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The Competence of an Engineer and how it is Built through an Apprenticeship Program: a Tentative Model*

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This paper presents some findings resulting from a four-year research aiming to identify what competence are developed by students following an apprenticeship program in engineering and what the developmental steps are in conjunction with the curriculum. The main findings presented here suggest: 1) that competence has three dimensions; 2) that the competence framework of an engineer has five main components; 3) that there are four main steps that comprise the competence development framework; 4) and that building competence results from three different and interlocking processes. Our competence framework is then discussed by comparing our graduates' profile with those of other engineers in France, as well as with existing international standards for professional engineers.

Keywords: competence of an engineer; competence development, apprenticeship program

1. Introduction

Since the end of last century, competency-based instruction has been developing worldwide, and this trend has now reached engineering education. As an example, in France, the '*Ecoles d'ingénieurs*' have been invited to develop a competency-based approach of their curriculum [1–3]. This invitation has been reinforced with the publication of the European Qualification Framework (EQF) in 2008 and the associated Recommendation of the European Parliament and of the Council, which specifies that starting 2012, each national qualification issued should carry a reference to an appropriate EQF level [4]. It means that the learning outcomes of a curriculum leading to a qualification should be described in terms of knowledge, skills and competence, and be associated with a given level of the qualification framework.

CESI '*Ecole d'ingénieurs*' pioneered in describing the learning outcomes of its curricula in terms of competencies as early as 1997. Nine years later, two questions were posed to CESI by the French national accreditation body '*Commission du titre d'ingénieurs*': 1) how do you know that the learning outcomes achieved are those described in terms of competencies in your competency framework? And 2) How do you assess this is so? This paper presents how CESI has answered these questions.

2. Presentation

This section presents the research program and the Apprenticeship program in Engineering which was investigated to furnish answers the above questions.

2.1 The research program

To answer such tough questions, CESI thought that a research program was needed, and ask a proposal from the *Laboratoire d'ingénierie des environnements d'apprentissage*, CESI's Research Department in Educational Sciences. The proposed research program included a) an initial phase of desktop aimed at defining the terms 'Competence' and 'Competency'; b) a second phase of research looking at the 3 years of the program, based on interviews conducted with 40 students and their mentors, in order to identify the main elements of the competence framework and the main steps of the competence development, as observed in the case of students attending the Apprenticeship program in Engineering; c) a third longitudinal study (aimed at identifying the steps and situations in which competence is developed even more precisely than in the second phase) in which volunteer students enrolled in the apprenticeship program were interviewed every six months over the course of their entire three years of study. Nearly 50 students participated in this study at the beginning, although a few stopped their contribution before their graduation.

After approval of this research program, the desktop research into the meaning of the terms 'Competence' and 'Competency' took place at the end of 2006. The result of this phase was an internal document [5] which provided the basis for further investigations. The first set of interviews was conducted between February and May 2007. The comprehensive analysis of these interviews, carried out by several researchers, resulted in two Master's degree theses in Educational sciences [6, 7], as well as

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in a presentation made at a conference on 'Socialization and Competency development' held in Montpellier, France, in September 2007 [8]. The longitudinal survey got underway in November, 2007, and lasted until September 2010. A first overview of the competency framework was presented in May 2010, at the 20th Anniversary of the Apprenticeship program in Engineering [9]. This article is the first presentation of a synthesis of the main findings arrived at in all the three phases of the research.

Before presenting the findings and in order to provide the unfamiliar reader with a better understanding of the peculiarities of an Apprenticeship program in Engineering such as we have designed, a short description of this program would be useful.

2.2 The Apprenticeship program in engineering

CESI was created in 1958 by a group of five French companies in the automotive industry lead by Renault. This creation intended to reduce the shortage of manufacturing engineers in the sector through continuing education and the training of skilled technicians. The inspiration of the founders came from the Cranfield School of aeronautics (UK), the CUCES experience in Nancy (France), and the 'Training within Industry' approach developed by the US War Manpower Commission during the Second World War to face the shortage of skilled and trained personnel in industrial plants due to conscription [10].

This means that CESI has never been a traditional '*Ecole d'ingénieur*', and to-day, active instructional methodologies such as Inquiry-Based learning, Project-Based Learning or Problem-Based Learning are commonly in use, along with more conventional methods such as lectures, hands-on exercises or case-studies. Nonetheless, CESI '*Ecole d'ingénieur*' curriculum was accredited by the National certification body '*Commission du titre d'ingénieur*' in 1978, and a newly proposed 3-year Apprenticeship program in Engineering was accredited in 1990. Since then, this program has been running successfully and now welcomes more than 850 freshmen every year. The students in this program are 21–26 years old, and have at least graduated as '*Techniciens Supérieurs*' or have got the equivalent of a BA degree. Each student has to find a company, in which he/she is employed during the whole program, and which provides work-based learning situations allowing them to carry out a series of 'Missions' planned within the curriculum.

These in-company missions, their content, their duration and their progression are designed in such a way that they appear to the students as 'learning challenges', each entailing specific learning objectives to be achieved (Table 1).

The Apprenticeship program in Engineering aims not only to develop knowledge, skills and competence, but also to promote 'becoming an Engineer', which means that it also aims at developing *professional identity*[1] [8]. By graduating from the program, a student acquires, along with knowledge, skills and competence, both a new self-identity [11]—i.e. he/she becomes an Engineer—and a new social 'distinction' inasmuch as he/she graduates and is granted an accredited diploma in engineering (a Master degree).

In this perspective, each 'challenge' successfully met appears as a milestone along a '*Professional Identity Transformation Path*' going from a 'Technician' profile to an 'Engineer' profile. This path comprises four steps which students successively pass through, namely: 'Technician', 'Still a Technician', 'Almost an Engineer', 'Engineer'. It comprises 3 steps for the identity-for- others in the organisation in which the student is working: 'Apprentice' or 'Newcomer', then 'Colleague' for everyone within the organisation, and finally 'Peer'[2] for the engineers and managers he/she is working with (Table 2).

Identity transactions and resulting identity transitions at each step of the Professional Identity Transformation Path are the results of organizational socialization processes [12, 13] produced during the activities performed at the workplace by the student.

Thus, in the Apprenticeship Program in Engineering developed by CESI *Ecole d'ingénieurs*, the 'missions' assigned to students during their in-company periods can be simultaneously regarded, as *productive* activities for the company in which the student is working; as '*constructive*' activities for the student in the sense that they are authentic learning situations producing knowledge, skills and competence; and as *professional socialization activities* accumulating identity transactions and generating transitions in the development of a new professional identity. This triple dimension of the missions performed during in-company periods by our stu-

[1] On Professional Identity, the main reference in France is Dubar [12]. This notion has also been developed in Anglo-Saxon studies on professional development of teachers [14–16] or of nurses [17, 18]. Dubar's viewpoint is more general: he assumes that any worker has a professional or vocational identity, build through socialization processes within the organisation. This professional or vocational identity has two faces: self-identity (the way an individual perceives him or herself) and identity-for-others (the 'label' others attach to somebody).

[2] The names of the different steps of self-identity or of identity-for-others are those given both by the students and by their mentors to characterize their perception of their development. Evidence of these steps are provided by the type of legitimate activity allowed to the student at a given time, and by the behaviour of his/her colleagues towards him/her, the way they talk to him/her at this time. . .

Table 1. The missions along the program and their specific objectives

When	In-company Missions	Learning objectives
All along the program	Reviewing Personalized learning path Interviews with the Mentor	To steer one's professional project 'becoming an Engineer'
Semester 1	'Rapport d'étonnement' Scientific Bibliography	To put across organizational socialization within the company as a Technician
Semester 2	Technical Report	To master technical aspects of a Technician job
	Defining Personalized Learning Path	To start a reflexive attitude
Semester 3	Scientific and technical Research project	To build scientific reasoning
Semester 4	Mission in a foreign country Scientific Modelling project	To become autonomous
Semester 5	Industrial project	To become responsible for a project
Semester 6	Industrial project Personalized learning activities	To achieve a first mission as an Engineer

Table 2. The 'Professional Identity Transformation Path'

Program steps	Graduate Technician ➨ Confirmed Technician (CT) ➨ CT + Mind-Openness ➨ CT + Mastering scientific approach ➨ CT + Acquisition of autonomy ➨ CT + Mastering project management ➨ CT + Mastering the mission of an engineer ➨ Graduate Engineer
Self-Identity (Student)	Technician ➨ Still a technician ➨ Almost an Engineer ➨ Engineer
Identity for others	Apprentice Newcomer ➨ Colleague *(for everybody from Secretary to technicians to engineers to managers)* ➨ Peer *(for engineers and managers)*
Social distinction	Technician ➨ Engineer

dents is the key to understanding the main results of our research program presented hereafter.

3. The Main Findings

The main findings of our 4-year research program on the competency of an engineer and how it is built through an Apprenticeship Program in Engineering are briefly presented in this section. They will be discussed in greater depth in the following section.

3.1 Competence and competency / competencies

This finding is a result of the first part of the research, the desktop research on competency definitions carried out in 2006, and which has been recently updated, due to on-going work with colleagues from several countries on competence description [19, 20].

Currently, there is no agreed definition of the terms 'competence' or 'competency', which are sometimes, but not always, used indifferently. The existing definitions can be classified into two main semantic categories.

The first one is generally associated with the terms '*competency*' and often with its plural form, '*competencies*'. This semantic category describes someone's abilities to perform a given activity, or to achieve an expected outcome, in a given context. These kinds of competencies are acquired in situations where they are required to achieve given outcomes; they are measurable in these situations. The second category is generally associated with the term '*competence*', used in singular, and describes a person's state, a global way of being, behaving and performing in situations. This kind of competence results from the experience of the person. It can be appreciated in a global way, but cannot be measured.

Taking into account these two semantic categories, it can be said that 'competency' is an ingredient of 'competence' [21]. But competence is more than the sum of its ingredients. In fact, when compiling the literature, it appears that 'competence' develops and is recognized at three different levels: at the level of an individual, at the level of the group in which the individual works, and at the level of the organization in which he/she works. At the level of the individual, competence has a cognitive

Table 3. The three dimensions of the 'competence' and their indicators

Dimension	Focus	Indicators of competence
Cognitive	Individual (micro)	Measurable Competencies Feeling of self-efficacy
Identity	Working Group (meso)	Feeling of belonging to the group (individual) Judgement of competence (others) Integration into the group
Institutional	Organization (macro)	*Title, Position* *Level of salary* *Field of action (prescribed / real)*

dimension: acting mobilizes cognitive resources (knowledge, skills, rules or procedures. . .) of the person performing the action, his/her reasoning modes, and at the same time tools and even other persons to achieve the outcomes expected in the situation. The result is a demonstrated level of proficiency, and a feeling of competence or of self-efficacy [22] for the person performing the action. At this level, 'competence' can be assimilated to a set comprising a finite number of 'competencies' which can be described. At the group level, competence has an identity dimension: when an action is performed according to the best practices in use in a professional group, it is recognized as such by the peers (judgement of competence). When expressed, this judgement generates, for the actor, a feeling of belonging to the group, and contributes to reinforce the integration within the group. At the organization level, competence has an institutional dimension, which is the first meaning of the term: the action performed within an organization can be recognized as being part of the legitimate field of actions of the person, and this recognition is expressed by a title, a position, and a level of salary. These three dimensions correspond to the focus of the observation [23, 24] as shown in Table 3.

Measurable 'competencies' thus appear as indicators of the cognitive dimension of 'competence'. They are characterized by the cognitive resources they mobilize (knowledge, skills, rules or procedures), the context in which their proficiency is measured, and the indicators of proficiency in the given context. This is represented in Fig. 1.

Our model includes the three dimensions of the competence and the characteristics of the competency, considered as an indicator of the cognitive dimension of the competence. It has been used as a basis for further investigations. The following findings use the same representations.

3.2 The engineer competence framework

This finding is a result of both the first study across the entire 3-year curriculum and the longitudinal survey. The pieces of the puzzle were reassembled during the analysis of the final interviews of the panel participating in the longitudinal survey, where students were asked to look back on their learning paths, on their key learning situations, as well as on the best and worst events they had experienced during the past three years. In order to check the consistency of the narrative of the panel students with what the rest of their colleagues had to say about their own learning paths, the collection of data was completed by twelve interviews of students in the final year who did not participate in the longitudinal survey and who were selected at random (the only criterion being that they had to be available on one of the three dates proposed by the researcher).

It appears from our analysis of the interviews that

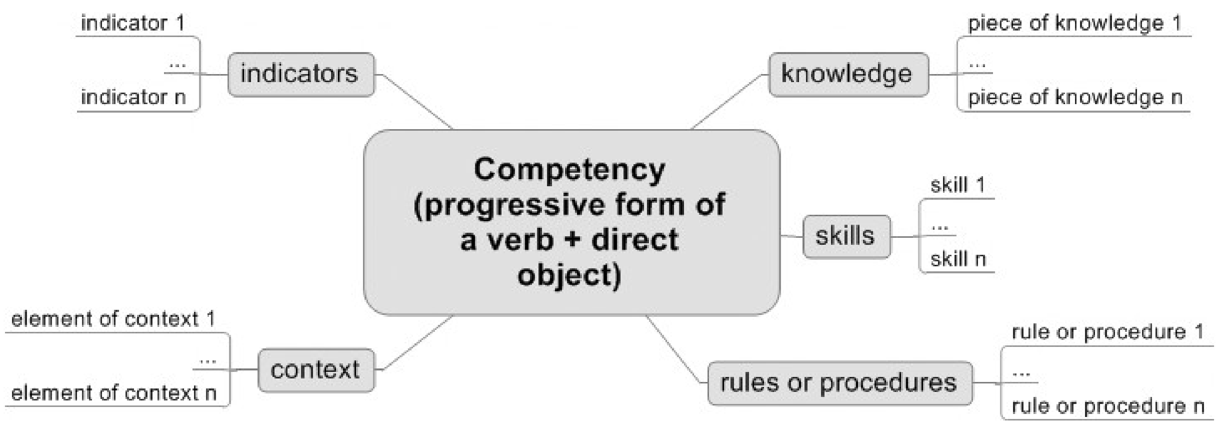

Fig. 1. The characteristics of a 'competency'.

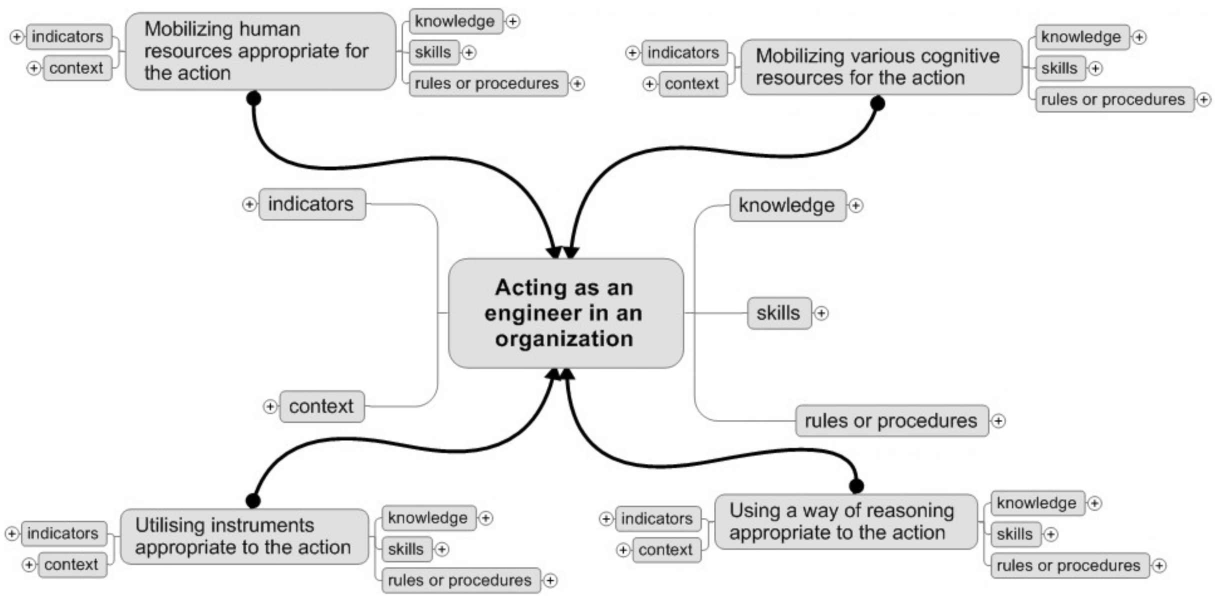

Fig. 2. The Engineer competency indicators (reduced map).

the cognitive dimension of the competence of an engineer has five main competency indicators, one being more central than the other four. These indicators are described hereafter in rather generic terms. This is done on purpose to present a general overview, but it is easy to contextualize them for a particular sector. For example, the term 'action' has to be replaced by the type of task an engineer has to achieve, such as designing the motor of a car or the wing of an aircraft; or managing the daily operations of a manufacturing plant or the project of building a bridge, etc. The knowledge, skills and rules or procedures that can be mobilized vary accordingly.

For the sake of legibility, only a reduced map of the full set is presented (Fig. 2), and then the competencies indicators will be presented in detail one after the other. Nonetheless, though presented one by one, these competencies indicators cannot be separated when considering the competence of the Engineer.

3.2.1 Acting as an Engineer in an organization

This is the core competency for an Engineer that aggregates the four others which contribute to the competence (Fig. 2). This is one of our key findings, namely that acting as an engineer in an organisation requires specific knowledge and skills about the action within its human and organizational context which are not very often described[3] and are generally forgotten in the description of an engineer competency framework like the one prescribed by the national accreditation body in France [3, p. 27]. This competency is a major learning outcome of the organizational socialization processes within the company. Its characteristics are represented in the following map (Fig. 3).

A first subset of knowledge characterizing this competency is related to what can be called the '*grammar of the action*': how the action is organised and planed, what are the related situations, which resources and tools are needed and when... A second subset is related to the *language of the action*, which has to do with the professional jargon, acronyms used, specific terms in use, etc. In this domain, some elements of pragmatics must also be familiar, such as what to say or not say, to whom something can be said, how to say something to a particular person, etc. A third subset of know-how, acquired later, is included in this competency, and is referred to as '*pragmatic knowledge*'. It is related to the action, and has to do with what Pierre Pastré calls 'pragmatic concepts' [25], professional gestures and postures, relationship modes with colleagues. . .

Skills associated with this competency include understanding and participating in the socialization rituals of the organization, deciphering and applying the tacit rules regulating the daily life of the company [26, 27], respecting usages and best practices in use.

Rules to take into account range from the internal regulation of the company to the laws regulating the sector and the professional activity of an Engineer, and include the standards of the domain.

The context in which this competency is measured is characterised by the nature of the activity (routine or not), the fact that the activity is managed in

[3] This issue has been addressed in some studies looking at socialization processes in the organizations [13, 28].

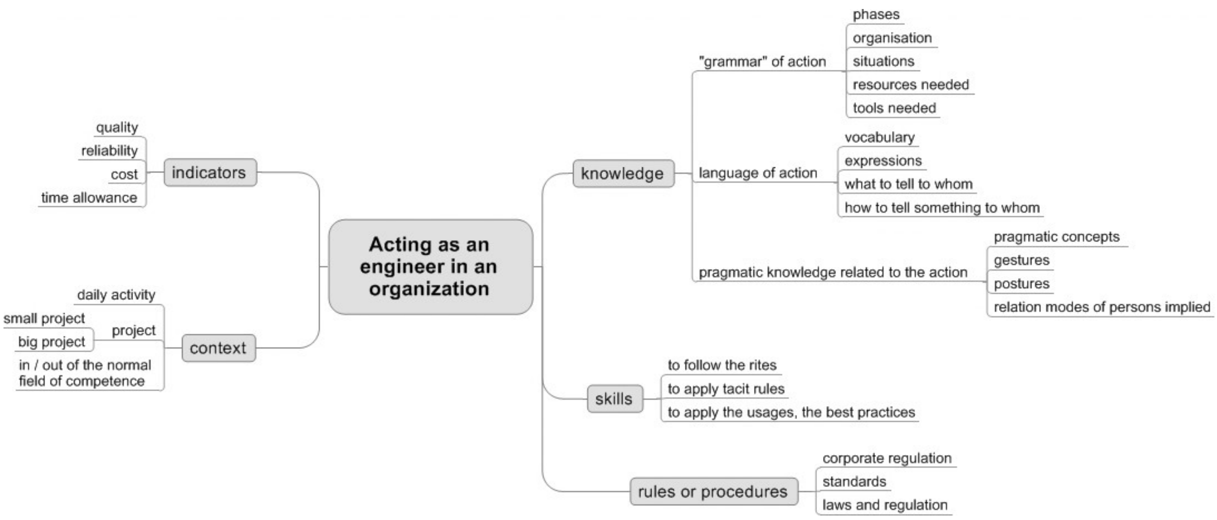

Fig. 3. The core competency of an Engineer: 'Acting as an engineer in an organization'.

project mode or not, the size of the project, the fact that the activity is part of a demonstrated field of competence of the person or not.

The indicators attached to this competency are the general indicators of proficiency in a company. They include quality, reliability, cost and time allowance.

The fundamental knowledge and skills that comprise this core competency must be quickly acquired by our students, since they need them to be accepted and become members of the team they are working with during their in-company periods. This acquisition progressively transforms the 'newcomer' in the organization into an 'insider', and corresponds to a first change in the identity-for-others: the apprentice becomes a colleague.

3.2.2 Mobilizing various cognitive resources for the action

This competency is generally the one which comes first when describing the competence of an Engineer. Its characteristics depend on the nature of the action: the cognitive resources (knowledge, skills, rules or procedures), mobilized for the action, vary according to the activity carried out as well as to the discipline of engineering, and to the projects. . . This is why they are expressed in broad categories in the following paragraphs as well as in the map (Fig. 4).

Knowledge relating to this competency is extremely diverse, as stated above. Usually, in CESI, knowledge required by an Engineer is divided into four categories: scientific knowledge, technical knowledge, economical knowledge (including knowledge in management and in finance), and knowledge in human sciences (including social and societal sciences). To these categories, should be added foreign languages, particularly English, which have an increasingly important place in engineering education in France. For example, a score of 750 at the Test of English for International Communication (TOEIC®) is now required to earn the diploma '*Titre d'ingénieur*'.

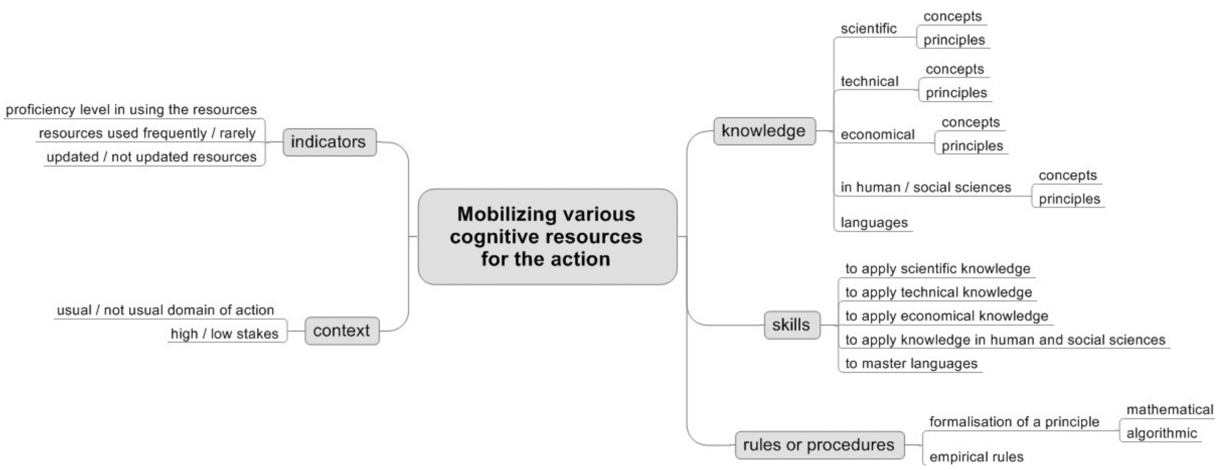

Fig. 4. A second competency of an Engineer, 'Mobilizing various cognitive resources for the action'.

The associated skills are those linked to the application of the four categories of knowledge described above along with mastering of foreign languages.

The rules and procedures which can be mobilized are those concerned with the formalisation of a principle, mainly for scientific and economic knowledge, and of empirical rules for technical and human sciences.

The context in which the proficiency of this competency is measured is characterized by the level of familiarity with the domain of action, and the stakes attached to it (high or low).

The indicators of proficiency are the level of mastery achieved in the different fields of knowledge and their applications, the frequency with which these resources are mobilized, and whether they are up-to-date or not.

3.2.3 Using a way of reasoning appropriate to the action

This competency is separated from the previous one because much research on conceptualization and reasoning in science show that concepts may often seem to be understood and used correctly by students, but the reasoning is wrong [29–35]. After a first study on our experimentation of Problem-Based Learning in Physics [36, 37], I put forward the hypothesis that what the didactics of sciences has discovered can be generalized, and that acquisition of concepts and principles and the competency to use these concepts and principles for reasoning accurately in a given situation are disconnected. The map for this competency is presented in Fig. 5.

Knowledge relating to this competency includes categories of reasoning that can be used (inductive, deductive, abductive, analogy. . .) and for which situations, together with global approaches which facilitates the apprehension of the reality, such as the 'systemic approach' [38]. This knowledge includes systems analysis as well as systems modelling.

Skills related to this competency are those which allow problem solving: formulating the problem, breaking it down if necessary, identifying concepts and principles that will help to solve the problem, applying the principles to the resolution of the problem. These skills play a key role in the global proficiency of the Engineer.

Rules and procedures related to this competency are mainly those dealing with information processing (search of information, validation of the information found) together with those linked to data collection and data interpretation.

The context in which the proficiency of this competency is measured is characterized mainly by the type of problem (simple or complex) and by the facts that the problem is known or not, and whether the problem is well- or ill-defined.

The indicators of proficiency are linked to the result of the reasoning applied to the problem (problem resolved or not, time needed to provide a solution), and to the quality of the solution proposed (innovative or not, simple or complex, easy or difficult to implement. . .).

3.2.4 Mobilizing Human Resources appropriate for the action

This competency is the one which is generally associated to the managerial role of the Engineer. It appears from our research that it relies on the core competency, since it requires knowledge about action: its grammar, its language, some pragmatic knowledge such as the preferred relational mode of various individuals (e.g. co-workers). It also requires skills useful for the action such as applying the tacit rules of the organization, or respecting its customs. The map for this competency is represented in Fig. 6.

Specific knowledge related to this competency deals, on the one hand, with the competencies requested for the action (what are the competencies needed, who is competent, where to find the compe-

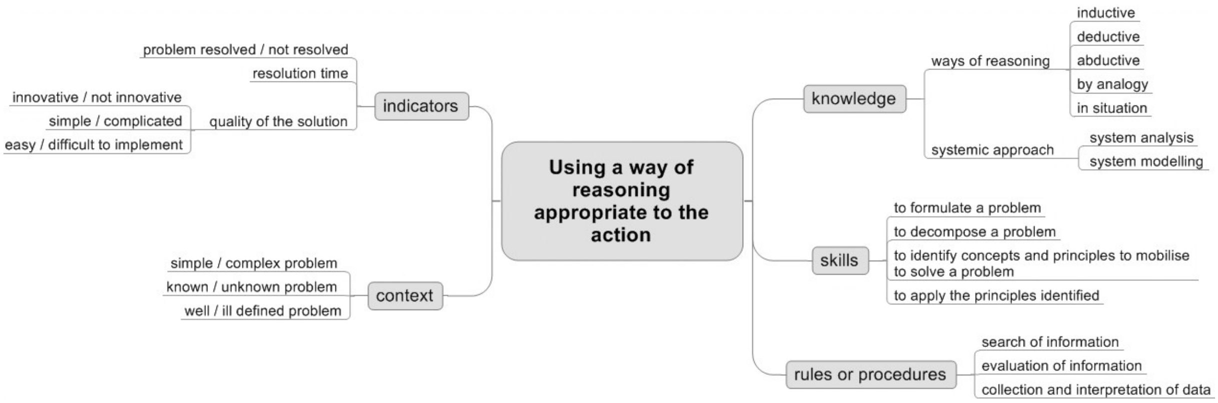

Fig. 5. A third competency of the Engineer: 'Using a way of reasoning appropriate to the action'.

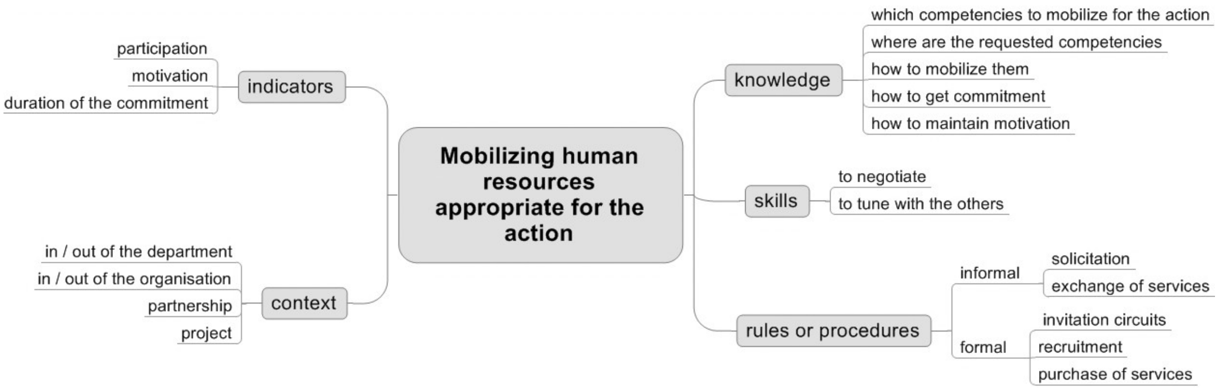

Fig. 6. A fourth competency of the Engineer: 'Mobilizing human resources appropriate for the action'.

tencies or competent people. . .), and on the other hand, with how to mobilize these competencies, how to get motivation for and commitment to the action. . . This knowledge is the basic knowledge associated with 'leadership'.

Skills associated with this competency are mainly those required to lead a team in order to meet the objectives assigned: negotiating, tuning with others.

The associated rules and procedures are of two kinds: informal rules on the one hand (how to solicit suggestions or advice from someone, how to ask someone for assistance. . . with or without reciprocity); formal procedures, on the other (official circuits to invite someone, procedures for recruiting someone or for buying a service, etc.).

The context is characterized by its institutional nature: internal (within the department or within the organization) or external (in partnership); in project mode or a more conventional mode.

The indicators of proficiency are those measuring the leadership and the active participation of those involved: type of participation, level of motivation and commitment, duration of the commitment.

3.2.5 Utilizing instruments appropriate to the action

The instruments mentioned here are both instruments allowing to act upon the material world (what I call 'tools') and instruments allowing to act upon a mental representation of the world, which can be called 'methods' [39]. The term 'instrument' has been chosen not only because it is generic, but also because it takes into account the work of Rabardel [40], who states that an instrument is a double-sided concept: it described simultaneously an artefact and the schemes (with the meaning used by Piaget) which allow for its use. These schemes are developed through two learning processes: one which links the instrument with the action for the user ('*instrumentalization*': learning that this instrument is used in such and such a situation), the other which allows the user to use the instrument ('*instrumentation*': learning how to manipulate the instrument in a given situation). The engineer has to learn both. This is obviously in close relation with some elements of the core competency, such as the 'grammar of the action'. With the development of computer-based tools and of modelling and simulation techniques, this competency might become a more important part of the competence of the Engineer. The map of this competency is represented in Fig. 7.

Knowledge related to this competency deals with the choice of instrument for a given purpose in a given situation, the domain of use of the instrument (including their limits), the functions of the instruments, how to use them.

Skills associated with this competency are those allowing for use of the instruments, and, in case of

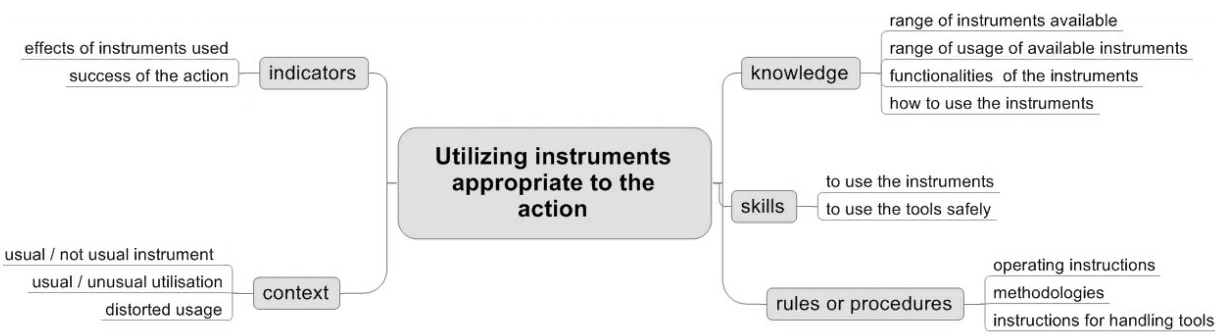

Fig. 7. A fifth competency of the Engineer: 'Utilizing instruments appropriate to the action'.

tools, those related to their use in acceptable safety conditions.

The associated rules or procedures are those concerned with the use of the instruments and their functioning, the use of methods, the handling of the tools.

The context is characterized by the level of acquaintance with the instrument (usual / not usual), the frequency of its use, and the fact that the usage is normal or is distorted.

The indicators of proficiency are the effects resulting from the use of the instrument, and ultimately, the outcomes achieved by the instrumented action.

3.3 The main steps of the development of the engineer competence framework

This finding is mainly a result of the longitudinal survey. The interviews during the last year of the curriculum confirm the role played by the professional identity transitions from the 'Technician' to the 'Engineer' in the development of the competence of the students attending the Apprenticeship Program [8]. In the interviews, the students relate their progress or their difficulties in developing their competence to Identity and its Institutional dimensions. They first measure their progress by the judgements of the professionals they work with during the in-company periods: their tutor, the members of their team (their colleagues as well as their hierarchy), and also their partners (customers, providers. . .). But, what confirms these judgements is whether or not it is taken into account at the institutional level, and whether it is translated into the allocation of a new field of responsibility, appropriate to their progress: responsibility of a small project at the beginning of the second year, then responsibility of bigger project during the second and the third year. They measure their progress when they come back to CESI after their in-company period by comparing their current or promised-for-the-next-period professional situation and the projects under their responsibility to those of their class-mates.

The development of the competence during the Apprenticeship Program is characterized by a distance from school life and an important investment in professional life in their company. Due to this investment, students become more demanding: they require from their school that it provide them with knowledge which is useful to their professional life when they feel they need it. This demand increases their motivation to learn what appears useful to them, and to reject courses which seem to have no utility for their current projects.

The development of the competence of the Engineer through the Apprenticeship Program appears to be driven by the development of the core competency, 'acting as an engineer in an organisation' (Fig. 3): *acting as a professional* drives the socialization / insertion process within the company. It also triggers and then fosters the development of the managerial competency ('mobilizing human resources appropriate for the action'). It makes the development of the other competencies necessary. It also maintains students' motivation for learning, at least for learning what they feel useful at the moment to solve the problems posed by their acting in professional situations.

It also appears that the situations which foster the development of the competence are characterized by an institutional adjustment of the field of responsibility of the student in professional situation to what I call, with reference to Vygotski [41], the '*zone of proximal development*' of the competence: it means the competence development is facilitated when the professional situation provides the student with new challenges which are not too difficult to meet. Adjustment of the support provided by the tutor and other professional partners to the new situation with enlarged responsibility may also facilitate the student's progress. In ideal conditions, additional learning opportunities for knowledge appropriate to the problems to solve may be provided as scaffolds to help meet the new challenges.

Following the thread of the joint evolution of the three dimensions of the competence and using the evolution of professional identities presented in the introduction as landmarks (Table 2) four steps were identified, which are described hereafter.

3.3.1 Step 1

This is the initial step, starting with the first days in the company. The student's status in the company is 'Newcomer', and the identity-for-others' label is 'apprentice' or 'newcomer'. He/she is maintained for a while at the periphery of the action, which he/she could disturb or at least cause interference.

This stage is characterised by progressive learning of the basic elements of the 'grammar of action' and of the 'language of action', by observing and eventually imitating while performing peripheral tasks more or less related to the main flow of action performed by the tutor and the rest of the team.

Then the student progressively learns the basic skills associated to the core competency by taking charge of parts of the main action. During this period, he/she practices 'vicarious learning' [42], through imitation and observation.

Then, when the student is considered as able to participate in the main flow of action, he/she acquires a new status and becomes a 'colleague'. This is also his/her new identity-for-others.

3.3.2 Step 2

This step starts with the first responsibility of an activity given to the student (autonomous task; small or very-short-term project). It can start only when the student is considered to be a 'colleague' having a potential to contribute to the global action. This step generally begins with the second semester.

This stage is characterized by further learning of the 'grammar of action' and of the 'language of action' together with the associated skills, thus developing the core competency through performing the activity-in-responsibility.

Progressively, the pragmatic knowledge related to the activity-in-responsibility and the associated skills are acquired through vicarious learning, trial and errors, and other on-the-job learning methods such as asking colleagues for tips and tricks, reading documents, etc.

The ways of reasoning are also explored through the same learning methods, and are reinforced by the formal learning situations that characterize the 'challenges' of this period (Technical report).

This second step also sees the beginning of the use of instruments (tools, methods) related to the action, to which the student is initiated.

The student starts to select the cognitive resources relevant to his/her activity when coming back to school. The main criterion for this selection is the immediate perceived utility.

3.3.3 Step 3

This step is characterised by taking on successive responsibilities of longer project (duration between 3 and 6 months). It generally starts by the end of the first year, because the in-company period including summertime is the first period long enough to allow for such projects.

During this stage, the 'grammar of action', the language of action and the related skills learned previously are applied, and enriched through practice; the pragmatic knowledge acquired is in use, as well as the ways of reasoning relevant to a given situation. This is also facilitated by the 'challenges' to meet during this period (scientific and technical research).

The use of instruments becomes more and more autonomous, at least for those related to the action-in-responsibility.

This step also sees the beginning of the development of the managerial competency ('Mobilizing human resources appropriate to the action'), through actions performed which include relationship with customers or providers, or management of a small team.

During this stage, students also develop a reflexive attitude towards their action, their professional objectives and their learning path; they become more demanding about the cognitive resources needed to perform their activity; self-study becomes part of the learning methods they use, and they become more selective regarding learning resources and learning opportunities provided. Utility is still the drive for their learning priorities.

Finally, at the end of this period, students feel they are 'almost engineers' (self-identity), but this has to be confirmed by their colleagues and by their company. Confirmation is given if they are allowed to go on to the next step. In that case, they are appointed as 'assistant engineer' or 'assistant project manager' and their field of responsibilities is institutionally extended.

3.3.4 Step 4

This final step, starting during the third year, is characterized by taking charge of a project which is considered important by the company. To manage this project, students have to use all facets of the competence they have progressively developed, and by managing this project, they reinforce them.

During this stage, students also reinforce their reflexive attitude towards the action they are managing, towards their career; they become able to identify their professional strengths and weaknesses.

Self-study becomes a way to acquire knowledge or skills which appear necessary for the actions. Knowledge fields which were neglected or even rejected previously may suddenly appear as important, because they are needed by the final project.

Finally, at this stage, though still students in CESI *Ecole d'ingénieurs*, they are institutionally considered to be engineers, project managers, works foremen in their company. And their colleagues who are engineers, project managers, works foremen, call them 'peers'.

3.4 Building the competence framework: three geared processes

Thus, it appears that the competence of the Engineer is progressively built through acting in professional situations which are organized in such a way that competence development challenges are to be met in each situation. It also appears that the competence development is closely related to identity transactions recognizing the progress made, and to changes in institutional position and legitimate field of responsibility taking into account this development. This section will wrap up the previous findings and provide a tentative model of the dynamics of the 3-dimensional competence building process.

The process of competence development of a student attending the Apprenticeship Program in

Engineering, as it appears in this research, seems to be as follows. The student is alternatively working in a company, where he/she is inserted and has to face various professional situations, or attends courses at CESI. The working situations, in agreement with the company managers and in particular with the company tutor are organised so as to provide 'learning challenges' to the students. These learning challenges are designed in order to be within the student's 'zone of proximal development' [41], i.e. they take into account the current stage of development of the competence of the student, and propose a reachable step further, requiring some effort, but not too difficult to reach; and, in addition, some support can be provided in the company by the tutor or by members of the team to facilitate student performance. What the student learns in a formal way during courses, or informally during working situations not only increase his/her knowledge and skills, but also transform his/her behaviour at work and his/her way to face and handle situations: this is a sign of the development of the student's competence. At some point, these transformations become visible for the student's colleagues, and this visibility triggers a new judgement of competence and new identity transactions within the team in order to recognize the progress made. When expressed, this judgement stimulates the feeling of competence of the student, while motivating him/her to take up another learning challenge and prepare for it. If the organization plays along, it will allow the tutor to enlarge the field of responsibility of the student, which will *de facto* create a new zone of proximal development beyond the current stage of competency development.

Three dynamics seem to be geared together to develop the competence of the Engineer through the Apprenticeship Program: the cognitive development of the student, which is fostered by the feeling of competence of the student; the institutional evolution of the student, which is fostered by the judgement of competence of the student's tutor and of the team he/she works with; and, as a central process, the identity evolution, which is fed through socialization processes within the working team. These three geared processes are represented in Fig. 8.

This model also works to explain cases of failure: when the company does not provide the legitimate field of responsibilities at a particular stage of competence development, the student's motivation drops and he/she rapidly stops learning and progressing. Similar effects are produced when the tutor does not recognize the progress made or does not say anything about student's competence, or when the student does not feel comfortable with the team. Other difficult situations are when the field of responsibilities given to the student is out of his/her zone of proximal development, i.e. the responsibilities given require a proficiency level which is too far removed from his/her current competence development stage: in such cases, the student feels unable to face the situations, his/her feeling of competence decreases, and he/she can finally drop out. When such cases occur, we generally request the company to be more attentive to the student development process. In some cases, we ask the company to propose another tutor, and in extreme cases, we advise the student to find another company for the remaining periods.

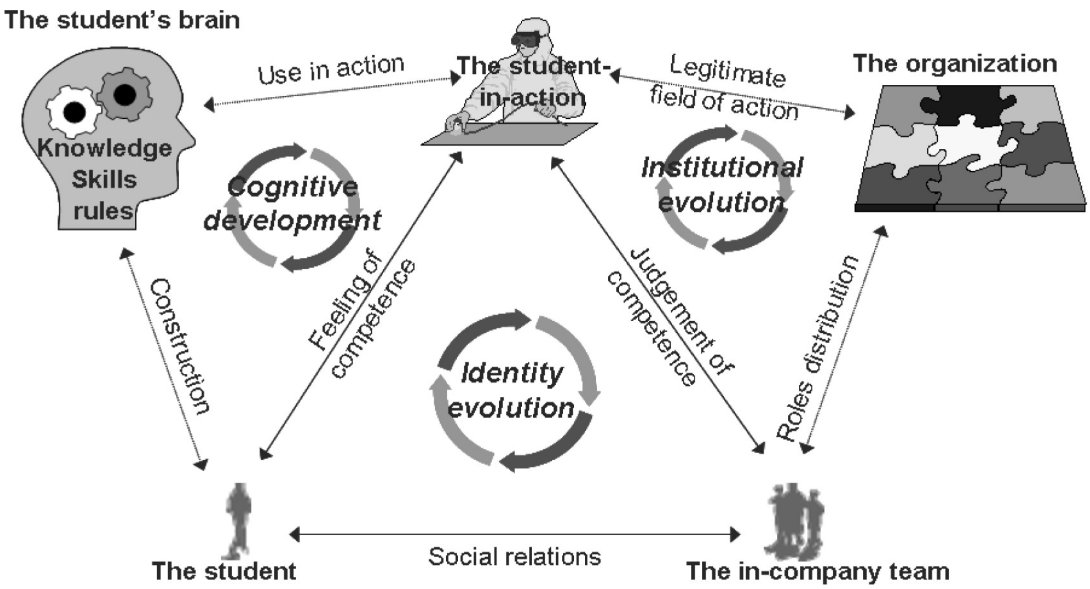

Fig. 8. The 3-dimension development process of the competence of the Engineer through the Apprenticeship Program.

4. Discussion

From the above, the company appears to play a very important role in the development of the competence of an Engineer through the Apprenticeship Programme in Engineering. That the company plays a role in the achievement of learning outcomes is normal in a work-study program, i.e. in a program based on in-company periods alternating with in-school periods. What is more surprising in our findings is that the core competency on which the competence of the Engineer is built develops only within the company and cannot exist without a rather long experience within a company. This raises the following question: is the competence of our Engineer, as we discover it in our research, the same as the competence of an Engineer attending a more traditional curriculum? As far as I know, no comparable research has been made on the competence of an Engineer graduating from a traditional curriculum. So, direct comparison of the competence framework is not possible. To answer this question, we will have to look at what is available about Engineers in employment. I will first compare the result of two recent surveys: one concerning our alumni, made in the beginning of year 2010 and the annual national survey on the Engineer's employment published in June 2010. Then I will compare our competency framework to professional engineers or chartered engineers published standards.

4.1 Comparison of our engineer profile with the average national profile

Fort the 20th anniversary of our Apprenticeship Program in Engineering, we have asked CEFI (*Comité d'études sur les formations d'ingénieurs*), to make a survey in order to know what the 4,500 engineers who have graduated from our Apprenticeship Program since its beginning 20 years ago are currently doing. CEFI is an independent institution specializing in observing the world of engineering education, and providing an annual survey on the engineers' employment for the French national organisation of Engineers (CNISF). Having our survey made by CEFI has the advantage to allow easy comparison between the survey on our Apprenticeship Program in Engineering and the national annual survey.

CEFI survey on our alumni was made during the first term of 2010 through an online questionnaire comprised of 46 questions. Information about the survey and a kind request to answer to the questionnaire was sent to all the alumni. 923 of them, mostly graduates from the last ten years, responded to the questionnaire, and 827 completed it. CEFI completed its survey with interviews of company managers having hired some of our students. The result of CEFI survey [43] compared with the national survey which got 45,000 responses at the same time [44], shows that there are few differences between the profile of those engineers who graduated from our program and that of others.

The more significant differences are the following: our students have more often than on average a lower social origin (34.7% have a father manager or engineer, against an average of 47.4% and 42% of their mother work, against an average of 16%); their unemployment rate is less than half of the average (2% versus 5.4%); project management is a responsibility quoted much more frequently than on average (72.5% as opposed to 48.5%).

It appears from the interviews that company managers particularly appreciate our alumni, their motivation, their ability to integrate the company, and, overall, the fact that they are immediately operational after graduation [43]. It thus seems that our engineers have the right competence for their employers, and this seems to be confirmed by their low unemployment rate.

4.2 Comparison of our competence framework with national standards

No national standards for Engineers exist in France. In the USA, to become a Professional Engineer, it is necessary to graduate with an academic degree accredited by the Accreditation Board for Engineering and Technology, to accumulate some years of professional experience in engineering and to pass examinations (the Fundamentals of Engineering examination test and the Principles and Practice of Engineering examination test). None of these examination tests is based on a competence framework[4]. In Canada, where the process is quite similar, no competence framework has been found either. Such standards were found in the UK [45], Ireland [46] and Australia [47]. These three standards are all considering competencies as sets of abilities to perform given activities. British and Irish standards are very similar: they both have five main competencies which are phrased in a very similar way; their elements of competency are also very close, and differ only in details. The Australian standard is different: it proposes three 'Core Units of competency' which should be demonstrated, and ten 'Elective Units of competency' covering various

[4] I have only found a reference to 'abilities' (which might be assimilated here to our 'competencies') in the description of the expected learning outcomes proposed by ABET as criteria for accrediting engineering programs [48]. These criteria are similar to those of our national accreditation body, and therefore they are met by our graduate students. But they cannot be considered as 'standards', since the evidence of the achievement of these learning outcomes has to be given by each candidate to the ABET accreditation in its own format.

fields of speciality, two of which should also be demonstrated together with the core units.

These standards are structured and phrased differently than our framework. Nonetheless, even if there are no common items, it is possible to see to what extent the standards overlap with our framework, because our description of a competency describes its ingredients, and not a given ability, thus avoiding semantic problems and byzantine discussions about whether a description of a competency is the same, or includes (or is included within) the description of another one.

It is clear that our second competency '*Mobilizing various cognitive resources for the action*' encompasses the UK competency A and the Irish competency 1 which is the same '*Use a combination of general and specialist engineering knowledge and understanding to optimise the application of existing and emerging technology*'. It is included within the very broad competency C1 of the Australian standard '*To apply a professional approach to a specific area of engineering practice*'.

Our third competency, '*Using a way of reasoning appropriate to the action*' encompasses the UK competency B and the Irish competency 2 which is the same: '*Apply appropriate theoretical and practical methods to the analysis and solution of engineering problems*'. This competency is also included in the very broad competency C1 of the Australian standard.

Our fourth competency, '*Mobilizing human resources appropriate for the action*' and elements of our core competency '*Acting as an engineer in an organization*' (more specifically knowledge related to the *language of action* and skills such as '*to follow the rites' and 'to apply the tacit rules*') covers UK competency C '*Provide technical and commercial leadership*' and competency D '*Demonstrate effective interpersonal skills*', which are similar respectively to the Irish competencies 3 and 4. These competencies are included in the Australian competency C3 '*To perform work competently, making judgements about work priorities and information requirements to achieve effective working relationships and engineering outcomes*'. In this broad competency, communication and management skills explicitly appear in sub-competency C3-2 '*Work effectively with people*' but are also needed for C3-3 '*Facilitates and capitalizes on change and innovation*' and C3-4 '*Plan and manage work priorities and resources*'.

Our fifth competency '*Using instruments appropriate to the action*' is implicitly included in the UK A and B competencies, respectively Irish competencies 1 and 2: '*specialist knowledge and understanding in engineering*' (UK A, IE 1) and '*appropriate theoretical and practical methods*' (UK B, IE 2) include at least methods, which are among our 'instruments'. Tools are not mentioned, as usual: for human sciences researchers, who sometimes produce competency standards, engineers live in an abstract world, like most human beings. But I will not talk about that here, since I already have written a book on this issue [39]. In the Australian standard, competency C1 explicitly mentions in C1.1.b '*Demonstrates use of appropriate engineering techniques and tools*', which is quite similar to our competency.

Finally, our core competency '*Acting as an engineer in an organization*', which I kept last because I think it is not obvious to consider it as a core competency, appears to be split between UK competency C and D (or Irish competency 3 and 4): we have already seen that when discussing our fourth competency. The remaining part of our core competency, namely knowledge related to the '*grammar of action*' and skill '*to apply the usages and best practices*' are ingredients required by UK competency C (or Irish competency 3), in particular by sub-competency C1 '*Plan for effective project implementation*' and C2 '*Plan, budget, organise, direct and control tasks, people and resources*' (respectively IE 3.a and 3.b). In the Australian standard, our core competency ingredients appear to be those required by the core competency C2 '*Engineering Planning and Design*'.

At the end of this comparison, it appears that our competency framework describes ingredients which are all included in the competencies described by the standards. These standards are broader than our framework, because they describe ethical behaviours in addition to the competencies (UK competency E, Irish competency 5, part of Australian competency C1), which were not studied in our research, and they also describe competencies specific to a particular sector or activity (Australian Elective Units of competency).

Consequently, in response to the question which initiated this discussion, i.e. 'is the competence of our Engineer, as we discover it in our research, the same as the competence of an Engineer attending a more traditional curriculum?', the answer is yes if we exclude ethical behaviour which was not included in our research and competencies related to specialities. But I have to qualify this affirmation somewhat, for the way it has been demonstrated uses, in one case, a competence framework built at the end of our Apprenticeship Program, and in the other, employment profiles and standards for chartered or professional engineers (instead of a competence frameworks at the end of a traditional academic curriculum). In other words, we were obliged, for this comparison, to take into account professional experience. Here clearly appears the difference between an Apprenticeship Program and an Academic Program: it provides, at the same time, academic knowledge and skills in engineering, and professional experience leading to the development of competence.

5. Conclusion

To conclude, I will provide an answer to the questions posed by our national accreditation body, the '*Commission du titre d'ingénieur*', which triggered the research work presented in this article. These questions were: How do you know that the learning outcomes achieved are those described in terms of competencies in your competency framework? How do you assess that this is so?

This research revealed that the competency framework established in 1997 corresponds only partially to the learning outcomes achieved by our students. The main reason is that, besides the five competencies resulting from our research, which were present in the first framework though described differently, it also included specific competencies, related to specific activities like research and development, or marketing. In fact we should have considered these competencies as 'elective units', like in the Australian standard: besides the five competencies, our students develop specific competencies which are needed in their company and for their specific job, but not all the competencies which are described in all the 'elective units'. The next version of our 'official' competence framework will take this into account.

The answer to the second question is easier, and has already been given in Table 3: the assessment is based on the indicators of the three dimensions of the competence. It was not formalised as it is now, but these indicators were taken into account in the following way: each student has to make regular entries in a 'log book' in which are noted the objectives of the semester, the competencies targeted and the competencies acquired, the results of assignments and examinations, the projects in which he/she is participating, the individual learning path negotiated. . . The information written by the student is reviewed at least once every semester by the tutor in the company and by the mentor in CESI. This is done during interviews with the student in which the outcomes of the learning path and of the work situations of the semester are discussed, and the learning path and the work situations for the next semester are planned. Evaluations noted in the 'log book', and in particular evaluation of competencies, must be agreed by the student, the tutor and the mentor. At the end of the final year, the 'log book' is analysed by the jury of professionals which decides, on the basis of its content, to attribute the diploma or not. Our research has put some theoretical grounds under what had been so far an empirical practice.

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