Learning and Assessing Competencies: New challenges for Mathematics in Engineering Degrees in Spain

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Abstract

The introduction of new degrees adapted to the European Area of Higher Education (EAHE) has involved a radically different approach to the curriculum. The new programs are structured around competencies that should be acquired. Considering the competencies, teachers must define and develop learning objectives, design teaching methods and establish appropriate evaluation systems. While most Spanish universities have incorporated methodological innovations and evaluation systems different from traditional exams, there is enough confusion about how to teach and assess competencies and learning outcomes, as traditionally the teaching and assessment have focused on knowledge. In this paper we analyze the state-of-the-art in the mathematical courses of the new engineering degrees in some Spanish universities.

Introduction

The Bologna process encourages the transition of higher education from knowledge possession to understanding performances and from a teaching-centered to a student-centered approach via learning outcomes. The *European Credit Transfer and AccumulationSystem* (ECTS) is a system based on learning outcomes and competencies (European Commission, 2009).

All degrees are defined in terms of the competencies that students should have acquired with a view to entering the job market. Such competencies are divided in generic and specific. All academic subjects, including mathematics, must define their learning outcomes in such a way that the acquisition of such competencies will be facilitated.

The concept of competency can be defined as *the ability of carry out tasks or to deal with situations effectively using knowledge; skills and attitudes* (see Weinert, 2001). Learning outcomes are statements of what a learner is expected to know, understand and/or be able to demonstrateafter completion of a process of learning.

The Tuning-AHELO conceptual Framework (OECD, 2011) defines Engineering as *the profession that deals with the application of technical, scientific, and mathematical knowledge in order to use natural laws and physical resources to help design and implement materials, structures, machines, devices, systems and processes that safely accomplish a desired objective*. This framework offers a summary of some of the most influential learning outcomes in the Engineering field. Graduates should possess generic skills needed to practice Engineering. Among these are: *The capacity to analyze and synthesize, apply knowledge to practice, adapt to new situations, ensure quality, manage information, and generate new ideas.* More particularly, graduates are expected to have achieved the following learning outcomes*:the ability to function effectively as* *an individual and as a member of a team;the ability to communicate effectively with the engineering community and with society at large;the ability to recognize the need for and engage in independent life-long learning; andthe ability to demonstrate awareness of the wider multidisciplinary context of engineering.*

Other international references for competencies and learning outcomes of Engineering are ABET (Felder and Brent, 2003) or CDIO (Crawley et al., 2011), with similar learning goals even though different words are often used for the same idea.

Concerning the Spanish case, regulation RD1393/2007 is a detailed procedure to implement the new grades adapted to the EHEA. No catalogue of degrees has been drafted; instead we have a system for the verification and accreditation of university degrees. This is run through a Quality Agency and a register of universities and degrees (RUCT,2008). The degrees are grouped into five areas of knowledge, one of which is *Engineering and Architecture*. According to the data available from this source, in Spain there are 50 public universities and 31 private ones. Only four of these universities are defined as polytechnic, but nearly all of them include *Bachelor Degrees* in the fieldof *Engineering and Architecture* (EABD) in their offer, there being (in April 2012) a total offer of 606 EABD.

All Spanish EABD have 240 ECTS credits, 60 of which correspond to basic subjects concentrated during the first three academic semesters. The generic competencies, described in Table 1, are collected in the definitions of most of these EABD.

Competencies	Description
GC1:Self Learning	The ability to engage in independent life-long learning
GC2:Critical Thinking	The ability to select, analyze, synthesize and apply relevant information, knowledge, methods and logical and well- motivated argument
GC3:Use of ICT	The ability to use modern ICT technology for communication and engineering practice
GC4:Problem solving	The ability to apply knowledge of mathematics, science, and engineering for formulating and solving engineering problems
GC5:Technical Communication	The ability to communicate effectively, by oral o written form, with the engineering community and with society at large
GC6:Team work	The ability to function effectively as a member of a multi-disciplinary team

Table 1: Basic Generic Competencies for Engineering

The purpose of this paper is to analyze the treatment afforded to thesegeneric competencies in the mathematics subjects of the Spanish EABD.

Competencies Associated with MathematicalSubjects

All students of Engineering and Architecture must follow different mathematics subjects (calculus, linear algebra, numerical methods, differential equations, statistics, etc.). In some EABD mathematical contents are limited to two 6-ECTS subjects, followed during the first two semesters. In many universities, in order to economize resources, the same subject, calculus or algebra for example, is offered to students following different EABD whose basic mathematics requirements are similar.

For each subject, teachers must prepare and publish a learning guide (LG) in which they outline: competencies to be acquired, learning outcomes, programs, methodology, assessment, planning, etc. To explore the treatment afforded to competencies in mathematics subjects we have analyzed a set of different LGs. We have chosen a varied and sufficiently representative sample of 60 subjects, imparted by 13 universities.

Table 2 shows the universities chosen for the study, with the number of EABD offered, by each of them, during the 2011-2012 academic year, and the number of LGs chosen for our research.

University		EABD	LG
USAL: Universidad de Salamanca www.usal.es	Public	16	5
UPM: Universidad Politécnica de Madrid www.upm.es	Public	38	12
UPCOMILLAS: Universidad Pontificia de Comillaswww.upcomillas.es	Private	4	2
UAL: Universidad de Almería www.ual.es	Public	5	2
UCLM: Universidad de Castilla la Mancha www.uclm.es	Public	14	4
UEM: Universidad Europea de Madrid www.uem.es	Private	11	4
ULPGC: Universidad de las Palmas de G. Canaria www.ulpgc.es	Public	9	3
UNED: Universidad Nacional de Ed. a Distancia www.uned.es	Public	6	2
UNIOVI: Universidad de Oviedo www.uniovi.es	Public	16	3
UNIZAR: Universidad de Zaragozawww.unizar.es	Public	14	3
UPV: Universidad Politécnica de Valencia www.upv.es	Public	19	10
US: Universidad de Sevilla www.us.es	Public	24	7
UVIGO: Universidad de Vigo www.uvigo.es	Public	12	3
Total	13	188	60

Table 2: Learning Guides Analyzed

For each LG, we have analyzed the competencies sought, the learning activities foreseen and the proposed methods of evaluation. All the analyzed LGs include as a specific competency: *The ability of students to demonstrate knowledge and understanding of the mathematical principles underlying their branch of engineering*. Also, all LGs aim at developing one or several generic competencies that coincide with, or are related to, the six generic competencies of our research. Table 3 shows the frequencies where the analyzed competencies appear in the LGs.

University	LG	GC1	GC2	GC3	GC4	GC5	GC6
USAL	5	5	5	4	5	3	2
UPM	12	10	7	7	10	4	4
UPCOMILLAS	2	0	2	2	2	2	2
UAL	2	2	2	1	2	0	0
UCLM	4	3	4	1	4	3	2
UEM	4	4	2	0	2	3	2
ULPG	3	2	0	3	1	0	1
UNIOVI	3	2	2	3	3	1	2

UNED	3	2	2	2	0	2	1
UNIZAR	3	3	2	2	3	3	3
UPV	10	7	5	9	10	3	6
US	7	5	4	2	7	1	2
UVIGO	3	0	3	3	3	0	0
Total/Percentage	60	45/75%	40/67%	39/65%	52/86%	25/41%	27/45%

Table 3: Frequency Table of Generic Competencies included in the LG analyzed

Although it is not possible to determine whether the students really do acquire the competencies, there is broad consensus with regard to ensuring that the activities carried out by students in mathematics subjects promotes the acquisition of competencies GC1 and GC4. Additionally, competencies from GC1 to GC5 are tightly linked to the mathematics competencies defined in the KOM Project (Niss and Højgaard, 2011).

Methodological changes

The student-centered programs, based on the development of competencies, require other methodologies and strategies than the traditional programs.

The CDIO Standard8 states*: Active learning methods engage students directly in thinking and problem solving activities. There is less emphasis on passive transmission of information, and more on engaging students in manipulating, applying, analyzing, and evaluating ideas. Active learning in lecture-based courses can include such methods as partner and small-group discussions, demonstrations, debates, concept questions, and feedback from students about what they are learning* (Crawley et al.,2011).

Regarding the LGs it may be deduced that many teachers have attempted to incorporate methodological changes aimed at adapting to the new scenario. These changes are mainly relatedto two aspects: the way to teach, increasing the use of the powerful technological support available, and the aims sought in the teaching activities, directed towards the acquisition of the different competencies mentioned above.

From the LGs studied:

- 70%propose solving problems with mathematical software. This activity allows the development of GC1 to GC5 competencies (Díaz, García and Villa, 2011).
- 55% incorporate teaching materials, managed through educational platforms such as MOODLE. This activity develops GC3 and promotes GC1.
- 38% include some method of active learning, which permits the development of the GC1, GC2 and GC3.
- 25% propose some collaborative learning activities activity for the development of GC6.

However the teaching based on the transmission of information persists in many mathematical subjects. That is, some teachers have tried to adapt their situation to the EHEA with as few changes as possible.

Assessment of Competencies

The change to competency-based learning implies differences in the assessment methods used to adequately determine the acquisition of those competencies. Baartman et al. (2006) state that *one single assessment method seems not to be sufficient*. They propose some quality criteria for a Competency Assessment Program.

In Spain no procedures have been defined for the separate evaluation of generic competencies. These competencies are evaluated together with the specific competencies in the subjects. There are universities that offer advice onhow to develop and assess competencies (VOAPE-UPM, 2011). But 23.3% of the LGs analyzed propose an assessment model based exclusively on traditional written exams.

For assessing each competency a set of measurable learning outcomes can be defined. For example, the learning outcomes for GC4 (Problem Solving) could be: gather and organize relevant information; translate the problem, expressed in usual language, to technical language in order to separate data from aims and choose a model; choose an effective strategy; use mathematical knowledge for solving the problem and interpret the result; and express the reasonableness of the solution. Also Niss and Højgaard(2011) proposea varietyof learning activitiesfor assessing mathematical competencies, which can be used for assessing generic competencies.

Other models for the assessment of generic competencies, based on indicators and rubrics (see Villa and Poblete, 2008) or using Miller's pyramid, can be used.

Student Performance

From a general point of view, academic results have improved in the new system. Nevertheless, the feeling amongmany students and instructors is that the new learning methods require more work time from both sides. In some cases, students continue to demand traditional expositive techniques and look unkindly upon attempts to match teaching and evaluation practices with what is demanded by the design of the degree. Despite this, and little by little, resistance is being worn down.

Fenoll, Vizcarro and Vieira (2012) made a study about the opinions of leaders of Spanish universities, teachers and students with respect to the Bologna Process. They conclude that leaders perceive the process as a driver for a positive change. Teachers' perceptions are diverse. The spectrum varies from the enthusiast innovators to the immobile teachers. Students are skeptics, but anti-Bologna sentiment has weakened.

Proposals of Learning Activities

Among the active learning activities that develop generic competencies, the following can be mentioned: solving problems using mathematical software (see Díaz et al., 2011); small projects for team work (García, García, Rodríguez and de la Villa, 2011); multidisciplinary projects (García, Bollain and Corral, 2011) and students' competitions (García, García, Rodríguez, Vila andde la Villa, 2011).

Conclusions

Mathematics teachers in EABD are making important efforts to change towards a competency-based teaching style. However, there is still considerable confusion regarding which teaching practices are best and the optimum way of assessing such competencies.

There is an interesting process of diversification of teaching scenarios, with the incorporation of Mathematics laboratories and the use of on-line methods with Learning Management Systems such as MOODLE.

Nevertheless, it should also be noted that the students' poor initial mathematical knowledge hinders opportunities for them to produce autonomous work – resources that could spectacularly increase the developmentof competencies.

It is indeed possible to appreciate an improvement in the results for the students following the courses with certain regularity and doingthe tasks set by their instructors, but we still need to design specific assessment tests that will allow the evaluation of competencies.

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