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From engineering to industrial design: issues of educating future engineers to systemic design

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Abstract

Within the recent "Ecam Engineering" five-year international program developed at Ecam Lyon in France, a "Design" specialization area is proposed to educate engineers to the issues of systemic design. This program has emerged from the collaboration of Ecam Lyon with Politecnico di Torino, Italy. By offering different courses from the two institutions to the students, this program attempts to broaden the scope of classical engineering curricula towards a large spectrum of "design" issues. However, there is a huge gap between the content and pedagogy of systemic design developed at Politecnico to address an audience of future industrial designers, and the classical engineering design curriculum based on methodological and systematized approaches. This paper discusses the conceptual and operational challenges faced in this program to manage efficiently the transition of the engineers' curriculum towards sustainable design.

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Keywords: Design; System; Education

1. Introduction

For years, authors have pointed out the necessity to rethink and reframe "design education" [1] while a growing emphasis is put on the need to educate future generations to systems thinking [2]. The societal and ecological transitions require the future generations being able to grasp the world complexity while efficiently living and evolving within it. The role of engineers and designers is to imagine and create the future artificial systems that should in turn, serve the evolution and the prosperity of the humankind. Consequently, the role of educational institutions should be the development of the students' capacity to understand the complexity of these natural-artificial systems interactions in their holistic dimension.

Ecam Lyon historically delivers a generalist high-level educational background in engineering, covering several fields like mechanics, electronics and information systems, energy efficiency and industrial management. From a recent collaboration with Politecnico di Torino, Italy, emerged a new Systemic Design Research and Education Center (Sydere), which aims at diffusing, developing and promoting the systemic design of sustainable products and services to support the emergence of sustainable smart cities and territories [3]. In line with the Sydere Center, two years ago was successfully launched at Ecam Lyon an international "Ecam Engineering" five-year program, which aims at delivering double degrees in different specialization areas, among which a "Design" specialty collaboratively managed with Politecnico contains advanced courses in systemic design in order to broaden the classical curricula of engineers towards a larger spectrum of sustainable design issues. Indeed, sustainable design is now urged to operate a breakthrough in education [4]. This requires the evolution of design towards a better interdisciplinary [5] or even, towards an "undisciplined" (in the meaning of transcending the disciplines) task [6]. The Design specialty program at Ecam aims at developing the future engineers' capacity to adopt system thinking in order to design sustainable systems.

If the program goals for systemic design education of engineers seemed commendable, after experiencing it with two batches of students, it actually reveals many challenges for

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operationalizing its implementation. The main issue stands in creating a comprehensive curriculum based on different approaches, contents, and pedagogies: those of engineering, lying on a strong scientific background and systematized problem-solving methodologies; and those of industrial design, dealing with “wicked problems” and historically integrating the creative dimension, i.e. fine arts.

There are many differences between French and Italian cultures of design and between the resulting pedagogical approaches. Engineering and industrial design are still differentiated domains – in the literature as well as in industry - and they adopt distinguished rationales and schemes of teaching and learning. Beyond this difficulty to articulate different design perspectives, this program also faces those of teaching “systemic” design in a manner that the “learning comes to focus” [2] by adopting innovative pedagogies. Concurrently, the Ecam Lyon institution still has the duty to improve the employability of its future engineers by training them to acquire and develop highly scientific and technical skills and know-how.

This paper details these issues faced in this program. The next Section (2) details the program goals and structure. Section 3 emphasizes the differences between industrial and engineering design. The resulting operational issues faced in the systemic design program are detailed in Section 4. Some perspectives to progress towards the building of a more efficient systemic design *program* by self-applying the systemic principles to its *design* are proposed in Section 5. A summary and a conclusion are presented in Section 6.

2. The systemic design program

2.1. Why a systemic design program?

Systemic design considers the design from a systemic viewpoint, i.e. as dealing with a complex set of interacting systems forming wholes. It aims at imitating the Nature in anthropic activities, and claims for the adoption of a holistic approach in design in order to raise the future generations’ awareness of their responsibility regarding sustainability [7].

In the engineering field, several practitioners call for the adoption of systems thinking in design [8] [9]. Concurrently, engineering *design* requires the adoption of “design thinking”. Design thinking is characterized for Dym et al. [8] via the skills often associated to “good” designers, namely: tolerate ambiguity that shows up as inquiry or as an iterative loop of convergent-divergent thinking; maintain sight of the big picture by including systems thinking and systems design; handle uncertainty; make decisions; think as part of a team in a social process; and think and communicate in the several language of design. Green et al. [10] discuss the differences between design thinking and engineering systems thinking. Authors argue that these two fields, originally studied separately, have several common concepts, and that their relationships are increasingly explored. The systemic design research and education program at the Sydere Center originates from the willingness to prepare the future generations for the highly challenging transitions required in the design curricula as well as in the design practices.

2.2. Structure of the program

The program structure is shown on Fig. 1. It follows a classical engineering curriculum starting with highly scientific courses during the first two years. Concurrently, students attend Design courses taught by Politecnico teachers. These courses are a set of selected modules usually taught to the Politecnico bachelor students. The specialization is chosen at the end of the 2nd year. The 3rd year contains both common core and specialization courses. Design specialized students then spend their 4th year in immersion at Politecnico to attend the 1st year of the Msc “Systemic Design” [7]. Finally, the 5th year is

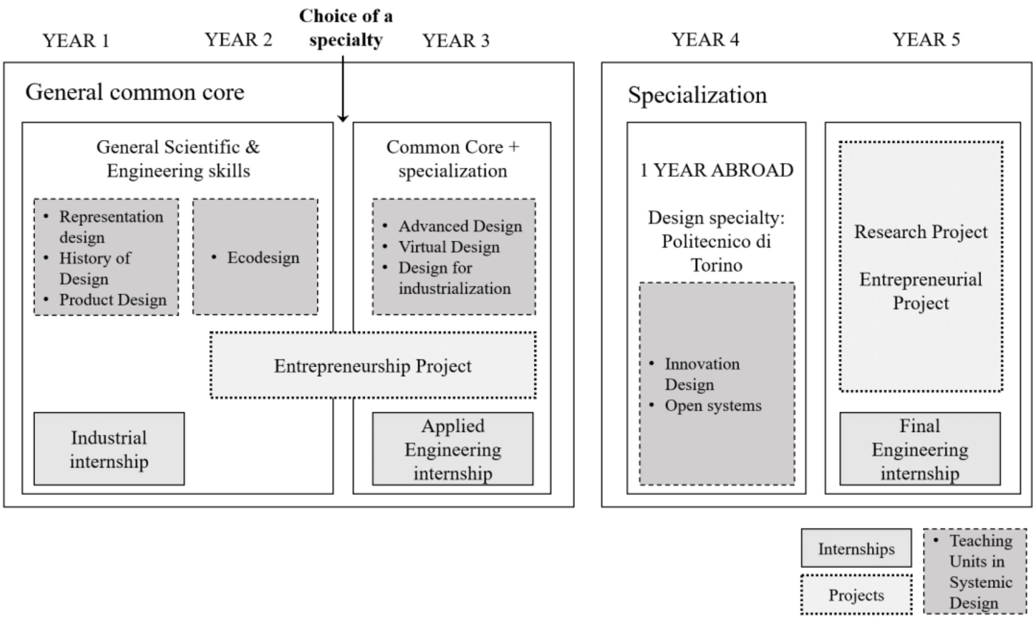

Fig. 1. Structure of the Ecam Engineering program, Design speciality

dedicated to projects (especially industrial R&D projects) and application of their full background during the final internship. The early integration of Design courses all along the scientific program pursue two main goals: inspiring the students and provide them an overview for the choice of their specialization area at the end of their 2nd year, and; providing the expected pre-requisites to attend the Msc Systemic Design at Politecnico the 4th year.

3. Differences between engineering and industrial design

3.1. Cultures of design and divergent education structures

As underlined in the literature [1] [6] [4] , there has been several streams in the design schools over the world after the Second World War. If the domains of arts, science and technology diverged at this time, resulting in the creation of schools more specialized in each field, the trend in Italy has been progressively reversed and *industrial* design education now tries to integrate artistic as well as technical viewpoints. People ensuring design teaching at Politecnico di Torino belong to the Architecture and Design department. Architecture and design are integrated, since architecture takes "on the task of highlighting, from the design viewpoint, the values of an industrial culture" [6]. The audience of the systemic design courses at Politecnico is composed of students aspiring to become industrial designers. If industrial and engineering design are concurrently taught in several Anglo-Saxon countries, such a correlation does not exist in French higher education: these two fields are taught and professionally practiced very separately [11].

Engineering design can be defined as "a systematic, intelligent process in which designers generate, evaluate, and specify concepts for devices, systems, or processes whose form and function achieve clients' objectives or users' needs while satisfying a specified set of constraints" [8]. Engineering education relies on an analytical, logical and rationalized approach, which is often criticized because of the gap this creates with the artistic and creative roots of design [4]. For years now, engineering curricula have been based on a model in which engineering is taught only after a solid basis in science and mathematics, currently two-years of studies with very few applications of the learned scientific principles to technological problems [8]. This model is still prevalent in French engineering schools. Engineering projects are lately integrated in curricula, since their practice is expected to train the students to reuse efficiently their previous scientific knowledge to solve problems being relatively well-defined [5].

In industrial design, the pedagogy assumes the "centrality of problems" to learning [12], i.e. the exploration of ill-structured and complex problems requiring knowledge from various disciplines. Design projects does not aim "to solve a problem, but to define what the problem is" [5]. Consequently, the process of knowledge acquisition is dealt very differently. "[Industrial] design has frequently been characterized as commonly dealing with unstructured problems, while design domains though rich in domain knowledge are also characterized by unstructured knowledge" [13]. In industrial design courses, "students study subjects in breath rather than depth" [4]: curricula engage students with a wide range of subjects from the outset of their studies, each subject being progressively deepened. The resulting "competence in design praxis [is not] measured by the quantity of knowledge gained, but by knowing where to find it, which specific kind of knowledge to apply in a particular situation, and how to use it when needed" [13]. Design-based curricula early integrate creative and reflexive activities, which train the students to efficiently use and link many non-specific knowledge contents, typically via design labs or design studios [13].

3.2. Impacts of curricula on the design styles

While they both use project-based learning activities, engineering and industrial design offer very different curricula which have a significant impact on students' thinking styles and on design behaviors [10] [5].

Analyzing design projects completed by students whose design education is preceded by an engineering curriculum, Wölfel showed that some students had some difficulties accessing and activating knowledge at the start of the design process [14] (after [15]). He argues that the strong impression created by the preceding engineering education inhibits the students' capacity to deal with emotional and subjective aspects, despite their equal importance with respect to the technical and functional ones [14].

Several studies have been conducted to compare the design behaviors and ways of thinking of different practitioners. For example, Jiang and Yen [5] compared the design behaviors of students in mechanical engineering and in industrial design, and observed that students in mechanics "consider the designed product as a self-contained system, to some extent detached themselves from relevant users and contexts. On the contrary, [industrial design] students apprehended design from the perspective of its ultimate aim, i.e., *the improvement of human quality of lives* […] The roles of user (human) and usage context were usually more emphasized than that of a product per se" [5]. In the Lawson's study [16] (also in [11] p.60 and in [5]), the comparison of senior undergraduate architecture and science students reveals different problem-solving strategies: scientists attempt to analyze the problem by identifying underlying rules that would allow optimized solutions; architects first extrapolate to suggest several potential solutions until they find a satisfying one. Scientists solve problems using *analysis*, architects use *synthesis*.

Guilloux [11] also discusses the differences between engineers' and industrial designers' thinking styles in problem-solving. For engineers, the generic problem is decomposed in sub-problems, several sub-solutions are identified for each of them, and potential generic solutions correspond to different assemblies of sub-solutions. In industrial design, often occurring upstream in a development project, identification of solutions serves the "wicked problem" framing: these two operations are then concurrent [11]. Engineers adopt a more systematic approach of decomposition because they attempt to define the optimal one.

However, this distinction somewhat caricature the real ways of thinking of both engineers and designers: the design mental process actually seems to be close to the Cross' concept revealing the coexistence and co-evolution of problems and solutions [17]. This coevolution has also been identified in engineering design [18]. The systematic decomposition process reflects the use of supporting methodologies rather than a rationale. Indeed, if industrial and engineering design have often been compared and discussed as decoupled disciplines, some authors argue that there is a generic design cognition, even if its practice can take different *forms* [19] because of different traditions and cultures [20]. Dym et al. [8] describe "design thinking" as a divergent-convergent questioning process. For these authors, the strength of engineering curricula is their perceived effectiveness in convergent inquiry processes, while divergent inquiry of industrial design seems to conflict with the deterministic principles of engineering science. They still claim for a better integration of design thinking in engineering curricula, in particular via a project-based learning pedagogy.

3.3. Design evaluations and decision-making

Industrial and engineering design have different evaluation and decision-making mechanisms. Precise requirements are currently provided to engineers who perform quantitative evaluations of the performance of their solutions to negotiate between design alternatives. In industrial design, criteria for evaluating a "good" design are more subjective. This statement corollary is that evaluation of the students in design-based courses is challenging. The design students are evaluated according to the quality of the process demonstrated rather than according to the produced design [8]. If engineers are often criticized for their lack of creativity and their difficulty to free their mind from constraints, Jiang and Jen [5] argue that the levels of risk differ: a "failure of engineering design usually has severe consequences of huge cost or even human lives. [Industrial design] is much more tolerant of failure and willing to take risks. The failure of [a] concept usually has a gentler consequence than an engineering failure." These differences in evaluation and decision-making processes influence the considerations of designers and engineers for design: designers perceive design as a space for creating, imagining and innovating, while engineers perceive design as a highly constrained area in which they must find optimized solutions.

4. Issues of the systemic design program for engineering

If developing systemic design *research* seems very necessary to foster sustainable innovation and to progress towards a design science that transcend multiple disciplines [6], the application of its principles and pedagogy within engineering *education* is highly challenging.

4.1. Systemic design value for engineering companies

The first issue is the difficulty to value the systemic design curriculum in industry in order to facilitate the employment of the future engineers. Indeed, the systemic design methodology is applied on large-scale projects at Politecnico [7] and results in efficient and sustainable re-designs of large systems within a territory. They currently involve a network of actors including public structures, local producers, and small and medium-sized companies. These projects are very efficient but require to be supported by a common willingness of cooperation between the involved actors. In industrial companies, such cooperation projects are decided at strategic levels, while the engineers' tasks occur at a more technical level. In addition, since engineering projects are time- and resource-constrained, engineers are evaluated on their capacity to propose the most optimized, cost- and time-efficient solutions. Industry is expected to operate a shift towards sustainability, but at the moment, ground practitioners would recognize that this shift has not occurred. Consequently, the current issue of the systemic design program is to make the related skills and know-how valuable for industrial employers.

4.2. Comprehensiveness of the pedagogy

As discussed in Section 2, during the first years of the engineering education, scientific courses are taught "in depth". Students are expected to acquire deep scientific knowledge and to develop high skills in mathematics, calculation, logical thinking, etc. Even if they are expected to actively participate to build their own learning process, teachers remains the main actors of the knowledge transmission and acquisition.

On the contrary, Design courses are taught in "breadth" and cover a large scope of themes. The systemic design pedagogy relies on a constructivist paradigm of learning, in which students are encouraged to perform their own research and to manage self-learning, taking the responsibility for their own learning process [2] [21]. Teachers become collaborators of the learning experience, and their role shifts from content provider to problem-solving facilitator [22].

When adopting two different types of pedagogies, the main risk is the students' misunderstanding: they are used to be supervised, guided, and content-provided in their scientific courses, while they are encouraged to autonomy and self-involvement in the Design ones. The big gap between these teaching behaviors sometimes creates a disengagement in design. From a pragmatic viewpoint, systemic design pedagogy seems very hard to extend to the scientific courses since the knowledge pyramid is built. An intermediation way should be found to create consistency between these pedagogies, via a hybrid form of project-based learning.

4.3. Consistency of the content

In the classical engineering curriculum at Ecam Lyon, many students have difficulties to imagine and define what "engineering" is, before their 3rd year. Students have no (or very few) previous knowledge in engineering methodologies. Due to their lack of professional experience, they miss some insights into the context of, the actors involved in, and the stakes of product design and development in industry. Consequently, many students logically expressed their misunderstanding of the links between the Design- and the other scientific courses. The program still misses some content elements bridging the two professions of engineer and designer, their respective tasks, and their required complementarity.

Moreover, systemic design courses attempt to cover "in breadth" a lot of issues linked to products', services', and systems' life cycles and feed-back loops to manage the sustainable balance of territories and of ecosystems. With a strong decoupling, engineering students can spend dozens of hours during their scientific courses to study, dimension, model and prototype a piece of a very small component within a mechanical module itself integrated within an industrial product. Under these conditions, it can be very hard for them to perceive other aspects of the product than the technical ones. The issues of user experience and of subjective value criteria like aesthetics, or even life cycle issues, are far from their daily scientific studies. Then , the program still requires to be carefully structured and the topics selected according to the students' concerns in order to maintain their interest.

5. Program design: self-applying the systemic design principles

By considering the systemic design program as a complex system-to-design, the systemic design principles should be applied. They have the potential to considerably improve it.

5.1. A learner-centered pedagogy

Systems thinking fosters a shift from instructional to learning focused education [2]. As previously discussed, some of the system thinking principles for pedagogy can be hard to apply. Nevertheless, the focus on the learner and on his needs is probably the weakest part of the current program. Indeed, its structure reflects a building that meets many types of expectations (i.e. providing a strong scientific basis to future engineers; providing the 4th year pre-requisites to future designers, etc.) but somewhat neglects the students' needs previously mentioned: comprehensiveness of the pedagogy, consistency of the content, logical learning progression, and curriculum valuation for industry. Two different types of curricula are "mixed" in a five-years program (without extending the duration of studies). Their integration cannot be made without a deep questioning and adaptation of each course type, and a collaborative re-design of the whole system.

5.2. Problem exploration and re-framing

Industrial design relies on the exploration and framing of ill-structured problems. This principle should also be further applied to the issues discussed in this paper. The question should be explored: Are we trying to solve the right problem? Or, after reformulation: *Is an "hybrid" curriculum the object that we should design?*

Several types of "hybrid" curricula already attempt to integrate some of these challenges. Fig. 2 illustrates the targeted position of Ecam Lyon among some different hybrid curricula (e.g. see [23]). Four main dimensions are represented to illustrate their differences: engineering design, industrial design, system thinking and environmental sciences.

The main types of hybrids are those coupling:

- Industrial and engineering design, like in the MA in "Innovation Design and Engineering" at the Royal College of Art, or in the Msc in Design and Engineering at Politecnico di Milano
- Engineering design and systems thinking, like in the Master in Global System Design at Aalborg University

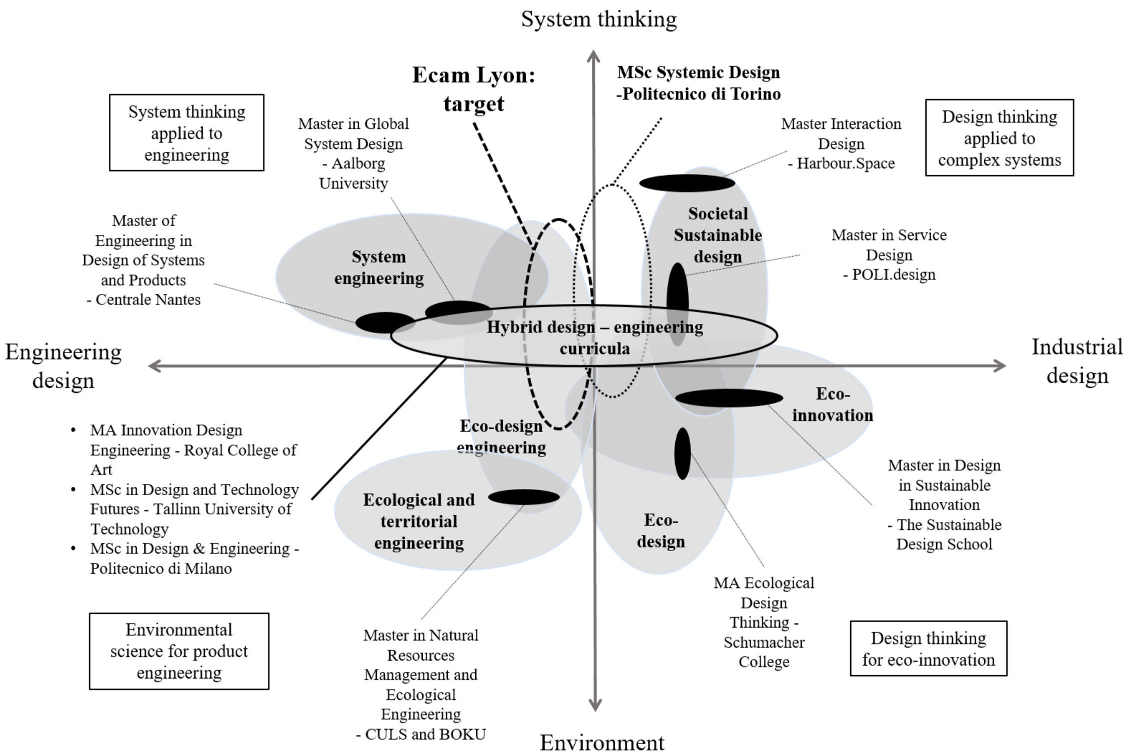

Fig. 2. Representation of different types of existing hybrid curricula and identification of the Ecam Lyon targeted position in Systemic Design for engineering

- Design thinking and environmental (and societal) issues, like in the Master in Design in Sustainable Innovation at the Sustainable Design School
- Design thinking and system thinking, like in some existing Masters in Service or in Interaction Design
- Environmental sciences and engineering design like in a broad variety of Masters related to eco-design for engineering.

The goal pursued in the Ecam Engineering curriculum is not to educate hybrid designers-engineers, but to *widen the future engineers' profiles to systems thinking and sustainable design*. In practice, these two professions have different skills and design styles resulting from different curricula. The role of our two educational structures should be to reinforce their complementarity by facilitating their efficient collaboration. Consequently, the program should develop the engineering students' *capacity to communicate* and *to collaborate* with industrial designers. To efficiently re-design the engineers' and designers' curricula from a systemic design viewpoint, we should focus on the interactions between our respective professions and on their future evolutions in order to facilitate their mutual enrichment.

5.3. Progress areas

The identification and exploration of the challenges resulting from our two professional cultures has been an initial phase. To pursue the efficient progression towards the program goals achievement, further research and experiments should be conducted. Our current research deals with the existing approaches among the different types of hybrid curricula (like those illustrated Fig. 2) to identify some supportive content and pedagogical elements. The structuration remains one of the most challenging part. One of the main strength of this program is the offered possibility to decompose the learning and the skills acquisition processes during five years - contrarily to most of the existing hybrid curricula focusing on Masters' degrees – but it also challenges our capacity to design a system with a high degree of novelty. From a more operational viewpoint, the competencies' grid is reframed concurrently with the development of indicators and success criteria to determine the pedagogical goals achievement, in particular via experiments in a mid-term perspective.

6. Summary and conclusion

Resulting from the collaboration between Ecam Lyon and Politecnico di Torino, a systemic design program for engineers has been recently developed. It aims at developing the future engineers' capacity to adopt systems thinking in order to design sustainable systems. However, because of several differences in the curricula, the integration of Design and systemic design courses in the classical engineering education is highly challenging. This paper discusses the differences existing between our two institutional backgrounds and the resulting issues faced in this program to articulate the curriculum in a comprehensive manner. As for design, this program requires to be experienced to reveal its intrinsic difficulties and allow us to improve it continuously. A feedback of a two-years' experience now supports the reframing of its *design*. Relying on the Sydere Center, Ecam Lyon and Politecnico di Torino will continue to collaborate in this direction.

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