Crossing technical and non-technical skills: French case study of ecodesign in engineering education

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Abstract

Nowadays, to deal correctly with sustainable issues, future engineers must have the ability to use non-technical skills. In order to evaluate all interactions and all possible solutions, a systemic vision of problematics should be adopted. We wanted to demonstrate the possibility of integrating all these non-technical competencies in a disciplinary training. For this reason, we developed some examples of activities to provide support to teachers and we proposed a skills and knowledge model to support teachers increating their own educational.

This model was tested to bachelor engineering students. We suggested them an eco-design problem-based learning activity. Objectives of this case study are to identify which type of skill mix was addressed by students and compared them with levels defined in the model. It's also the opportunity to assess how associations are made between these two kinds of competencies

The paper presents results of our case study. Including improvements needed in our competencies model. Some future work will be drawn at the concluding section to propose the next of our research for integrating sustainable competencies into engineering curricula.

1 Introduction

1.1 Global context

Nowadays, more and more students feel a lack of teaching development for sustainability topics in their curriculum. In French engineering schools or universities most of training courses do not answer to this challenge because they modestly include the question of sustainability in their curricula. Thus, according to the Shift Project (a French think tank) report (Vorreux *et al.*, 2020), environmental questions are mentioned in 56% of French engineering courses but in 71% of those cases, the courses are attended at a master level, and "these new degrees have become very specific, with a high level of specialization and a reduced scope." (Felgueiras *et al.*, 2017). However, sustainable development is a major preoccupation for each of us. So, students express more and more a special interest on environmental transition problems. In 2018, students from different French engineering schools wrote a Manifesto for a wake up on the environment. The Manifesto[1] has been signed by 30,883 students (from universities and engineering schools). They wanted to highlight that: "As we get closer to our first job, we realize that the system we are part of steers us towards positions that are often incompatible with the result of our reflections. This system traps us in daily contradictions". Thus, new graduates search to integrate companies which share same values on sustainability as them. At the same time, these companies meet new challenges driven by politics

[1] Manifeste étudiant pour un réveil écologique. 2018. https://pour-un-reveil-ecologique.fr/.

(standards and regulations) and customer expectations (Hanning *et al.*, 2012). So, integrating sustainable competencies into engineering curricula has becoming one of the main challenges since few years in French education system but also an industry's need which are looking for trained engineers who can answer to these questions.

1.2 Sustainability in Engineering Education

For several years, the question the integration of sustainable development in higher education is discussed. Our research work focuses on engineering education in France and the main issue comes from nature of competencies and skills to achieve. The question arises how can be improved the integration of basics of sustainable engineering in trainings rooted in technical knowledge. In previous work, we have identified that engineer's skills are obviously necessary but it is also important to develop cross skills to train student in a sustainable engineering way (Perpignan *et al.*, 2019). Developing such curricula is often complicated because education system always lays on knowledge transmission while today knowledge must be integrated into competencies-based framework. This term of competency is easily misinterpreted and in the educational literature competence have a polysemic sense (Joannert *et al.*, 2015). Teachers often develop curricula that are addition of courses and obtain a patchwork of not linked competencies and knowledge. Indeed, they are specialists on specific technical area and working with a competencies-based framework means to solve complex tasks in a multidisciplinary context supported by cross skills. So, in our research work we have chosen to use the OECD definition: "competence involves the mobilization of knowledge, skills, attitudes and values to meet complex demands". It means that knowledge, skills and attitudes & values must be interlinked. Thus, to achieve sustainable engineering, working with a competency framework is essential. "These types of problems [...] require students to acquire an integrated set of problem-solving skills or competencies, far more than a body of knowledge" (Wiek and Kay, 2015). Based on this literature review, we have retained two recommendations. The first is that sustainable engineering training must be progressive and it must be based on holistic vision of sustainability during secondary school, undergraduate and master's training. The second is that sustainable engineering training must always contains knowledge, skills and values. So, according to this postulate our goal research is to propose a competency framework which could be integrated into engineering curricula in order to complete student's training.

In this paper, we will identify what kind of competencies must be outlined in a sustainable engineering competency framework and how is it possible to integrate them in an engineering curriculum. The aim is to propose a sustainable engineering based-competences pathway and to describe and analyze an experimental situation based on those two hypotheses.

2 Toward a sustainable competency framework

2.1 Competencies for sustainable engineering

Many researchers have written about the necessity to acquire key cross-disciplinary competencies to answer to the global issue of sustainability. All these authors have in common to highlight communicative competence, interdisciplinarity and a more global vision of the issues with system or systemic thinking methodology (De Haan, 2006; Barth *et al.*, 2007; Segalas *et al.*, 2009; Wiek *et al.*, 2011; Quelhas *et al.*,2019). But student engineers have also specific competencies to achieve established by some organization like ABET[2] in US or ENAEE[3] in Europe. These organizations edited specific engineer's skills such as: engineering design, engineering analysis… Question is: how can we cross all these competencies in order to train engineers who will contribute to sustainable development effectively?

In a previous work we have proposed an analysis of these skills. We have tried to evaluate if links exist between engineering skills as defined by ENAEE and cross-disciplinary skills (Perpignan *et al.*, 2020). This work allows to show that some engineering skills and cross skills are naturally interconnected. For example, "solve a complex problem" can be both an engineer's skill and a cross one. That's why it will be easier for this competency to integrate it in an engineer's training. On the other hand, competencies like critical thinking or systemic thinking are more abstracts for teachers. So, it's necessary to describe them more precisely and to propose some in case situation in order to understand what is expected.

Table 1: Cross skills and engineering skills (Perpignan *et al.*, 2020).

Cross-disciplinary skills / Engineering skills	Critical thinking	Collaboration	Solve a complex problem	Systemic thinking	Normative competence	Self-knowledge	Anticipatory	Strategic competence
Fundametal Scientific Knowledge	✓		✓	✓				
Engineering Analysis	✓	✓	✓	✓	✓	✓		
Engineering Design		✓	✓	✓	✓	✓	✓	
Investigations	✓		✓	✓	✓	✓		
Engineering Practice	✓	✓	✓	✓	✓	✓	✓	✓
Making Judgements	✓	✓	✓	✓	✓		✓	✓
Communication and Team-working		✓	✓		✓			✓
Lifelong Learning	✓		✓	✓	✓	✓	✓	✓

Objective was to use these links and to propose structured training modules in a global curriculum allowing at the same time the development of competencies and knowledge. Based on this work of skill's identification and on the rise of competence-based education in universities and higher education, we propose to work with a competency approach in order to create a competency framework including sustainability into curricula.

2.2 Methodology to develop a sustainable competence-base program

Competencies approach "should reflect the skills and knowledge that students will need at the next stages of their development […]. The process for developing program-level competency definitions should be iterative, evolving to incorporate marketplace demands, academic expectations, and student needs" (Johnstone and Soares, 2014). So, to achieve cross disciplinary skills and engineering skills, we must organize our training path and we have chosen to refer to (Poumay and Georges, 2017) who have proposed a methodology to develop a competence-based program. This methodology consists of six principles:

[2] ABET : Accreditation Board for Engineering and Technology
[3] ENAEE : European Network for Accreditation of Engineering Education

1. Using real professional situation and active learning
2. Flexibilising the training
3. Choosing useful resources to develop skills
4. Fostering learning through collaboration
5. Allow reinvestment of skills already mobilized
6. Assess the level of skill's acquisition

In following this methodology, we have developed a competence-based model which is represented in Figure 1. Competence is "*a complex know-how based on the mobilization and combination of knowledge, skills, attitudes and external resources applied in specific families of situations*" (Tardif, 2006). According to this definition, we have identified 5 types of situations where an engineer could be called upon to mobilize skills within the framework of sustainable engineering. These families correspond to blocks because in the French educational system, the concept of competences' block was introduced by law n° 2014-288 of March 5, 2014 relating to vocational training for employment and social democracy. This concept of block allows to personalize the training courses and to adapt to the needs of the learners. Thus, blocks were defined to build a path-curriculum for engineering education (Figure 1).

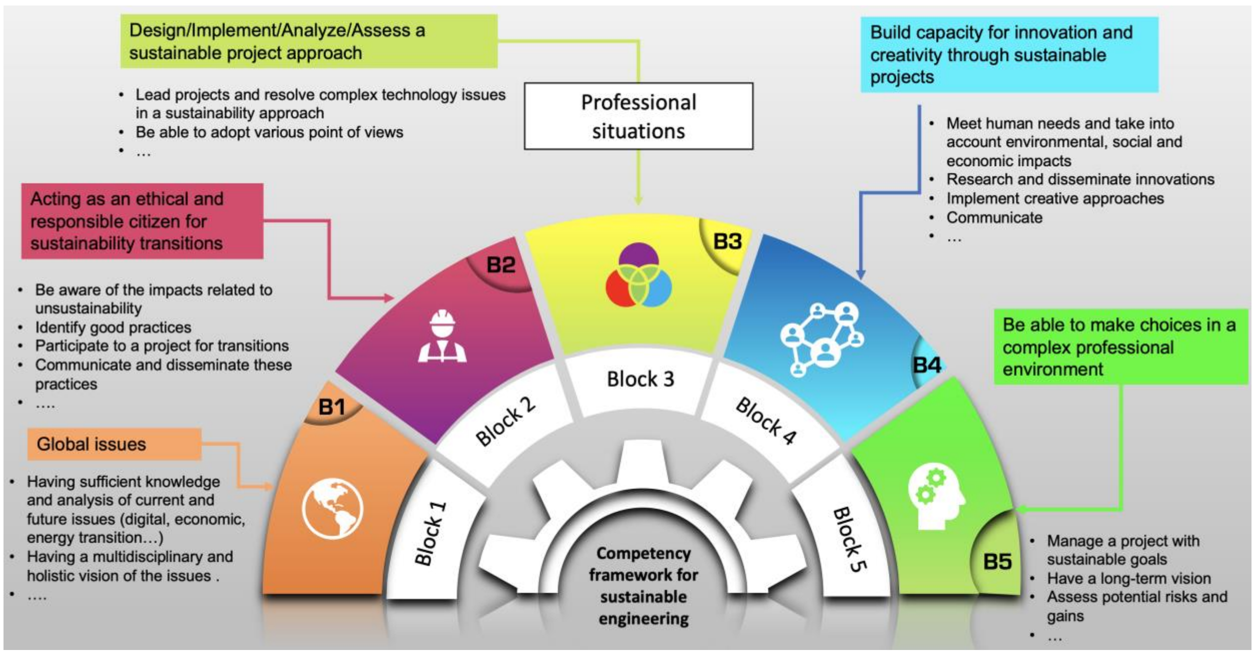

Figure 1. Model of a competency framework to achieve sustainable engineering

All these blocks will be always present during the student curriculum but according his level they could be adapted. Moreover, each block will consist in sub-competencies. Indeed, "Each institution and faculty have their own view and interpretation of sustainability engineering and its application in their educational program" (Sharma et al., 2017). This proposition gives some common basis on sustainability which are essential to take into account all issues but we keep a margin of freedom to allow teachers to develop modules which consider their specificities. Future engineers must acquire all or part of these competence-based model but they also must continue to improve their level of acquisition during their job life. It means also that during all this path, teacher must assess the level of acquisition of skills. To define some steps, we use the scale established by (Dreyfus and Dreyfus, 1980). In this scale, a student goes through five successive levels: novice, beginner, competent, proficient and expert. Three first levels can be achieved during initial education and the last ones in a professional context. That’s why lifelong learning has a more and more important place in engineer’s careers. Blocks B1 and B2 correspond to concepts, values, behaviors, etc. which are the “basis of sustainability” from primary school to university. The block B3 completes B1 and B2 by proving a more technical, operational and contextualized vision of sustainability. This block will be “customized” by teachers depending on training objectives and students' target occupations during students’ undergraduate years. It is advised for teachers to develop relevant and close to reality professional situations in this block since it is the more operational one. In such training situations, students will use previous skills and knowledges that they have acquired. Teachers can focus on technical aspects but keep a look on transversal skills that students must to deepen. Block B4 concerns the development of some students’ soft skills as capacity of innovation or creativity. B4 allows students to reinvest knowledge and competencies of blocks B1, B2 and B3 in a personal or training project in university/engineering school. Block B5 regroups necessary competencies to put in practice all the other blocks. It can only be really complete during a real professional situation. It is the block in which students to achieve the “proficient” and “expert” levels of the competency framework. “Proficient” level can eventually be achieved during the final diploma’s internship and “expert” level is achieved during lifelong learning.

3 A case study: eco-design training for novice technological teachers

3.1 Scope

To test our sustainable engineering competency-based framework, an eco-design training was proposed to future engineering science teachers. Indeed, they must acquire a first level of knowledge in eco-design. So according to our scale it means that they must achieve a beginner level for eco-design skills but we can target a competent level for cross disciplinary skills. Thus, our case study belongs to block 3, it’s for bachelor’s students who have some knowledges on sustainability and who followed a previous engineering training but some competencies belonging to block 1 and 2 will be also necessary. We have chosen a problem-based learning session. Indeed, problem base learning activity includes knowledge acquisition, collaboration and communication in a real context. “These skills are encompassed by the pedagogy of problem-based learning (PBL), which provides students with opportunities to learn to think, specifically ‘‘how to think’’ rather than ‘‘what to think,’’ and potentially within the framework of sustainability (Thomas, 2009)”. The aim of these activities is to test our model and to validate if students use cross skills during the learning activity. That’s why we suggest our students the following problem: “Bottle or gourd?”

The professional situation of this session was: “Assess eco-design maturity degree of an existing product”. Some cross skills are targeted, as our students have already an engineer background, beginner level could be easily considered. The aim of this activity is to work on critical thinking, systemic thinking, solve a complex problem and self-knowledge for cross skills. At the same moment, students will work on knowledge and understanding, engineering analysis, investigations and making judgements for engineer’s skills.

The session consists in 3 activities and the objective is to start from a technician Eco-designer vision (it means using an eco-design tool) to progressively open the scope to a more global vision which will drive students towards more cross skills and values:

- Activity 1: objective is to use an eco-design tool to determinate which bottle has the biggest environmental impact. This activity doesn't really highlight cross disciplinary skills but engineering skills are very strong. It's a traditional approach concerning eco-design problem. At the end of this activity we can begin to check what kind of questions students have answered and if these questions are only technical or if some of them have wider questions.
- Activity 2 is more ambiguous. Indeed, we will oblige students to think about the choice of the bottle they have made during the previous activity. We want them to propose some improvements in order to reduce the environmental impact, but their reflections must not be limited to a material choice. So, activity 2 is a first mix of cross disciplinary skills and engineering skills.
- Activity 3 is principally focus on cross disciplinary skills. Students must think about the necessity of a bottle to drink. So, for example some subjects as water pollution or health consideration could be evocated.

3.2 Identification and description of competencies

In this organization, we can see that we have interlinked cross skills and engineer's skills. Some would be addressed several times in order to deepen their acquisition. Main difficulties for teacher in this kind of organization is to define precisely what means for example critical thinking or solve a complex problem. These skills are so fuzzy and not really teachable. Thus, we have to define some descriptors that will permit to identify if students use their soft skills in order to analyze a situation or solve a problem. For example, critical thinking must be very difficult for teacher to assess in training curricula. Thus, Robert H. Ennis defines critical thinking as a *"reflective and reasonable thinking that is focused on deciding what to believe or do"* (Ennis, 1985). We need to translate this definition into some comprehensive descriptors which could be used in a teaching situation (Sanchez et al., 2006). The Dreyfus's scale was used in order to define a progressive way to develop critical thinking. Thus, four levels could be identified associated to the four level of acquisition. Figure 2 describes these levels. In our study case we target the competent level.

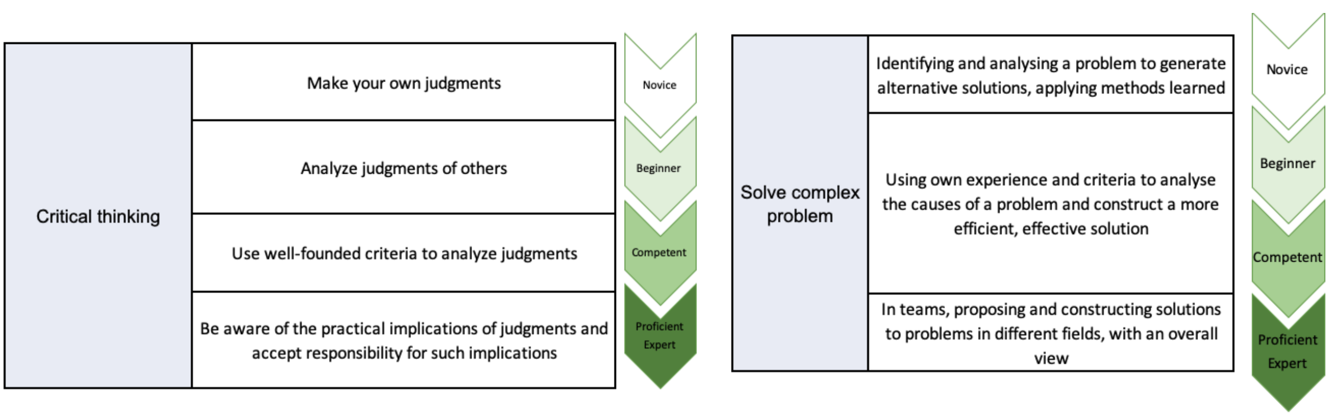

Figure 2. Description of critical thinking and solve a complex problem and level of acquisition

3.3 Skills development grid

In order to help teachers to be aware of soft skills integration in their learning activity a grid was established (Figure 3). Thanks to this grid, teachers and students can identify which skills are requested to answer to the professional situation. To complete this grid, teachers must be aware of select both engineer's skill and cross skills, they also consider that Block 1 and Block 2 could be resources which can support their learning activity. This grid can also be used to check if students have really achieved the target level.

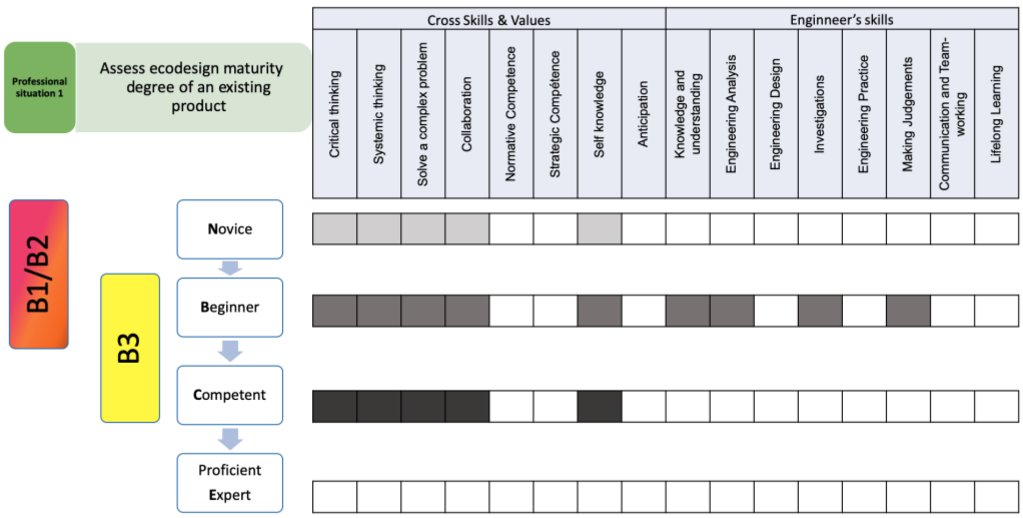

Figure 3. Skills development Grid

4 Discussion et perspectives

Our framework model is still in progress, we have just begun our test with a student group and we have to verify if we address correctly skills that we have chosen for activities. We can present our results during oral session. In our future work, we have to test our competency-based framework in others professional situations with different student groups in order to check if we assess all cross skills. We have also to think if this grid can integrate a portfolio for students which allow to follow their capacity to acquire this kind of competencies.

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