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FROM ECODESIGN TO DFS IN ENGINEERING EDUCATION

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ABSTRACT
Sustainability concept is becoming ingrained in the international engineering community. The next generation of engineers has to be trained to appreciate economic, environmental, and societal impacts of its decisions, with an international perspective and at a local and global scale. Such complex problems require an integrative approach and engineers must be prepared to meet challenges that extend beyond the boundaries of a single discipline or culture. To achieve this issue, students need time but also adapted curricula focused on sustainability and ecodesign concepts to support evolution of their skills, their knowledge and their culture. In this paper we propose an analysis of sustainable and ecodesign trainings in France to estimate if French students have well-adapted programmes and enough time to develop skills and knowledge about sustainability. Our study concerns curricula from secondary school to university and engineering school. We put in evidence the limits of the French system and we propose preliminary recommendations for the development of progressive and coherent curricula about sustainability for engineers.

Keywords: Design for Sustainability, Systemic decision-making, Complex thinking in design

1 INTRODUCTION

According to a normative point of view (ISO standard), ecodesign can be defined as "a process integrated within the design and development that aims to reduce environmental impacts and continually to improve the environmental performance of the products, throughout their life cycle from raw material extraction to end of life" (ISO 14006, 2011). Even if ecodesign is sometimes compared with green design, ecodesign approach is a more global one since it concerns the whole lifecycle of products from extraction of raw materials to their end-of-life [1,2]. As ecodesign concept is clearly positioning at a product innovation level, during the last two decades companies who have wanted to enter in an ecodesign perspective have only made and evolved their design process on a technical point of view (focused on environmental aspects). They done it according to the different steps defined in the ISO 14062 and the NF X 30-264 guidelines. These guidelines have been proposed to small and medium companies to help them to start an ecodesign strategy. In such a context, companies have worked on cleaner production, waste management or pollution prevention and not really on economic and social aspects of sustainable development. Moreover, plenty of methods and tools have been developed to operationalise ecodesign process in industries and this plethoric offer sometimes discouraged some companies [3]. Even if, ecodesign theoretically allows designers to identify environmental impact of products across all life-cycle phases to be able to compare between different product concepts of the same category and helps design decision making [4], there are also barriers to surmount to make in place an environmental strategy in industry [5]. However, research has demonstrated that there is a gap between ecodesign theory and practice: "actors in the ecodesign process enforce their own tools or methods which correspond to their own practices and that create a non-efficient eco-designed product" [5]. So, to reduce this gap, it seems to be crucial to integrate training courses in engineer curricula to allow future engineers to work with a global and prospective thinking system to adopt the right methods, tools and choice depending on the situation and to communicate and share information. Courses have to expand the traditional ecodesign scope towards the more managerial and strategic issues [6,2]. Consequently, new needs of skills and knowledge have raised and researchers have defined general competencies that must possess engineers in sustainability [7]. In France, plenty of curricula are focused on a normative approach of ecodesign and technological skills. They don't allow students to develop sustainable solutions that are "products, services, hybrids or system changes that minimise negative and maximise positive sustainability impacts economic, environmental, social and ethical throughout and beyond the life-cycle of existing products or solutions, while fulfilling acceptable societal demands/needs'' [8]. Our aim is to proposed curricula in universities and engineering schools to allow companies to find this kind of collaborators. We are working progressively by first defining the existing situation in ecodesign training (section 2) to be able in a second time to propose possible evolutions (section3). In the following section we realise an analysis of the place of ecodesign in the French curricula from secondary school to university and engineering schools in France.

2 ECODESIGN IN FRENCH CURRICULA FROM SECONDADRY SCHOOL TO UNIVERSITY

In France, students have a compulsory education in technology and engineering sciences in secondary school but it becomes optional when they are in high school and depending to their choice of orientation. This compulsory education allows us to begin laying the foundations for notions of sustainability in the industrial context. It will then be partially deepened in high school. Moreover, economic, social and ethical impacts are generally not studied in secondary and high schools because they refer to non-technical disciplines and teachers are not trained. Teachers have difficulties to develop technical courses that are not anymore specialised. As a consequence, before university ecodesign courses lead to a global and superficial technical culture integrating the constraints of sustainable development. So, when pupils are going to university they don't have a clear vision of sustainable development and ecodesign or they have an oriented vision of what it is. It depends also on their specific trainings: 80-85% of pupils at the end of high school are not aware about sustainable development and ecodesign because these courses only appear in technical baccalaureate. So, some universities often integrate basic courses on sustainable development and ecodesign during first-year university level. Other problem is that universities and engineering schools are organised according to disciplines so it is not very easy to promote a multidisciplinary approach in courses. Finally, multiplicity of training opportunities in high schools and universities is a real difficulty when we try to analyse if a continuous curriculum in engineering education focused on environmental transition from secondary school to university exist.

In Table 1, we realise a synthesis of some elements of courses in ecodesign and sustainable development in French curricula from secondary school to university. We analysed programmes by focusing on design and ecodesign to make appear technical skills, specific skills concerning ecodesign, and knowledge about sustainability and systemic vision. We also identify links and relationships between school levels to make appear possible continuum in programmes. We make appear progressivity in skills and knowledge thanks to using colours: green is for basic notions, orange is for fundamental skills and knowledge and red is for expert skills and knowledge. Some boxes are bicoloured because the level of skills achieved depends on teachers' ability to follow the programme (particularly in high school) and on particular objectives of university programmes.

We use official programmes of secondary schools - http://www.education.gouv.fr/cid81/les-programmes.html and high school - http://eduscol.education.fr/pid26017/programmes-du-lycee.html to study the place of design and eco-design in courses before university or engineering schools. Concerning university and engineering schools we use existing curricula of different French universities (Bordeaux, Grenoble, etc.) and different engineering schools (Ecoles Centrale, Ecole des Arts et Métiers, Ecoles des Mines, Universités de Technologies, etc.).

Our aims are to check if there is continuum in ecodesign training from secondary school to university and to be able to work on breaches if they appear to increase future decision-makers' awareness about sustainability and ecodesign.

Table 1. Non-exhaustive list of skills and knowledge in ecodesign in French curricula

	Secondary school	High school (technical graduates only)	University / Engineering School
	Pupils aged from 11 to 15	Pupils aged from 16 to 18	Age 18 to ...
Technical skills related to design			
Main technical domains			
Mechanics and Design theory			
Electrical engineering			
Civil engineering			
Materials science			
...			
Software tools dedicated to technical domains			
CAD tools			
PLM solutions			
Finite elements tools			
LCA tools			
...			
Manufacturing processes and industrialization			
Machining			
Molding			
Welding			
Plastics			
...			
System modelling, analysis and decision making			
Methods, tools and formalism for analyzing and describing systems			
Decision-making process based on models and simulations			
Methods to study technical solution to improve productivity, quality and safety			
Value chain analysis			
...			
Specific skills related to eco-design			
Principles of systems design and sustainable development			
Environmental impacts			
Life cycle Management			
Tools and methods			
...			
Sustainable development aspects: social and economic visions integration			
Human factors in design and manufacturing processes			
Human factors influences in during Product Life Cycle			
Circular economy			
Social responsibility of companies - ISO26000			
Environmental management			
...			
Large scale vision of sustainaiblity and ecosystems			
Design for sustainable approaches			
Integrated design			
Territorial perspective			
Multi-disciplinary and multi-dimensional vision			
Pro-active dimension			
...			

We completed our analysis with a study that places curricula in a global perspective of sustainability by proposing a parallel between institutional programmes and the 14 invariant dimensions of sustainability [9] (Table 2). With such representation we show how all dimensions of sustainability are addressed (or not) across curricula programmes. We also highlight complexity to cover all dimensions of sustainability with the existing programmes and possible evolutions of ecodesign trainings in a more global sustainable vision closed to companies' expectations.

Table 2. Dimensions of sustainability [9] addressed by ecodesign training in France

Dimensions of sustainability	**Secondary school**	**High secondary school (Technical graduate only)**	**University / Engineering School**
	Pupils aged from 11 to 15	**Pupils aged from 16 to 18**	**Age 18 to …**
Economic dimension			Partially addresses depending on eco-design methods and tools selected by teachers or institution
Social dimension			Partially addresses if social LCA is presented for instance
Ecological dimension	Addressed (impacts on wildlife and environment, biodiversity evolution)	Addressed (climate, pollution, wastes, recycling and biodiversity	Addressed (climate, greenhouse gas, water pollution, wastes, recycling)
Time dimension			Addressed (LCA and prospective)
Values dimension			
Geographical dimension			Partially addresses (LCA and influence of design project all around the world)
Performance dimension	Addressed (materials, resources, energies)	Addressed (materials, resources, energy and risk analysis)	Addressed (LCA, prospective, risk analysis)
Participation dimension			
Waste dimension	Addressed (energy, recycling, water pollution, materials)	Addressed (energy, recycling, materials)	Addressed (eco-management of organization and product)
Transparency dimension			
Accountability dimension			Partially addresses (decision-making process, risk management)
Cultural dimension			
Risk (reduction) dimension	Partially addressed (identification of "basic" risks, cause/effect links)	Partially addressed (interdependencies between complex phenomenon)	Addressed (risk management, prospective)
Political dimension			

3 DISCUSSION AND PERSPECTIVES

Our analysis of ecodesign trainings emphasises that there is no integration of concepts and disciplines and that there is not a continuum between pre-secondary school, high school and university. As a consequence, students at the end of the high school are not comfortable with issues of sustainability and ecodesign and main difficulties are:

- Links between knowledge and action is essential in ecodesign to evaluation impacts of decisions but students systematically provide simple answers to complex problem. Rapidity and facility are often preferred to quality...
- Values and ethics of sustainability depend of institutional injunctions and are clear so students know these elements. Worse still, few students have a counterproductive filling of guilty and a feeling of powerlessness.
- Students have to adopt a complex thinking posture to understand sustainability but a great number of them have not systemic competence. They are used to provide simple answers by applying determinist methods.
- Students are able to identify problems to solve but have difficulties to identify the way to solve these problems.
- Development prospective thinking is a crucial issue for sustainable development but students often develop this competence in personal sphere but it seems to be not so easy in the sphere of education.
- There is not still a systemic vision of their actions and an important key is that " the crucial element of specification in ecodesign is the state of the environment(s) in which the solution will function" [10]. It means that all aspects and a global vision are necessary.

History and culture of French education system could partially explain these difficulties. In our system, training was historically based on magisterial courses and students have to listen carefully teachers. In such a context it is not easy for students to express their ideas and to develop personal initiatives. Nevertheless, the system is evolving and pedagogic approaches based on projects, collaborative activities and considering students are the main actors of their learning are encouraged. In France, curricula have to evolve but also teachers' state of mind and trainings (initial and continuous ones). To sum up, concerning teaching strategy we have to bring students at the highest level of intellectual development according to Felder and Brent [11]:

- Possess the scepticism and inclination to challenge what is currently known
- Question the assumptions underlying all accepted wisdom
- Are reluctant to accept the first reasonable explanation
- Employ both logic and intuition
- Avoid transferring judgments made in one situation to another situation without critical evaluation.

These kinds of skills must be developed during technology or engineering sciences courses since the secondary school to university master. In the same time, it is also an important issue to train pupils and students to all dimensions of sustainability and associated skills and knowledge to provide a large vision of sustainability problematic. So, to achieve this issue, it could have in interest to explore potential synergies between ecodesign and other DfS approaches to enlarge the scope of the concept. Ecodesign could be integrated with DfS approaches of Spatio-Social and/or Socio-Technical System innovation levels [12] to obtain a global DfS approach addressing the environmental, socio-ethical and economic dimension of sustainability. In table 3, we specify themes ("focus on") for each dimension of sustainability at each graduate level that possibly permit to develop multidisciplinary curricula focused on sustainability (ecodesign, geography, political sciences, human sciences, etc.).

Table 3. Themes proposal to develop multidisciplinary curricula focused on invariant dimensions of sustainability

Dimensions of sustainability	***Pre-secondary school***	***High secondary school (S2IT baccalaureate)***	***University / Engineering School***
	Pupils aged from 11 to 15	***Pupils aged from 16 to 18***	***Age 18 to …***
	"Focus on"	***"Focus on"***	***"Focus on"***
Economic dimension	Fair trade and globalization of exchanges	Globalization of exchanges, circular economy	Globalization of exchanges, circular economy
Social dimension	Responsibility toward environment	Health, fair trade	Health, fair trade, human resources management
Ecological dimension	Wildlife and flora evolutions, biodiversity evolution	Climate, pollution, wastes, recycling and biodiversity	Climate, greenhouse gas, water pollution, wastes, recycling
Time dimension	Human's role in the evolution of the earth (climate, landscape, etc.)	Human's role in the evolution of the earth	Prospective and evolution modeling
Values dimension	Responsibility toward humanity	Responsibility toward humanity	Ethics, Social Responsibility
Geographical dimension	Evolution of landscapes (mechanism of human's actions on landscapes)	Climate and evolution of landscapes	Influence of projects all around the world
Performance dimension	Resources, energies	***<u>Ecodesign</u>***, risk analysis	Prospective, risk analysis, ***<u>ecodesign</u>***
Participation dimension	eco-citizenship, awareness to the others	Relationships with subcontractors	Management, communication, ethic
Waste dimension	Production of energy, recycling, water pollution, materials	Production of energy, recycling, materials, ecodesign	Eco-management of organization and product
Transparency dimension	Eco-citizenship	Eco-citizenship	Decision-making process, management,
Accountability dimension	Eco-citizenship	Eco-citizenship	Decision-making process, risk management
Cultural dimension	Patrimony, political and economic issues in the world	Cultural, political and economic issues in the world	Systemic vision, awareness to the world
Risk (reduction) dimension	Identification of "basic" risks, cause/effect links	Interdependencies between complex phenomenon	Risk management, prospective
Political dimension	Global political organization of the world	Politics in EU	Political sciences, strategic studies

4 CONCLUSIONS

Table 3 represents our first reflection about evolution of ecodesign teaching and a multidisciplinary approach of sustainability to answer the question “how can we better train engineers so that they have a full vision of the issues of sustainable development?” Our future research concerns specification of more precise criteria to develop curricula and associated courses to give guidance to teachers from secondary school to university and engineering schools. The future works will focus on the building of a grid that will permit to identify influences of multi-technical disciplines in the ecodesign process. Then it will be interesting to think to a progressive course throughout the student schooling to provide them a solid base of technical knowledge for sustainable design and production and in parallel to build course block for teachers.

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