

Vincent Boly, Laure Morel, Mauricio Camargo¹

*Innovation management: twenty-three years of higher education
in a French engineering school*

ABSTRACT:

Innovation management is a major educational concern within business schools as well as in engineering schools. Besides technical, economical or marketing skills, new abilities are required in companies for people in charge of R&D-I services, the elaboration of the technological strategy or the piloting of innovative projects. As a consequence, new courses are continuously being developed to prepare future top managers to assume innovation responsibilities.

The École Nationale Supérieure of Génie des Systèmes et de l'Innovation (ENSGSI) has twenty-three years of experience teaching innovation to engineering students. The objective of this paper consists in going into deeper detail about the process of elaboration of the educational program and in exposing the main characteristics of its pedagogy. The ENSGSI program has been elaborated using two main conceptual foundations. The first one is the modeling of the processes to be managed within innovative companies. This model integrates: the main innovation management practices in the form of operational levels that decision-makers focus on and the corresponding methodologies (Boly, 2009). The second foundation is an Employment Competencies Referential. It consists of a list of skills and attitudes established in collaboration with human resource managers of international companies and French SMEs.

As a result, attention is directed toward these two paramount foundations when establishing and renewing: the nature of the courses, the pedagogical objectives and the evaluation approach of each module, and the links between the different modules.

KEYWORDS: innovation, technology management, education, competencies, pedagogy.

¹ Professor Vincent Boly, Professor Laure Morel, Professor Mauricio Camargo. Equipe de Recherche sur les Processus Innovatifs, Université de Lorraine, 8 Rue Lepage, 54000 Nancy, France. E-mail: <vincent.boly@univ-lorraine.fr>; <Laure.morel@univ-lorraine.fr>; <Mauricio.camargo@univ-lorraine.fr>.

Introduction

Innovation management is now a major educational concern within business schools as well as in engineering schools. Within innovative companies, people in charge of R&D-I services generally attest to a great experience in terms of technology, the specific needs of the company's customers, or the functioning mode of the organization. They are involved in the elaboration of the technological strategy and/or the supervision of projects. But as attention is more directed toward innovation, many companies propose assignments in the field of innovation to young people: they collaborate on new product development studies or get more responsibilities, mainly in small and medium companies where knowledge about innovation processes is weak. Besides technical, economic, or marketing skills, new abilities are required in companies for people in charge of these processes and it can be hypothesized that particular jobs have emerged. Moreover, innovation processes have a highly evolutionary character due to competition, new strategies developed by companies and a better understanding of innovation processes through academic production (McGee & Thomas, 2007). Thus corresponding responsibilities are moving. Some recent phenomena may be highlighted, including: openness (companies collaborate with partners to innovate; these may be customers, other companies, social networks, or internet contributors) (Chesbrough, 2003), interdisciplinary activities (innovative concepts emerge at the boundary between different technical and scientific disciplines) (Guang, 2016), and agile design (new operational sequences between studies and material artifact elaboration) (Roucoules and Tichkiewitch, 2015). As a result, new educational programs are proposed to train people involved in innovation tasks. This paper is based on the experience of one French team of former innovation process researchers: they launched an engineering school dedicated to innovation management. Since 1993, Ecole Nationale Supérieure en Génie des Systèmes et de l'Innovation (ENSGSI-Nancy-France) has been providing training courses for engineers of three years and five years in length (integrated course with an option for two preparatory years on top of the three-year engineering course) (Castagne, 1987). ENSGSI-Nancy-France has today achieved an average of 75 students per course. Final employment areas of the engineers cover a large range: manufacturing and services. The employment rate before obtaining the

final diploma is 65 percent on average and the maximum employment search period after school is six months, corresponding to very good outcomes in the current European context.

To fulfill the global educational objectives, a structured approach has been established in order to go into deeper detail in the description of the professional skills required. This approach is regularly renewed to adapt to recent labor market trends and theoretical models are used to organize updating programs. One special interest is taking into account all the different forms of in situ situations (designer tasks versus strategic tasks, long-term versus short-term activities among others). More precisely two referentials are proposed to define a fundamental corpus in terms of education (Yanez, 2010). One referential consists in a theoretical model representing the innovation processes: the aim is to describe the «domain to be managed». The second referential lists the general competencies required to manage uncertain processes. Then, by combining the general necessary skills with the constraints of the process model, it is possible to define the ad-hoc skills: «what an engineer has to master in order to pilot innovation within companies».

The first educational referential: the five innovation process management operational levels

One referential is used to go into deeper detail about innovation piloting activities, and consists in establishing the description of the tasks to be managed, with consideration for: the type of people in charge, a temporal dimension, and the associated methodologies. This referential helps to define the different professional profiles related to innovation management (a designer does not have the same tasks and objectives as an R&D & Innovation department head) and as a consequence a training structure has to distinguish different courses. Secondly, innovative projects are complex as decisions about product, production processes, sales modes, and the business model are interdependent. Moreover, decisions at the top management level are interconnected with those made at the design team level. Then, students have to understand the interrelation between the different

training modules and, consequently, teachers have to visualize the relation between their training and the rest of the program. Innovation processes appear in industrial systems in the form of technological innovation management actions, knowledge management practices, and organizational change operations (Linton, 2009).

Thus, five innovation process management operational levels are proposed by Boly *et al.* (2014), each constituting a sub-process, an area of action. This theoretical model is then valorized to distinguish five different types of interconnected courses. More precisely, it is possible to elaborate the structure of the program by a cross approach between the general competencies to be mastered and the five fields of coherence and coordination.

The innovative object itself represents the first level. It is the artifact of the process. It can be a technology, a process, a service, a product, or even a business model. Its nature evolves during the process: from an idea to a technical or marketing concept, a specification form, a sum of solutions, a prototype... As a consequence, the status of the new object is alternatively a sum of knowledge or a concept. The process may be modeled with any representation describing a technological system, with the concept of Intermediary Design Object representing the sequence of material aspects taken by the new products (Tichkiewitch & Brissaud, 2000), or through the concept of product lineage (Le Masson *et al.*, 2006).

Individual and collective stakeholders inside the company with their mental activities represent the second level. It is the level of learning processes and cognitive assets (Baharadwajb, 2000). Depending on how he views his role within the company, an employee may become an important actor, influencing only his immediate surroundings or spreading newness all over the organization. This level is concerned with learning the knowledge required to master new technologies: newness appears when designers succeed in solving new problems and, as a consequence, when they learn from a new experiment or when they acquire new knowledge before trying to overcome a new obstacle. Moreover, «think different» is a basic assumption in innovation, meaning all approaches and behaviors that help people to adopt new

reasoning modes are important. The main logical sequences developed by innovators constitute cognitive processes to be known by students. They also have to be aware of their cognitive approaches in order to develop mental ruptures.

The third suggested level is the innovative project. It is the design activities support level. The project is a complex system made up of acting employees, means, and actions. These elements are assembled in order to satisfy a demand from marketing or top management. There are several starting points for innovative projects, including: customer demands, technological survey outcomes, and ideas emerging from creativity. The major characteristic of the project level remains its time constraint. Project management is a major concern at this level, but differences between innovative and non-innovative projects have to be taken into account: a high level of uncertainty, information incompleteness, and intellectual property among others.

The fourth level relates to the company globally and its particular way of managing innovation. It is the global mastering level of the unit's innovative potential. Among others: know-how, methods, experiences, and incentives. This domain is concerned with strategy, culture, and general organizational schemes (Koc & Ceylan, 2007). In contrast to the previous level, it is a permanent process.

The external environment of the firm and its networks constitutes the fifth level. There are two dimensions at this level: institutional and industrial. Government through various structures stimulates innovation in their territory. The management of these structures in relation with companies and entrepreneurs attests to particular tasks. Finally, open innovation, co-innovation, and partnership induce specific collective sequences of activities in order to launch new interconnected activities and products (Huizingh, 2009).

Hence, from an educational point of view, teaching innovation management corresponds to being prepared to manage these five sub-processes. The model is then transformed on the basis of five professional objectives and the innovation training is organized for five related modules.

The five-level referential finally consists in considering innovation as processes. And consequently the aim is to develop the student's abilities to manage these particular processes. Indeed, innovation can be considered as a non-linear chain-linked model, characterized by the following aspects:

- Two temporal dimensions considering that, in parallel with permanent tasks, some activities include time limits. More precisely, students may be able to pilot projects with a beginning and an end. Moreover, the innovation process integrates permanent data collection and treatment approaches in order to prepare future projects. Both technological strategy definition and improvements to innovation practices are ongoing activities. Consequently, students will be confronted with the management of a permanent organization dedicated to innovation. Moreover, they will have to deal with a complex contextual organized process. In fact, the nature and quality of both the innovation process and its results are highly dependent on the external environment of the company and on the culture of acting employees (internal environment).
- The confrontation between routines and non-routines. The innovation process mainly corresponds to a knowledge creation process (Shu-hsien, 2008). Students then face a paradox: how to reinforce the technical capacities to manage the innovation process and thus to generate routines, and simultaneously, how to change the referential at the firm's global level in order to break the routines and, as a result, favor creativity?
- The C-K properties: This model is a new theory of design called C-K theory, elaborated by Hatchuel and Weil (Hatchuel and Weil, 2003). According to this theory, designing products requires an interaction between a knowledge set (referred to as K) and a concept set (referred to as C). Knowledge space (K) gathers propositions which have a logical status for a designer or a group of designers. A proposition's logical status is its degree of confidence (true, false, or fuzzy value). Concept space (C) gathers propositions which have no logical status relative to K (K-relativity). According to C-K theory, design

is the process that consists in transforming concepts from C space into other concepts or into knowledge in K space. Consequently, students have to master formal approaches and logical demonstrations, but also creative developments.

- A cooperative dimension: The innovation process necessitates both collective and organizational learning. Because innovation can be found in every person but involves colleagues and multi-functional teams as well as external partners within open innovation processes (Chesbrough, 2003), managerial skills are major concerns in innovation educational programs.
- Uncertainty is a major aspect of innovation. Evidence of a necessary constructivist approach in SMB innovation management emerges from in situ observations (Boly, 2003).

The second educational reference: the competence referential

Taking these aspects into account, the ENSGSI-Nancy-France program has been elaborated using an Employment Competencies Referential. It consists of a list of skills established in collaboration with researchers and human resource managers of international companies and French SMEs. Note that this approach is complementary to those of Mallick and Chaudhury (2000), representing a benchmark of present Management of Technology education programs. More precisely, researchers and practitioners are asked to give a realistic description of the professional skills requirement relating to each characteristic of the previous list. Three connecting items were investigated:

- Description of industrial cases corresponding to one aspect of the list: for example, experts describe an experience where people in a company face a necessary operation of industrial process optimization (routine) and a complementary situation where optimization failed and newness was the solution (non-routine).
- Census of the tasks achieved by people involved in these industrial cases. Also, census of the main decisions made by these people.

For example, what are the principal activities of engineers optimizing the industrial process (project gantt), and those of the designers of the innovation solution? Moreover, what are the decisions made by these people and by top managers during the optimization projects and then the innovative project?

- Elaboration of a list of competencies and behaviors required to achieve these tasks and make these decisions.

Table 1 gives examples of data collected in a winery.

Table 1 - *Example of data collected to describe the interrelations between professional activities and required skills*

In situ situation: problem faced	Activities achieved by people in the company	Decision taken during the project	Required skills
All grape producers deliver to the company (winery) at exactly the same time. And quality is heterogeneous.	<ul style="list-style-type: none"> - Interviews of the stakeholders - Census of all the problems - Study of the variables influencing grape maturity - Proposition of supplementary tests of maturity in the fields 	<ul style="list-style-type: none"> - To use FMECA methodology - To launch a chemical study about grape compounds - To invest in some adapted solutions in measurement equipment 	<ul style="list-style-type: none"> - Ability to manage FMECA (Failure Modes, Effects and Criticality Analysis) - Ability to process chemical data
Production lost due to fermentation before the start of the winery process. Complementary objective: reduce additives.	<ul style="list-style-type: none"> - Systemic description of the upstream production steps - Experts' enquiry about cause analysis - Elaboration of the specification of a new unitary operation within the winery process - Benchmarking of technology in different domains - Multicriteria analysis to select a candidate technology - Elaboration of a prototype and test in partnership with an equipment supplier - Financial analysis - Employee training 	<ul style="list-style-type: none"> - To innovate through the adoption of a new technology replacing one step of the former process - To invest in innovative equipment - To pay for the employee training 	<ul style="list-style-type: none"> - Out of the box thinking - Ability to model industrial processes (material flows, information etc.) - Functional analysis of a machine - Technological intelligence capability - Ability to manage a cross functional team - Ability to achieve a technical survey in the field of biological processes - Ability to manage the adequation between required skills and competencies at disposal in the company

By means of this approach, a list of in-situ situations is obtained. Based on behavioral theories, this catalog describes the competencies (knowledge and know-how) and attitudes (personal competencies) relating to innovation activities. Consequently, this reference highlights the learning, technical, and cognitive skills that any student has to develop as part of his or her course curriculum. Finally, a classification is established in order to aid the further step: elaboration of the training program.

Two generic competencies have been defined:

- The ability to identify, express, and formalize a problem with all its characteristics (technical, economic, organizational, managerial) in such a way as to identify action levers and priorities.
- The ability to solve a problem and to integrate, implement, and distribute the problem-solving methodology within the business context. One characteristic is that the solution set is not limited. Classical solutions as well as new combinations of previous solutions and brand new options constitute the solutions space.

This can then be divided into four main functions/activities that have to be specific to innovation when teaching them:

Activity 1: Describe. This relates to activities upstream of the innovation process. The innovation process may start with a highly candid and entrepreneurial approach up to a highly informed position. Description activities concern different domains: marketing, use, technology, and regulation, among others. It focuses on trends, problems, and opportunities. Moreover, there are two temporal scales: present and future. Description is based on data collection (observation and reading), data treatment and modeling.

Activity 2: Design. This is the center of the process where new concepts and knowledge emerge. These activities relate to studies, realization, and tests. In the case of innovation, this activity is highly uncertain and newness is the main characteristic of the artifacts.

Activity 3: Pilot. As innovation mobilizes people and different types of means, including material and financial resources, coordination is required. Piloting is a challenge as efficiency is targeted, in addition to creativity and initiative. Supervision integrates simultaneously being coherent and agreeing that people may break the rules.

Activity 4: Develop. The innovation capacity of a company can increase or decrease considering its strategy and inner management but also the policies of its competitors and the evolution of the environment. Thus some practices aim at sustainability in the emergence of new products, linked with human resources, investments, and links to the surroundings.

Program curriculum

Affecting all the competencies listed (and classified through four activities) in the five sub-processes of innovation, it is possible to elaborate a structured training program. The interrelations between the modules are visualized. In [Table 2](#), only innovation centered subjects are discussed as technology centered knowledge depends on students' background.

Table 2 - *Innovation training program at ENSGSI-Nancy-France*

Competence: to be able to do	Company network	Global company level	Project level	Product level	Learning and cognitive level
Activity 1: Describe	Partner identification, Open innovation process description.	Corporate technology forecasting and planning, technology foresight, innovation capacity evaluation, Technology diagnosis and strategy definition, New product development process (NPDP) description.	Business plan, Business model, Value management, Marketing, Technological survey, Macro-environment diagnosis.	Scientific abilities, Failure mode and Effect Analysis, Newness degree and nature diagnosis for innovative product, Morphological analysis, Data collection and treatment, Benchmarking.	Listening, reading, observing environment trends.
Activity 2: Design	Design of external supply chain, Preparation of partnership with customers, academics... Preparation of customers integration in the innovation process, Plannig on the internet open innovation,	Change management, Intellectual property strategy definition,	Adapted new Product development process (NPDP) definition, Development of various creativity approaches, Use of decisions taking methodologies, Experimental design.	Ergonomic, System anlysis, Finding and implementing design methodologies, Mathematic model development, Management of different types of tests, prototyping.	Creativity, Change management Learning and Self directed learning process.
Activity 3: Pilot	Management of consortium, Finding and implementing collaborative methodologies,	Knowledge management, Change management and strategic vision diffusion, Use of indicators	Project management, Put in place a supervision process (stage gate), Value/Risk management and use of indicators	Performance evaluation,,	Learning, Entrepreneurship,
Activity 4: Develop	Collaboration legal frame definition, Outsourcing,	Innovation capacity development.	Team management	Fostering of technologies in the field of communication and information.	Human resources management.

This three-year program represents 1,350 hours of teaching and 2,000 hours of working on real projects. A vertical analysis of each column highlights the specific abilities between each operational level and the necessary global vision for innovative top managers. Some abilities are common to several domains, including FMEA (as the default may be analyzed on product and project management) or data treatment (as data may concern the market, technical testing, or environmental trends). Skills are specific to innovation (creativity and intellectual property strategy definition, among others) or declination of capacities also valorized in other domains (project management and business planning, among others).

Conclusion

This paper highlights the approach to elaborating an innovation management training program. This program aims at being a declination of management of technology contents promoted by the IAMOT association (International Association for Management of Technology) through the International MOTAB accreditation. Particularities exist between educational structures due to the context, the objectives, and also the profile of students (business or engineering). Thus, program elaboration methodologies are still a major concern. In this case, a structured and adapted template is obtained through two main referentials, a professional competencies list elaborated with researchers and practitioners, and a theoretical five-level model of the innovation process. Regular evaluation (during the training and post-diploma) with students and companies attests to the pertinence of the approach. However, the training elaboration methodology requires a continuous application, as companies' needs and innovation management background evolve. Consequently, this methodology is resource consuming and has to be integrated into the strategy of the education board as well as the day-to-day functioning mode of the training staff.

Pedagogical methods have to be coherent with the program itself. Through the role given to students, the relation between teachers and students, and the pedagogical approaches, it is possible to influence the personal skills of the future innovation managers. The aim is to stimulate behaviors in line with innovation. One aspect concerns entrepreneurship.

This behavior is often difficult to promote (Carayannis *et al.*, 2003), therefore training workshops on real industrial projects or company creation contests may be complementary options (Okudan & Rzasa, 2006). Attention must also be directed toward some other managerial skills such as customer-oriented conduct (Athaide & Klink, 2009).

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