointment with his professor.

5. A cross-cutting organisation

A specific department is dedicated to this teaching and to the other **multi-disciplinary** and horizontal studies (patent studies, marketing studies, and projects, for instance).

This department is multi-disciplinary, trans-structural, trans-temporal:

- The multidisciplinary dimension : The department covers every field of study (mechanical engineering, automatic engineering, process engineering, industrial engineering, human and societal dimensions).
- The trans-structural dimension: Whatever the organisation of the teaching (according to years of study, departments, options, or centres of research) the teaching is in close relation with the other components of the school. It is transversal by its methodology (organisation of the work and of the **papers turned in**)
- The trans-temporal dimension: from the student's viewpoint, the department supervises their 4 years in the engineering school.

This organisation enables to **de-compartmentalise** the different fields of study, highlighting the **horizontal connections within the whole system** and enables to grasp the complexity, for the professors and the students.

6. A reasonable workload for the professor

Given the aim of the exercise and the results obtained, the workload for the professor is reasonable and limited, and we have reached its optimal level.

Thus, neither is it totally inexistent (full self-learning on the part of the student), nor is it excessive (as it could be imagined on account of the combination of a subject of study chosen by each student, with an individual monitoring).

The total amounts to 600 hours for 100 topics of research, which represents **6 hours** dedicated by the professor to each student (including the oral and written evaluations). The yearly time allotted to each student amounts to **120h**.

7. An increasingly specialised group of professors

Staff professors and visiting professors working on this teaching programme have a transdisciplinary training and experience, and are used to working in complexity. They have a thorough knowledge of the business world, and are prospective of its evolution.

They ensure the follow up of the surveillance work, and by diversity of the topics, they are very interested in the evolution of latest technologies, and the evolution of the organisations of companies. Professors are the paradigm of "learning skill".

8. Some keys for success

- *The student chooses the topic of his study, that is to say his process and its scope.*

This enables him to develop his knowledge in his favourite field relevant to his career prospects. This should boost his motivation as a student.

- *A cross-cutting tutoring concerning the fields of knowledge and the methods, a multi-disciplinary staff.*

The topics and the requirements of transdisciplinary studies enable to de-

compartmentalise the different scientific fields and courses, to establish connections between them and to understand how they interact on each other.

A structural cross-cutting tutoring enhances this dynamic of “de-compartmentalising”.

- *Participation during the lectures.*

The learning process is a process in itself.

- *A very strict framework, very precise and shared terms*

These exacting landmarks must be shared with the tutors, but the tutors themselves must also share the same exactness.

- *Face to face appointments.*

The necessity of maintaining a physical connection must be stressed. This connection will be of a face to face and oral nature. Men are social beings and we give a prominent importance to the benefits of kinaesthesia and feelings (Hourst 2005). After twelve-years’ experience, we consider that distance self-learning is inefficient to deal with the question of “complexity”. Men are not digital beings yet.

- *High expectancies concerning the quality of the papers turned-in.*

The student must be taught to be more professional during the course, so that he can reach the expected level concerning his faculty to learn, and his overall vision of the systems in which he is immersed. Maintaining constraints concerning the respect of concepts is a prerequisite to ensure the evolution of the student in “complexity”.

- *Precise and “open” evaluation sheets.*

These evaluation sheets and the framework are given to the students at the beginning of the exercise. Knowing this evaluation sheet enables them to define more accurately and to appropriate the aim of the “learning system”.

- *Marked and commented/ annotated assessments on each item.*

Indeed, just like for the measurement of any physical characteristics, the measuring tool and the action of measuring change the value of the measure.

- *The tutor can not and must not be judge and jury.*

The person who evaluates must not have followed the student throughout the contents of his study, but must only have followed him regarding the framework and the concepts concerned.

- *No extension can be granted*

Indeed, deadlines are at the core of the method which does not suggest any specific procedure to the students.

9. Conclusion

The twelve years’ experimentation of this training, and the feedback we got from former classes of engineers currently progressing in their professional career, give us full confidence in the pertinence of our method. This process study through self-teaching guarantees learning skill. The topics and the framework of the study, both cross-cutting, enable the students to de-compartmentalise the different fields of study and to have an overall view of the systems to which they belong. The unrestricted access to the knowledge and intellectual limits of mankind, that is, a space whose scope has been greatly expanded by digital technologies, enabled them to develop their own faculty of self-questioning and their capacity to make responsible decisions in an uncertain system. Managing these six “complexities” (professional context, process, work required, implementation, student, relation with the teaching contents and

methods) by the same body guarantees that the students will be able to **learn, understand, feel and take action in the complexity of systems**. That means that will be competent in the “real life”. **They will be able to anticipate in an uncertain situation, and suggest strategies and make responsible decisions**. Let us not forget that these process studies in self-learning and cross-cutting mode are combined with traditional modes of teaching of process engineering, they are not in themselves a sufficient solution.

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