Competence learning challenges in Engineering Education in Spain: from theory to practice

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Abstract - The aim of this paper is to analyse in what manner competence and competence-based learning have been introduced and are currently used in Engineering Education in Spain. First, we provide a conceptual overview of competencies as implemented in a variety of settings, including key concepts, definitions and efforts carried out in order to identify, measure and integrate competences. Second, we go on by making a critical analysis of the information provided in projects concerning the degrees in Engineering Education elaborated in co-operation with the Spanish National Agency for the Quality Evaluation and Accreditation. Finally, we present the actions taken into consideration as an adaptation experience to the European Higher Education Area at the School of Engineering Design of Valencia.

Index Terms – Competence, learning, engineering curricula, European convergence.

INTRODUCTION
The process of Bologna started to be developed two decades ago and represents the answer to the economic and socio-cultural impacts derived from globalization and the advance of the Knowledge society [1]-[2]-[3]. The fast development of the Information and Communication Technology (ICT) has brought about deep changes in our way of working and living, as the widespread diffusion of ICT is accompanied by organisational, economic, social and cultural innovations. New necessities in the knowledge production and management are originating imbalances between the supply and the demand of job competences, and this has direct incidence on the formation that is being developed in higher educational institutions [4]-[5]-[6].

In this change context, competence and competence-based learning emerge as nuclear concepts in the majority of European universities. The “New Engineer”, besides unquestionable technical skills, must have abilities such as team working, knowledge of foreign languages and cultures, creative thinking, efficient oral and written communication, and appropriate profile for the market needs. Furthermore, future engineers needs to develop habits of life-long learning, must be conscious of their social role and be able to assume their social tasks. It is necessary to graduate professionals that are flexible and open minded to cope with the important changes in the present world; they need to be able to “learn how to learn” [7]-[8].

Employers demand graduates who are able to operate in complex environments, i.e., environments characterized by ill-defined problems, contradictory information, informal collaboration, and abstract, dynamic and highly integrated processes [9]. Although in Spain employers generally have expressed satisfaction with the technical knowledge and skills of current engineering graduates, they usually affirm that some competences in certain non-technical areas such as communication ability, economics, leadership, teamwork and management are not practically being considered in their formation [10]-[11]. The development of these competences are seen by employers as highly desirable and necessary. Also Accreditation Boards, Engineering Associations, and governments in Spain have been demanding the incorporation of these competences for the actual and the future engineering degrees. In this paper, we present some reflections about competence-based education in Spain and how some universities in engineering education areas are developing initiatives according to this new engineer profiles competency based.

COMPETENCES AND THE NEED OF NEW UNIVERSITY MODEL
On the last decades, Spain has undergone profound social and economic changes that have greatly affected the higher education system. The structural reforms and the intends to modernize and democratize the universities, as well as adapt the higher education system to the socioeconomic needs of the country could be judged as very positive [12]. Despite these approaches the actual academic culture, involving the formative processes in which teachers and students are implied, is not still giving a suitable answer to the new exigencies [13].

Ginés Mora (2004) affirms that the university model in Spain and in some European countries and Latin America, corresponds to the necessities of a society and a labour market that are disappearing [10]. The Spanish university model has been conceived to give answer to a labour market characterized by defined professions; with clear professional attributes and competences, in many cases, legally fixed. The
little inter-communication between the different professions caused that the required competences were related to a concrete aspect of the labour practice [14]-[15].

Spanish universities are now entering a new period, in which adaptation to the dynamic change and search of high quality will be the most important challenge. Introducing market forces will allow the higher education system to achieve an equilibrium in which the state (representing the whole community), academia (representing the experts in the production process), and the market (as the most effective mechanism to satisfy the needs of students and employers) are able to act in harmony [15].

There is an intense debate about these themes, trying to identify and harmonize the perspectives of the different stakeholders [16]-[17]. Beyond the debate, there are no doubts that competences constitute a common language for the harmonization of the European educative systems [17]-[18]. (Reichert y Tauch, 2003; González y Wagenaar, 2003). In the Berlin Communiqué, the Bologna Working Group on Qualifications Frameworks (2004) encourages Member Status “to elaborate a framework of comparable and compatible qualifications for their higher education systems, which should seek to describe qualifications in terms of workload, level, learning outcomes, competences and profile”.

The situation is too complex. Although formation based on competences is view like one of the pillars to advance in the harmonization and convergence towards the European Higher Education Area (EHEA), in some European countries there is little clarity in its conceptualization and applicability [9]-[19]-[20]-[21]-[22]. On the other hand, research has showed it do exist different patterns between acquired and required competences in the Mediterranean countries and the rest of European countries [23].

COMPETENCES: CONCEPTUAL OVERVIEW

While competences and competence-based teaching and curriculum tendencies are consolidated in diverse countries, mainly in the Anglo-Saxon world, in the case of Spain and other countries of Europe they have appeared recently. Until the present in Spain competences make reference to the professional attributes more than educative aspects or curricular treatments.

Although competences and competency are concepts very used in the educative area in some European countries (United Kingdom, Denmark, Finland, France, among others) it exist an increasing criticism about the ambiguity of its use, and the lack of a theoretical frame [9]-[24]-[25]. There is such confusion and debate concerning the concept of “competence” that is impossible to identify or impute a coherent theory or to arrive at a definition capable of accommodating and reconciling all the different ways that the term is used [26].

Some authors consistently use competency when referring to occupational competence [27] or treat competence and competency as synonymous [28]. Elkin (1990) associates competences with micro-level job performance and competencies with higher management attributes and, in defining managerial competencies for the future [29]. Boak (1991) argues that competency in the American sense complements competence as used in the UK occupational standards [30]. Mansfield (2004) contrasts three different usages of competence: outcomes (vocational standards describing what people need to be able to do in employment); tasks that people do (describing what currently happens); and personal traits or characteristics (describing what people are like) [31]. The few attempts to establish coherent terminology have had little impact to date and competence is called a “fuzzy concept” [21]-[32]; Weinert (2001) affirm that there is no basis for a theoretically grounded definition or classification from the seemingly endless inventory of the ways the term competency is used. Many different theoretical approaches exist and meanings vary depending on perspective and underlying objectives associated with the use of the term both in scientific discussion and in the policy discourse [33]. However, making a bibliographical analysis, three historical approaches in the use of this term can be observed: in the psychological field, in the business and human resource field and in the educational one. We can compare different definitions on the following Table I.

<table>
<thead>
<tr>
<th>Author</th>
<th>Definition</th>
</tr>
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<tbody>
<tr>
<td>Hamel &amp; Prahalad</td>
<td>Advanced the idea of “core competencies” and “capabilities”. Core competencies is the “collective learning” of the organization [34].</td>
</tr>
<tr>
<td>Bunk</td>
<td>A person who has occupational competency has the necessary knowledge, skills and capacity to perform in a profession, is able to solve occupational problems in an autonomous and flexible manner and is able to contribute to his professional environment and the organisation of work [35].</td>
</tr>
<tr>
<td>Gonzci</td>
<td>A complex structure of necessary attributes to perform in specific situations. This has been considered a holistic approach in the sense that it integrates and relates attributes and tasks, it enables several intentional actions to occur simultaneously and it takes into account the context and the culture of the workplace [16].</td>
</tr>
<tr>
<td>Mertens</td>
<td>While qualification is a group of knowledge and capacities that individuals acquire during socialisation and training processes, competency refers only to certain aspects of the store of knowledge and abilities: the ones necessary to achieve certain results demanded by a specific circumstance; the actual capacity to achieve [36].</td>
</tr>
<tr>
<td>Spencer, McClelland &amp; Kellner</td>
<td>An underlying characteristic of an individual that is causally related to criterion-referenced effective and/or superior performance in a job or situation [37].</td>
</tr>
<tr>
<td>Le Boterf</td>
<td>A construction obtained from a combination of resources (knowledge, know how, qualities or aptitudes and environmental resources -relationships, documents, information, etc.) which are mobilised to achieve a satisfactory performance [38].</td>
</tr>
</tbody>
</table>

TABLE I

EXAMPLES OF COMPETENCE DEFINITIONS IN MANAGEMENT AND HUMAN RESOURCES APPROACHES (1980-90)
Diverse authors argue that competence-based education was historically based on a behaviourist model of training and learning, within a Taylorist industrial model. In the recent competence-based movement, a holistic approach is normatively put forward [22]. Although a holistic approach is in advance, the practical design of learning processes and assessment procedures is still based on a narrow definition and a behaviourist conception. In addition, while educators usually define competences like indicators of profits, knowledge and capacities, employers and economists, however, associate them to the performance, productivity, efficiency and professionalism. Consequently, it exist great difficulties to establish common guidelines for program designing based on competences.

We can conclude that providing a basic understanding of these concepts requires a multiple and interdisciplinary approach, with the necessary participation of various stakeholders (particularly government, industrial bodies, the education profession and enterprises) working together with a common purpose.

**COMPETENCE-BASED GUIDELINES IN SPAIN**

In the majority of the Spanish initiatives, the holistic and integrated approach on competences is considered, but there is no a clear conceptual definition. In the official document provided by the Education Ministry, called “The integration of the Spanish Higher Education System in the European Higher Education Area” (2003) it affirms that the official degrees will have to provide a university formation in which the generic competences are integrated harmonically with basic ones; transversal competences related to the integral formation of the people and specific competences than make possible a professional profile that allows the graduates integration in the work market [43].

In the last years, government promoted and sponsored the creation of university networks in some disciplines in order to analyse different ways of implementing the European Credit Transfer System (ECTS) in the curriculum. The scope and methodology adopted in the great majority of the developed initiatives have been taken from the project “Tuning Educational Structures in Europe” o, more briefly “Tuning Project” [17]. On summer of 2000, a group of universities took up the Bologna challenge collectively and designed this pilot project, developing a working programme during the period 2000-2004. As part of the methodology, Tuning has developed reference points for first and second cycle programmes for generic and subject-specific competences for diverse subject areas (Engineering is not included). These reference points have been used to define cycle descriptors. In the framework of the Tuning project ECTS has been developed further as an accumulation system by linking credits to learning outcomes. Tuning makes the distinction between learning outcomes and competences to distinguish the different roles of the most relevant players: academic staff and students/learners. Desired learning outcomes of a process of learning are formulated by the academic staff, preferably involving student representatives in the process, on the basis of input of internal and external stakeholders (employers, graduated, etc.). Competences are obtained or developed during the process of learning by the student/learner. Therefore:

- Competences represent a dynamic combination of knowledge, understanding, skills and abilities. Fostering competences is the object of educational programmes. Competences will be formed in various course units and assessed at different stages.
- Learning outcomes are statements of what a learner is expected to know, understand and/or be able to demonstrate after completion of learning. They can refer to a single course unit or module or else to a period of studies, for example, a first or a second cycle programme. Learning outcomes specify the requirements for award of credit.

Questionnaires for academics, graduates and employers were prepared and a review of over twenty studies in the field of **generic skills and competences** was carried out. A list of 85 different skills and competences was identified and they were regarded as relevant by institutions of Higher Education or companies. These items were categorised as instrumental, interpersonal and systemic.

**Instrumental Competences**: Those having an instrumental
function. They include:

- **Cognitive** abilities, capacity to understand and manipulate ideas and thoughts.
- **Methodological** capacities to manipulate the environment: organising time and strategies of learning, making decisions or solving problems.
- **Technological** skills related to use of technological devices, computing and information management skills.
- **Linguistic** skills such as oral and written communication or knowledge of a second language.

**Interpersonal Competences**: Individual abilities relating to the capacity to express one’s own feelings, critical and self-critical abilities. **Social skills** relating to interpersonal skills or team-work or the expression of social or ethical commitment. These tend to favour processes of social interaction and of cooperation

**Systemic competences**: those skills and abilities concerning whole systems. They suppose a combination of understanding, sensibility and knowledge that allows one to see how the parts of a whole relate and come together. These capacities include the ability to plan changes so as to make improvements in whole systems and to design new systems. Systemic competences require as a base the prior acquisition of instrumental and interpersonal competences [17].

The Tuning methodology and its taxonomy were adopted in the majority of initiatives developed in engineering education in Spain.

**COMPETENCES: FROM THEORY TO PRACTICE**

The School of Design Engineering has worked in co-operation with the Spanish National Agency for the Quality Evaluation and Accreditation (ANECA) in pilot projects called White Paper for the adaptation of the future engineering degrees to European framework [44].

In these projects, other interesting and extensive studies on competences were considered, specially the results of CHEERS (Careers after Higher Education – A European Research Survey) [43], The ABET criteria [46]-[47] and the IEEE Technology Standards [48].

A set of surveys in 2004/2005 were applied to graduates, employers and academics in five degrees of engineering (chemical, mechanical, electrical, electronics and design). Twenty-six competences were selected from three categories, with the general taxonomy of Tuning: instrumental, interpersonal and systemic. For each of the competences, the respondents were asked to indicate the importance of the competence for work in their profession and the level of achievement of the competence that they estimate they have reached as a result of taking their degree programme.

Some of the results obtained with this study are showed in the following Tables IV, V and VI.

The knowledge of a foreign language (2,21), recognition to diversity and multiculturalism (2,06), work in an international context (1,91) and knowledge of other cultures and customs (1,72) are considered little important by the employers. These competences are directly related to the European convergence goals and also they are showing the low implication of the Spanish enterprises in economic innovation [13]-[45]

**TABLE III**

<table>
<thead>
<tr>
<th>Stakeholders</th>
<th>Samples</th>
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</thead>
<tbody>
<tr>
<td>994</td>
<td>Employers.</td>
</tr>
<tr>
<td>2,085</td>
<td>Graduates of the last 5 years.</td>
</tr>
<tr>
<td>1,423</td>
<td>Academics.</td>
</tr>
</tbody>
</table>

**TABLE IV**

<table>
<thead>
<tr>
<th>Competences</th>
<th>X</th>
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</thead>
<tbody>
<tr>
<td>Problem-solving (ability to identify, formulate, and solve engineering problems)</td>
<td>3,41</td>
</tr>
<tr>
<td>Decision-making, taking responsibilities</td>
<td>3,40</td>
</tr>
<tr>
<td>Planning, coordinating and organizing</td>
<td>3,39</td>
</tr>
<tr>
<td>Ability to apply knowledge in practice</td>
<td>3,30</td>
</tr>
<tr>
<td>Team-work</td>
<td>3,26</td>
</tr>
<tr>
<td>Motivation for quality and continuous improvement</td>
<td>3,26</td>
</tr>
<tr>
<td>Capacity of analysis and synthesis</td>
<td>3,22</td>
</tr>
</tbody>
</table>

**TABLE V**

<table>
<thead>
<tr>
<th>Competences</th>
<th>X</th>
</tr>
</thead>
<tbody>
<tr>
<td>Problem-solving</td>
<td>3,55</td>
</tr>
<tr>
<td>Ability to apply knowledge in practice</td>
<td>3,67</td>
</tr>
<tr>
<td>Basic knowledge</td>
<td>3,61</td>
</tr>
<tr>
<td>Innovation</td>
<td>3,36</td>
</tr>
<tr>
<td>Initiative</td>
<td>3,52</td>
</tr>
<tr>
<td>Team-work</td>
<td>3,33</td>
</tr>
<tr>
<td>Decision-making</td>
<td>3,36</td>
</tr>
<tr>
<td>Leadership</td>
<td>3,21</td>
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<table>
<thead>
<tr>
<th>TABLA VI</th>
<th>RANKING OF SOME GENERIC COMPETENCES (N = 1,423 ACADEMICS)</th>
</tr>
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<tbody>
<tr>
<td>Competences</td>
<td>X</td>
</tr>
<tr>
<td>Ability to apply knowledge in practice</td>
<td>3,47</td>
</tr>
<tr>
<td>Basic knowledge</td>
<td>3,44</td>
</tr>
<tr>
<td>Ability to understand professional and ethical responsibility</td>
<td>3,42</td>
</tr>
<tr>
<td>Ability function on multidisciplinary teams</td>
<td>3,41</td>
</tr>
<tr>
<td>Critical reasoning</td>
<td>3,34</td>
</tr>
<tr>
<td>Problem solving</td>
<td>3,26</td>
</tr>
</tbody>
</table>

Problem solving is indicated in first place for the employers and graduates and it appears in sixth place for the academics. These results, in which prime the attention to the
professional knowledge and the capacity to apply them are coherent with the actual academic university model. It is excessively focalized in the transmission of knowledge and it has deficit in important skills and attitudes development.

Of another part, it is of interest to analyze the competences from “theory” to “practice”. Although many educational institutions display themselves with a competency-based educational concept, on the level of concrete educational programs and practices this philosophy does not materialize. This may be caused by the holistic character of competences, which confronts teachers with a very complex concept, still in some cases undefined. The shift from knowledge-based to competency-based education forces teachers to change their way of thinking and working. The traditional knowledge-based curriculum was not very demanding with regard to the design of instruction in the form of learning tasks. The learning materials only contained piecemeal practices that consisting of isolated knowledge and skills that make up the whole task. Instead, in the new competency based curriculum, teachers have to think holistically in terms of the whole authentic task that competent professionals perform. It is not an easy task, and all the faculty staff must participate in embedding the competence educational model.

**CONCLUSION**

How competences are to be worked, realized and assessed and the impact of this change, both at individual level and at the level of European university structures, needs further reflection and debate. It is not clear how problems related to transportability of competency assessment and credentials across states and institutions will be resolved. The principal theme is future work should examine issues of transportability of learning, experiences across academic programs and institutions by focusing on how reliability and validity are addressed. It is important that faculty staff can explore validate and reliable ways to design and evaluate competence based curriculum.

**REFERENCES**


