A model for evaluation of generic competences in engineering: Application to the problem-solving competence at UPM

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Abstract: *The competence evaluation promoted by the European High Education Area entails a very important methodological change that requires guiding support to help teachers carry out this new and complex task. In this regard, the Technical University of Madrid (UPM, by its Spanish acronym) has financed a series of coordinated projects with a two-fold objective: a) To develop a model for teaching and evaluating core competences that is useful and easily applicable to its different degrees, and b) to provide support to teachers by creating an area within the Website for Educational Innovation where they can search for information on the model corresponding to each core competence approved by UPM. Information available on each competence includes its definition, the formulation of indicators providing evidence on the level of acquisition, the recommended teaching and evaluation methodology, examples of evaluation rules for the different levels of competence acquisition, and descriptions of best practices. These best practices correspond to pilot tests applied to several of the academic subjects conducted at UPM in order to validate the model. This work describes the general procedure that was used and presents the model developed specifically for the problem-solving competence. Some of the pilot experiences are also summarised and their results analysed.*

Keywords: *Competence assessment, problem solving, European Higher Education Area (EHEA).*

Description of the project

The Technical University of Madrid has awarded a grant to the project *"core competences in engineering. Proposal of a model for UPM"* in the call for Educative innovation projects for the academic yeat 2010/11. This project is divided in four coordinated subprojects that pursue the following goals:

1. To analyze how core competences are treated and viewed by relevant national and international professional institutions and associations.
2. To analyze the industry´s view on the core competences of graduates from UPM..
3. To analyze how core competences are treated at UPM in relation with other institutions and associations.

4. To propose a generic model for the evaluation of core competences that may have application in the different fields of UPM.
5. To elaborate with the assistance of a specialized consultancy firm a tool for measuring the core competences of students.
6. To carry out pilot studies of the competence assessment model for each core competence in different university degrees and different educational levels.
7. To develop an Internet portal to help teachers in teaching and assesment of core competences.

The development of the Project is structured in five levels which objectives are related to the general goals of the Project (see Figure 1). Each one of these levels is divided into different tasks.

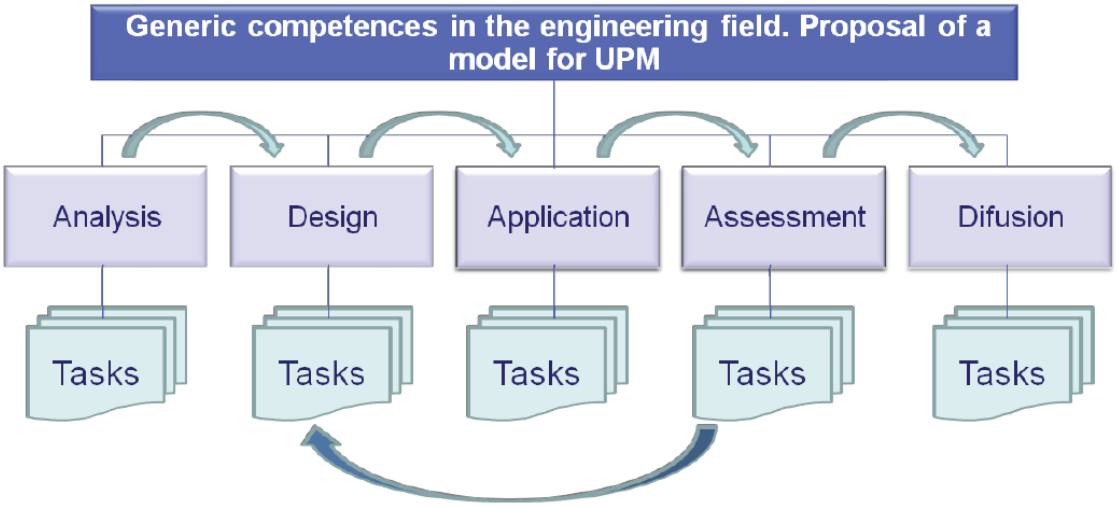

Figure 1: Project structure

Level 1: Analysis of the treatment of core competences

In this level the following tasks have been carried out:

- State of the art of the competence evaluation. Analysis of the methods applied by academic institutions and international professional associations.
- Analysis of the industry viewpoint on core competences of UPM graduates.
- Analysis of the management of competences in the different centres of UPM.
- Elaboration of a summary with information and recommendations about the teaching and assessment of core competences at the UPM.

As a result of these tasks a report has been written where the different competence evaluation strategies and the models developed by prestigious institutions are summarized. At the same time, this information has been compared to the results obtained from the analysis of the situation at UPM. This has allow us define the guidelines to follow in the next level of learning and evaluation of competences.

Level 2: Design of the core competences learning and evaluation model

The purpose of this level is to design a model for learning and evaluating core competences using the information obtained at the previous level. This model must be able to have an application on the different fields of UPM. The following tasks have been planned:

- ✓ To structure and prioritize the competence map for the graduate and postgraduate levels.
- ✓ To define the level of acquisition and control of competences.
- ✓ To define the learning and assessment methodology.
- ✓ To design a competence assesment system.

As a result of this work, the main characteristics of a test for the evaluation of core competences of students have been designed. Also the Internet portal of the UPM about core competences has been launched with relevant and useful information for teachers to help them to teach and evaluate core competences, that can be very useful to teachers that can apply the core competences assessment in their classes.

Level 3: Validation of the core competences learning and evaluation model

Various pilot studies have been launched in different colleges in order to validate the model for the following competences: oral and written communication, teamwork, leadership, problem-solving, creativity, analysis and synthesis, use of the Information and Communication Technologies (ICT) and organization and planning skills. Some of the programmed tasks are:

- ✓ To select subjects to apply the model. Taking into account that there are different levels based on the degree –for instance graduate and undergraduate levels.
- ✓ To define the levels of acquisition of the competence for three selected competences.

Level 4: Revision and feedback of the model depending on the results

The purpose of this level is to share the experiences carried out by the different working groups to enrich the model and improve its applicability in different contexts and fields of knowledge. The main tasks at this level are:

- ✓ Implementation of an interdisciplinary workshop to present the results of the pilot studies.
- ✓ Elaboration of a best-practice report.

The result of the work at this level will be the precise definition of the structure and contents that will be incorporated to the UPM Internet portal of core-competence assessment. This information will be the basis of all the UPM for teaching and assesment core competences.

Level 5: Development of contents and diffusion from Educational Innovation Portal

Once the model is improved by the previous experiences, the contents will be transferred to the Internet portal and a strategy to disseminate the contents of the portal and all the know-how acquired to the university community will be designed. A final report of the project will be prepared.

To organize the work developed by the different groups forming this Project, a group responsible of the coordination for the task is designated. Monthly reunions of the persons responsible for the different groups have taken place coordinated by the Vice Chancellor of Educative Innovation.

Competence in problem-solving

Among the different tasks of the project, our group has been responsible for working out problem-solving competence. A problem is defined as a situation in which an individual wants to do something, but do not know how to achieve their goal [1], or a situation in which an individual acts with the purpose to achieve a goal using a particular strategy [2]. Also, a problem is a situation, quantitative or not, that requires a solution which the individuals involved do not know obvious ways to find [3].

Problems are situations that require individuals to respond with new behaviours. This activity is closely related to various skills such as analysis, synthesis, critical thinking, planning or creativity. Solving a problem involves tasks that require reasoning processes more or less complex and not simply a routine, associational task (as in exercise-solving).

The aim of our work is to promote among students the right mental attitude that stimulates their ability to learn, understand and apply knowledge in an autonomous way. The development of this competence requires an active approach by the students – "you learn to solve problems by solving problems". These problems must be appropriate to the level of the studies (but not mere exercises), the wording must motivate, not be direct and promote the development of concepts. In this regard, one must consider to select practical problems, meaningful and contextualized in the current reality of students and their future career. Learning should deal with the results and analysis but above all with resolution procedure. The process can be enriched by the diverse contributions involved by teamwork.

Among the various strategies for teaching problem-solving skills we have chosen the procedure originally proposed by Polya [4]. The reason is that it is a very general strategy that can be easily adapted to the usual problems of every field of knowledge. This strategy is structured in four steps:

1. Comprehension of the problem: Read carefully the problem and represent it in different ways. Detect both the significant data and the unknowns.
2. Planning the solving process: The most difficult phase. It is necessary to discover relationships between data and unknowns, and establish a plan for resolution. Practising, i.e., solving many problems, provides resources to tackle it successfully.

3. Implementation of the plan: If the problem-solving plan is well conceived, its implementation is usually relatively easy. However, it is common that changes has to be made during its implementation.
4. Assessment of both the solution and the procedure. This step is essential to improve learning in solving problems. You should critically examine and evaluate the results obtained as well as the procedure used. It is important that the details do not prevent short-term general ideas that have been consolidated.

The method must be first explained in class. The teacher has to provide the students a summary form including questions, suggestions and techniques that can help them in each of the four steps. Then, several problems are solved in class to exercise the procedure. At this point it is important to promote a participatory attitude among the students in order to facilitate their involvement in the problems, detect blockages and stimulate an appropriate attitude regarding problem-solving.

As part of the assessment procedures to measure the progress in problem-solving skills, students will be consulted on their perceptions of the usefulness of the method. The entries should evaluate the whole process, not just the result.

Problem-solving procedure

In accordance with the four rules procedure proposed by Polya we have developed a set of generic rules to guide the students on what aspects they should considered when solving a problem and in which order they must consider them. First of all we have elaborate a very generic procedure based on all the rules relevant to solve problems. This procedure should be able to be used with any problem, regardless of its approach or complexity. To be able to accomplish the problem completely the students must be able to take into account the following aspects:

- Recognize the problems within the whole situation and can express it in a clear and precise way.
- Decide to deal with the problem and are willing to try hard to solve it.
- Pick up, describe and organize all the information relevant for the problem.
- Figure out different ways to tackle the problem, study, in a preliminary way, the success probability of each one based on the principles and methods required by each alternative.
- Compare their information sources and can deal with data rigorously.
- Study several alternatives in a rigorous and justified way. Analyse the success probabilities and the advantages and disadvantages of each alternative.
- Choose the best alternative and apply it to solve the problem.
- Analyse the solution achieved, noticing if it is coherent with the conditions of the problem.
- Participate actively in the work group, particularly in the decision-making phase.
- Communicate the solution in a clear, practical and efficient way.
- Transfer what he has learned from the problem to real situations.

Each one of these aspects can be evaluated from 0 to 4 points (from E to A) applying the following criteria:

- 0 (E), unacceptable. The students has not taken into account the aspect considered.
- 1 (D), poor. The student has taken into account the aspect but in a erroneous way.
- 2 (C), fair. It is the minimum to be required from the student. He/She approaches the considered aspect correctly but does it in a disorganized way so much so that it may not be helpful to solve the problem.
- 3 (B), good. The student deals with the aspect in a correct and organized way, it clearly helps them to solve the problem.
- 4 (A), excellent. The student also justifies the work done and the alternatives they have chosen.

These rules are designed to be applied in problem solving but they are very generic. It is clear that there are hundreds of different kinds of problem, so applying the same rules to all of them it is not a good way to deal with the problem-solving competence. Sometimes this rules can be too vague, too wide, too difficult to evaluate with a 5-point scale, etc. To deal with this situation we have restricted ourselves to the sort of problem that usually appears in the engineering studies. This includes, however, a wide variety of problems depending on the subject and the year of the studies. While during the first year the problems usually are mere exercises where the students usually have to apply a quite direct method to solve them and often they only have one way to solve it, in the top courses of a university degree the problems are much more difficult, very near to life cases, where the statment of the problem is complex, and the solution can be approached in several ways, some of them much more efficient than the others. Thus, we have divided the problem-solving competence in four levels, each one with his proper procedure and with different rules –always based on the above described rules.

At this stage of the project we have limited to the level-1 rules. We have also designed a pilot study of the use of the students of this rules.

3.1 First level problem solving procedure.

The first-level problem-solving rules are designed to be applied mainly to the first and second semesters of engineering studies. It deals with problems, more complex than a mere exercise where the wording includes more information than the strictly needed, the development of the problem is long and the students have to choose between two or more ways to solve the problem (usually one correct and the other not).

In the following table you can find the rules used to the assessment of the problem solving competence. It is clearly shorter than the initial one and the evaluation steps have also been reduced.

Criteria	Unsatisfactory (D)	Acceptable (C)	Advanced (B)	Excelent (A)
Comprehen-sion	The information obtained is clearly not enough and/or irrelevant.	The relevant information -data, variables, conditions needed... is identified but in a in a disorganized or unproper way.	The relevant information of the problem is identified properly.	The student also justifies the need for and utility of the information.
Application of the method	The method has not been applied or its application is not correct.	The method has been properly ap-plied but in a disor-ganized way and without explana-tions.	The method has been applied sys-tematically but it does not have ex-planations.	All the steps have been explained.
Justification and clarity	There are few -or even no-explana-tions that make the reading and under-standing of the res-olution of the prob-lem easier.	There are some ex-planations but they are not well organ-ized and have little mistakes.	All the explanations needed are in-cluded in a organ-ized way.	The explanations are also expressed in a clear and rigor-ous way. The solu-tion is highlighted.
Results	The results are not present, are not correct or are incomplete.	The results are correct and complete with unimportant mistakes (numerical or notation).	The results are correct and complete. They are properly expressed (adequate notation and unities).	The results are also expressed clearly and rigurously.
Efficiency	The possible alternatives are not present and the procedure chosen is a bad one.	There are more than one alternative but the chosen one is not the best.	The alternative chosen is the best one	All the alternatives are presented and reasoned out. The choice is justified.
Critical Analysis	Neither the results nor the procedure are checked.	The results are checked and they are coherent with the conditions of the problem but the procedure is not analysed.	Either the results and the procedure are checked.	The solution is checked and verified. Its application is extended to other contexts and generalized. The procedure is analysed and some improvements are proposed.

Pilot study

Once we have designed what we think it is a good problem-solving procedure the next step is to make the students use it and evaluate the suitaqbility of the method. To this aim we have prepared a group of pilot studies. In these studies the procedure will be explained in detail to the students and the teacher will solve some problems using the rules to show the students their advantages. Once the students have become familiar with the rules the teacher will propose a problem to be solved applying the problem solving rules. This

problem will be evaluated both, by the student and by the teacher in order to obtain the degree of comprehension of the rules. Finally the teacher will conduct a survey among the studentsto know how comfortable do they feel with the procedure and whether they think this way of solving a problem is better.

At this stage of the project we have designed the pilot studies but we have not applied it yet. We plan to conduct the pilot study in the following subjects:

- Physics, Mathematics, Statistics, second semester of the Degree in Environmental Engineering.
- Electronics, second semester of the Degree in Forestry Engineering.
- Chemistry, first semester of the Degree in Environmental Engineering.
- Mechanisms, fourth semester of the Degree in Aerospace Engineering.
- Mechanic, third semester of the Degree in Aerospace Engineering.

The study will be finished at the end of the next academic year. However, this summer we will have some preliminary results of the studies carried out in the subjects of Physics and Mechanism. These preliminary results will be explained in an oral communication at the "Edulearn" meeting.

Conclusion

The UPM is making a great effort to develop and evaluate the core competences of its students. In this paper we have shown the methodology that is being used to achieve this goal. We have focused in the problem-solving competence. We have shown the assessment rules we have developed and how we have adapted them to the first years of the engineering studies. Finally we have proposed some pilot studies that will be carried out within the next months.

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