Development Of A Method Of Assessment Of The Problem-Solving Competence At The Technical University Of Madrid

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The competence evaluation promoted by the European High Education Area entails a very important methodological change that requires guiding support to help lecturers 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 the objective of developing a model for teaching and evaluating core competences and providing support to lecturers. This paper deals with the problem-solving competence. The first step has been to elaborate a guide for teachers to provide a homogeneous way to asses this competence. This guide considers several levels of acquisition of the competence and provides the rubrics to be applied for each one. The guide has been subsequently validated with several pilot experiences. In this paper we will explain the problem-solving assessment guide for teachers and will show the pilot experiences that has been carried out. We will finally justify the validity of the method to assess the problem-solving competence.

Keywords: European High Education Area, Competences Assessment, Problem-solving, Rubrics.

1   Introduction

1.1   *Context of the project and purpose*

The construction of the European Space for Higher Education (ESHE) has configured a new scenario in university teaching. The change proposed from the Bologna declaration is not limited to a reorganization of the studies which has been captured in the new Catalogue of Degrees; it is much deeper and significant because it implies a rupture with the traditional culture focused on the acquisition of knowledge [1].

No one doubts that university education must provide students with a good academic background, which means a domain of the knowledge. However, now more than ever, it is also necessary that it promotes the development of skills applicable to social and labor situations which must be lived at the end of the studies [2]. Therefore, one of the fundamental goals of the process of European Convergence is to guide the academic education towards the acquisition of the competences required in the professional field [3].

Although the notion of competence has multiple definitions [3-5], there is a consensus in the pedagogical literature in which the concepts of "knowledge", "know how" and "know how to be" there are integrated under this term [6]. According to Delors report [7], when a person gives answer the different situations and tasks presented at work, he does it in a global way, using his knowledge and technical capabilities as well as his personal qualities and social attitudes.

In Spain, the model used for the design of studies by the Agencia Nacional de Evaluación de la Calidad y Acreditación –ANECA- (The National Agency for Quality Assessment and Accreditation of Spain) is based on the formulation made in the "Tuning Educational Studies in Europe" [3,8,9]. There is a distinction between the specific competences of the different areas of study, and the generic competences, common to any degree and essential for preparing students for their professional and social integration.

Generic or core competences are gaining nowadays a major importance, since they are essential skills (e.g. oral communication, synthesis, and problem-solving) enabling graduate students to deal with hurdles and challenges during their professional career. Enterprises and industry seek competent graduates being able to express ideas in front of people and solve problems effectively; i.e. to afford difficult circumstances and lead changes in their professional domain. Students without training in these skills may not success in their future jobs [1,2].

Following the Tuning model, the profile of graduates must be based on the needs identified and recognized by society. Therefore, each degree matches an academic-professional profile previously defined in an ensemble way between university and employers [3].

In order to identify the most important generic competences for students' education, several investigations have been made. In the international scope, apart from the Tuning project, it is also worth mentioning the "Alfa Tuning project for Latin America" [9] and the "Higher Education and Graduate Employment in Europe" project [11], also known as "Careers after Higher Education. A European Research Survey (CHEERS)", which has been used as a base for the "Reflex project" (Flexible Professional in the Knowledge Society) [12]. Within the national scope, several academic research projects have been carried out, conducting surveys to postgraduates and professional organizations in order to design formative programs which ease the employability of their graduates [3,13-16].

Meanwhile, in order to carry out this task, the Technical University of Madrid has financed the project "Core Competences in Engineering. Proposal of a Model for the UPM", which is part of a greater set of Educative Innovation Projects for the academic year 2010-2011 [17]. The core competences selected for every degree are the following: a) team-work, b) oral and written communication, c) use of the ICT (Information and Communications Technology), d) respect for the environment, e) analysis and synthesis, f) creativity, g) organization and planning, h) leadership and, i) problem-solving.

For each core competence, a work team has been created with the aim of studying that competence and facilitate to the teachers the task of teaching and assessing it. The UPM´s work teams have developed different levels of competence acquisition by varying its complexity gradually. Our goal is to integrate the most relevant aspects of each competence within the lectures and academic activities. At the end of the studies, students should not only have learned technical knowledge but also general skills. The methodological change in High Education is a big challenge for teachers due to several reasons. On the one hand, every course should promote the improvement of a group of competences, coherent to the content of the course and its learning level. On the other hand, an impartial evaluation method is needed in order to ensure that students are actually acquiring these competences [18].

This work describes the general procedure that was used and presents the model developed specifically for the problem-solving competence. The first step has been to elaborate a guide for teachers to provide a homogeneous way to asses this competence. This guide considers several levels of acquisition of the competence and provided the rubrics to be applied for each one. The guide has been subsequently validated with several pilot experiences [17,19]. In this paper we will explain the problem-solving assessment guide for teachers, taking special attention to the level I rubrics, and will show the pilot experiences that has been carried out. We will finally justify the validity of the method to assess the problem solving competence.

1.2 *Problem-solving competence*

Among the different tasks of the project, our group has been responsible for working out problem-solving competence. Some definitions are needed. According to Newell and Simon [20], a problem is defined as a situation in which an individual wants to do something, but do not know the way to achieve the goal. Chi and Glaser said that it is a situation in which an individual acts with the purpose to achieve this goal using a particular strategy [21], Also, for Krulik and Rudnik a problem is a situation, quantitative or not, that requires a solution for which the individuals involved do not know obvious ways to get it [22].

Problems are situations that require individuals to respond with new behaviors. This activity is closely related to various skills such as analysis, synthesis, critical thinking, planning or creativity. Solving a problem involves tasks that require more or less complex reasoning processes more or less complex and not simply a routine, associational task (as in exercise-solving) [23,24].

Problem-solving is not new in education but it is still a scarcely implanted competence, remaining a lot to be done. According to Gaulin [23] several reasons can explain the increasing emphasis on developing this competence. The first can be found in the current social-constructivist perspective of learning. It defends the importance and influence of context (learning environment) in the construction of knowledge [25]. Arguing with colleagues, team work and social interaction are important factors that influence students learning and problem-solving provides a good chance to work according to these ideas.

The second reason arises from the need of training students to live in an increasingly complex and changing world, facing more and more difficult situations, even with technology. Problem-solving can enhanced the learning of strategies and skills that enable students to autonomously deal with new situations.

The third and last reason relies on the current educational policy, which emphasizes competences training in order to ensure that students not only learn contents, but can also apply them to real situations in different contexts [24]. Learning problem-solving is learning to face new scenarios, where you have to think and use new strategies. Therefore, emphasizing problem-solving will probably make easier to the students to acquire general competences [27]. However, it is not an easy task, since some international studies have revealed that most teachers feel unprepared to teach problem-solving.

The aim of this work is to promote among the students the right mental attitude that encourages them to learn, understand and apply knowledge in an autonomous manner [28,29]. The development of this competence requires an active approach by the students. The proposed problem must be appropriate to the level of the studies (but not merely exercises) [23], the wording must be motivating, be not direct and provide the development of concepts [28-32]. In this regard, the problems must be practical, meaningful and contextualized in the current reality of the students and their future career [32]. Learning should deal with the results and analysis but above all, with resolution procedure.

1.2.1 Problem-solving procedure:

There is not a universal strategy for teaching problem-solving competence. We have chosen the original procedure proposed by Pólya [34]. The reason is that it is a very general strategy that can be easily adapted to the usual problems of each field of knowledge. This strategy is structured in four steps [23,34]:

1. Problem comprehension: read carefully the problem and represent it in different ways. Then, highlight significant data and the unknowns.

2. Planning the solving process: It is normally the most difficult task, since relationships between data and unknowns have to be established in order to find a problem-solving plan.

3. Implementation of the plan: if the problem-solving plan is well conceived, its implementation is usually relatively easy, though some changes in the plan may be required.

4. Assessment of both, the solution and the procedure. This step is essential to improve how to learn problem-solving. You should critically examine and evaluate the results obtained as well as the procedure used. It is important not to let the details distract us from the general ideas.

Attending to the four rules procedure proposed by Pólya [34], we have developed a set of generic rules to guide the students on the main aspects and the right order to be considered when solving a problem. First of all we have elaborated a very generic procedure based on all the relevant rules to problems-solving. This procedure applies to any problem, regardless of its approach or complexity. Each one of these aspects can be evaluated from 1 to 4 points (from D to A) according to different criteria. The proposed problems differs a lot depending on the subject and the year of the studies. Thus, we have divided the problem-solving competence in four levels, each one with its proper procedure and with different rules – always based on the rules we are exposed above in this section.

In this paper we have defined the first-level problem-solving procedure which is designed to be specifically applied to first year students of the engineering degrees. This procedure enhances students to deal with more complex problems rather than merely exercises. The wording of task includes more information than the strictly needed to solve the problem. Students have to choose between at least two ways to solve the problem (usually one correct and the other not). In upper university courses, the problems statements are more complex and their solution can be approached in several ways, in which some of them may be more efficient than the others.

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 effectiveness of the method.

1.2.2 Rubric: Assessment criteria of the problem-solving competence:

Rubrics are guidelines used to assess different grading through some fixed criteria [35-37]. Each problem is evaluated two times; lecturers and students use the same rubrics. This method helps us in different ways. Firstly, it makes the students more conscious of their own grade of competence command. Secondly, it allows us to compare lecturers'evaluation, so that the general results can be better contrasted. At last, the participation and motivation among students increase significantly, when they feel more involved in the task.

In the pilot studies, the problem-solving competence is analysed through six different aspects or criteria: comprehension, application of the method, justification and clarity, results, efficiency, and critical analysis. The possible punctuations to the mentioned criteria are:

A- Excellent

B- Advance

C- Acceptable

D-Unsatisfactory

Our set of assessment criteria have been summarized in Table 1.

Table 1. Set of assessment criteria developed for the problem-solving competence [40].

Criteria	Unsatisfactory (D or 1)	Acceptable (C or 2)	Advanced (B or 3)	Excellent (A or 4)
Comprehension	The information of the problem is neither clearly enough identified nor relevant.	The relevant information (data, variables, conditions needed…) is identified but in a disorganized or improper 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 applied, but in a disorganized way and without explanation.	The method has been applied systematically, but it does not have explanations.	All the steps have been explained.
Justification and clarity	There are few ore even no explanations that make easier the reading and understanding of the resolution of the problem.	There are some explanations but they are not well organized and have a few mistakes.	All the explanations needed are included in an organized way.	The explanations are given in a clear and rigorous way. The solution is highlighted.
Results	The results are not present, 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 given (adequate notation and unities).	The results are also given clearly and rigorously.
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 analyzed.	Both the results and the procedure are checked.	The solution is checked and contrasted. Its application is extended to other contexts and generalized. The procedure is analyzed and some improvements are proposed.

2 Pilot studies

2.1 General data of the pilot studies and their development

Pilot studies were conducted in four subjects of the first and second years for the degrees of Aerospace Engineering and Natural Environmental Engineering. The total number of volunteers was 146. Students who achieved an A grade in the pilot study got a raise of up to 0.5 points into their course grade mean. This means an extra 5 % from the total grade. This raise descended gradually for worse grades.

Assessment criteria from table 1 were explained in detail to the voluntary students, before beginning the pilot study. To this aim, the lecturer formulated some examples of problems to the students and explained to them possible ways to come up with some suitable solutions, as well as the advantages of using these evaluation criteria. Afterwards, the lecturer proposed them a problem to be handed in according to the problem-solving rules.

Some general data are provided below, at the Table 2. Maths II refers to the subject "Mathematics II".

Table 2. Summary of the subjects and degrees from the pilot study.

About the degrees				About the students		
Academic year	Semester	Subject/ Course	Degree	Number of participants	Registered students	% participation
2010-2011	2nd	*Physics II*	Natural Environmental Engineering	11	72	15.2
		Maths II (stage 1)		48	75	64.0
		Maths II (stage 2)		29	75	38.7
		Maths II (stage 3)		9	75	12.0
		Mechanisms	Aerospace Engineering	23	150	15.3
2011-2012	1st	*Chemistry*	Natural Environmental Engineering	25	99	25.3

2.2 Brief description of the pilot study topics

Chemistry problem-solving experience was exemplified with Water Quality Global Indicators. Students had to elaborate a concept map with all the concepts involved in these indicators, and hence use them in problems with different conditions.

In **Mathematic II**, the pilot study was divided into three stages, gaining the following stage in difficulty and number of assessed criteria. Statistics and River Hydrology also took part in the study. Firstly, a Hydrology lecturer taught a seminar of some river flow concepts, such as return periods for some heavy diary rains and expected flow. Afterwards, Statistic lecturers were teaching ways to estimate these flows and some Statgraphics' tools. Finally, the Mathematics teacher asked the students to evaluate and justify the choice of a particular estimation method.

In **Physics II**, students had to calculate the calorific energy needed to increase a room temperature and then the following descend of temperature, when the insulating material was reduced.

In **Mechanism** the teacher gave the students the design of a cam-follower mechanism used to shake samples and asked them to calculate the parameters necessary to work properly. The students should study the problem during that afternoon and the next day they were requested to solve it in the classroom and give the solution to the teacher.

3   Results

Pilot study results can be consulted on the followings subsections, in where information can be extrapolated from the entire sample. Although problem-solving competence is studied through different fields (Physics, Maths, etc.) and in different careers, the acquisition level of the competence is similar among all the subjects, so similar statistic distributions are expected to be found among these fields. Therefore, these results are not always grouped by subjects.

3.1   *Results for each assessment criteria*

3.1.1   General score distribution:

Global results for the whole set of criteria are shown in Fig. 1, from worse to better punctuations over the abscissa axis. Student´s evaluation matches to the stripy bar charts and lecturers' to non-stripy ones. Notice that the ordinate axis refers to percentages (%).
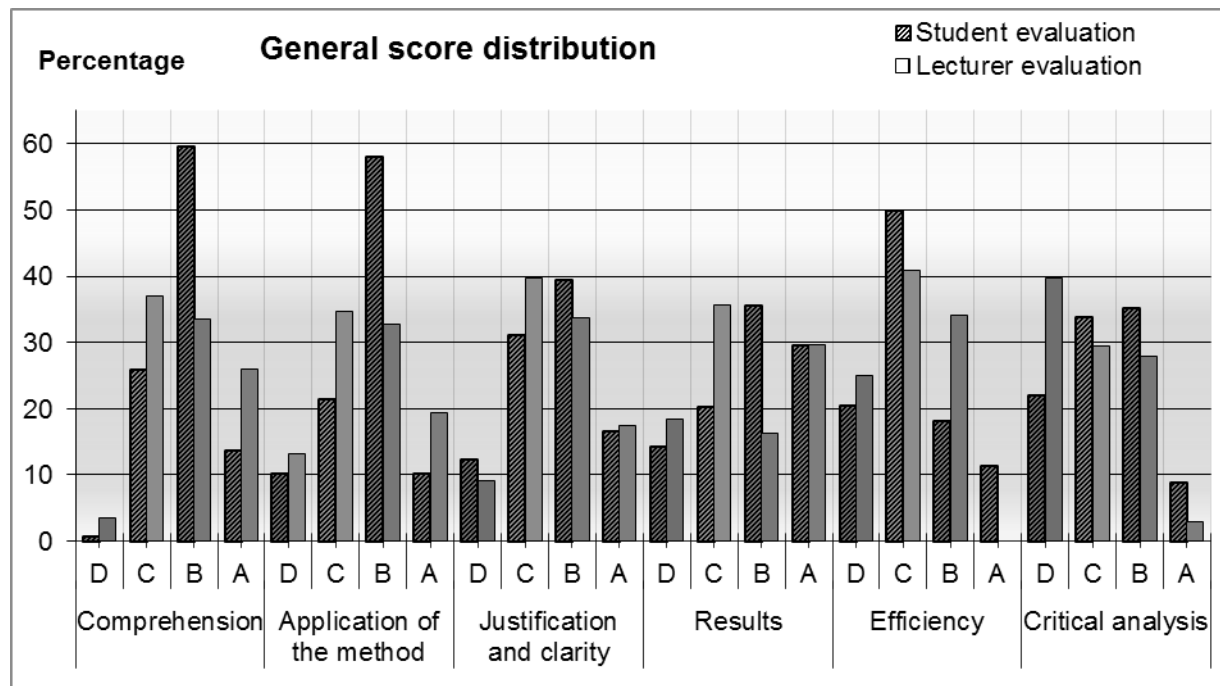

Fig. 1. Global score distribution from D to A for each assessment criterion. Evaluation for both students' and lecturers' point of view are shown here.

The first five aspects considered follow a similar distribution, for both, student's and lecturer's assessments. However, students usually tend to correct themselves with slightly higher marks. Later, this fact is also visible in Fig. 2.

The average punctuation of these first five criteria is between C (acceptable) and B (advanced). Nevertheless, comprehension and application of the method achieve a higher percentage of B's and A's (excellent). In contrast, critical analyses have always worse mark than the others; since D punctuation (unsatisfactory) is significantly higher from lecturer's point of view (around 40% of students were given a D). The number of excellent grades is notably high in results, with almost 30%.

3.1.2   *Average score and standard deviation for the whole sample:*

Global average scores and standard deviation for the whole set of assessment criteria are shown in Fig. 2. An acceptable level of each criterion is achieved when the score is equals or above 2 points; i.e. a C grade. This acceptable level is underlined by a discontinous line on the graphics. Notice that mean scores from lecturer's point of view overpass the C level in the first four levels, while in efficiency and critical analysis the score is a little bit under acceptable level. This can be explain taking into account we are evaluating the first level of the competence; following levels of the competence will be evaluated in the last courses of the graduate and in post-

graduate masters). The same students are expected to have better results in these criteria in the following levels (not yet studied) as they requiere more experience and maturity.

Standard deviation is normally above 0.75 but below 1.0 in most of the assessments. Punctuation dispersion is slightly higher in evaluations of the lecturer for comprehension, application of the method and results. Critical analysis is evaluated for students with a mean value of 2.3, which differs for lecturers, who give them an average of 1.9. This difference is the biggest encountered among students' and lecturers' average evaluation for the whole sample.
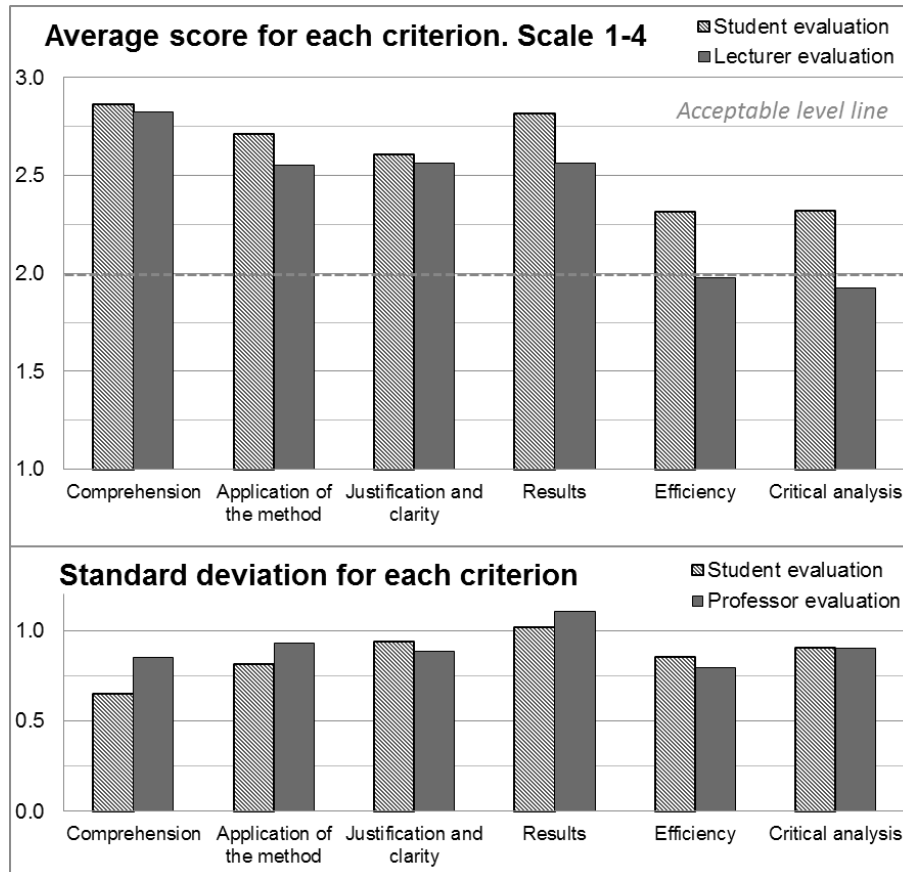
Fig. 2. Mean value and standard deviation for each assessment criteria. Evaluation for both students' and lecturers' point of view are shown here.

3.2 *Results for each subject and assessment criteria*

Once the global results have been analyzed, more particular data is summarized in the Fig. 3. Here, average scores are presented for each subject and assessment criteria. Remember that the subject Mathematic II was divided into 3 stages. Efficiency was not evaluated in Chemistry.

Subject	Evaluator:	Comprehension		Application of the method		Justification and clarity		Results		Efficiency		Critical analysis	
		Mean	σ	Mean	σ	Mean	σ	Mean	σ	Mean	σ	Mean	σ
Chemistry	Lecturer	4.0	0.2	2.7	1.0	2.6	1.1	3.7	0.7			1.8	0.9
Maths II (stage 1)		2.4	0.5										
Maths II (stage 2)		2.9	0.7	3.0	0.6	2.6	0.6	2.8	0.9				
Maths II (stage 3)		3.3	0.9	2.3	1.4	2.9	0.8	1.8	1.0	2.1	0.9	2.3	1.0
Mechanisms		2.3	0.9	2.3	0.7	2.5	1.0	1.8	0.6	2.0	0.8	1.9	0.8
Physics II		2.5	0.7	1.9	0.9	2.2	0.9	1.6	0.5	1.8	0.8	1.9	1.0
Chemistry	Student	3.1	0.6	2.9	0.6	2.3	0.7	3.2	0.6			2.8	0.7
Maths II (stage 1)		2.7	0.5										
Maths II (stage 2)		3.1	0.7	3.1	0.4	3.1	0.7	3.6	0.5				
Maths II (stage 3)		3.5	0.8	2.0	1.2	2.1	1.4	3.1	0.8	3.3	0.9	2.2	1.5
Mechanisms		2.6	0.7	2.6	0.7	2.7	1.0	2.0	0.9	2.0	0.6	1.9	0.8
Physics II		2.5	0.7	2.1	1.1	2.3	1.0	1.5	0.7	2.3	0.6	2.3	0.6

Fig. 3 Mean value and standard deviation (σ) for each subject and problem-solving aspect considered. Evaluation for both students' and lecturers' point of view are shown here.

Among the subjects belonging to the sample, some different results can be found (e.g. mean value or standard deviation (σ) of a given criterion for some subjects). The largest difference appears among the subjects within the item "results". This fact can be explained because results are normally more dependable on the pilot study task than the other items. Indeed the global standard deviation for results is relatively higher among the entire sample (Fig. 2) than the particular deviation for each subject (Fig. 3).

Efficiency and critical analysis obtain worse average punctuations if compared to the rest of criteria considered. This statement occurs for assessments of both, students and lecturers. In contrast, comprehension is normally better evaluated, especially in Chemistry, where most of students were given a 4 (excellent). However, the majority of the subjects reaches or overpasses a mean level considered as acceptable (C) and there is not a remarkable difference in the standard deviation between the different subjects as it is expected for a transversal competence as problem-solving.

3.3   Satisfaction survey

In this type of experiences is also recommended evaluating the satisfaction grade of both, students and lectures. Therefore, students were asked to punctuate some aspects of the pilot study and lecturers had to write down a short standard report.
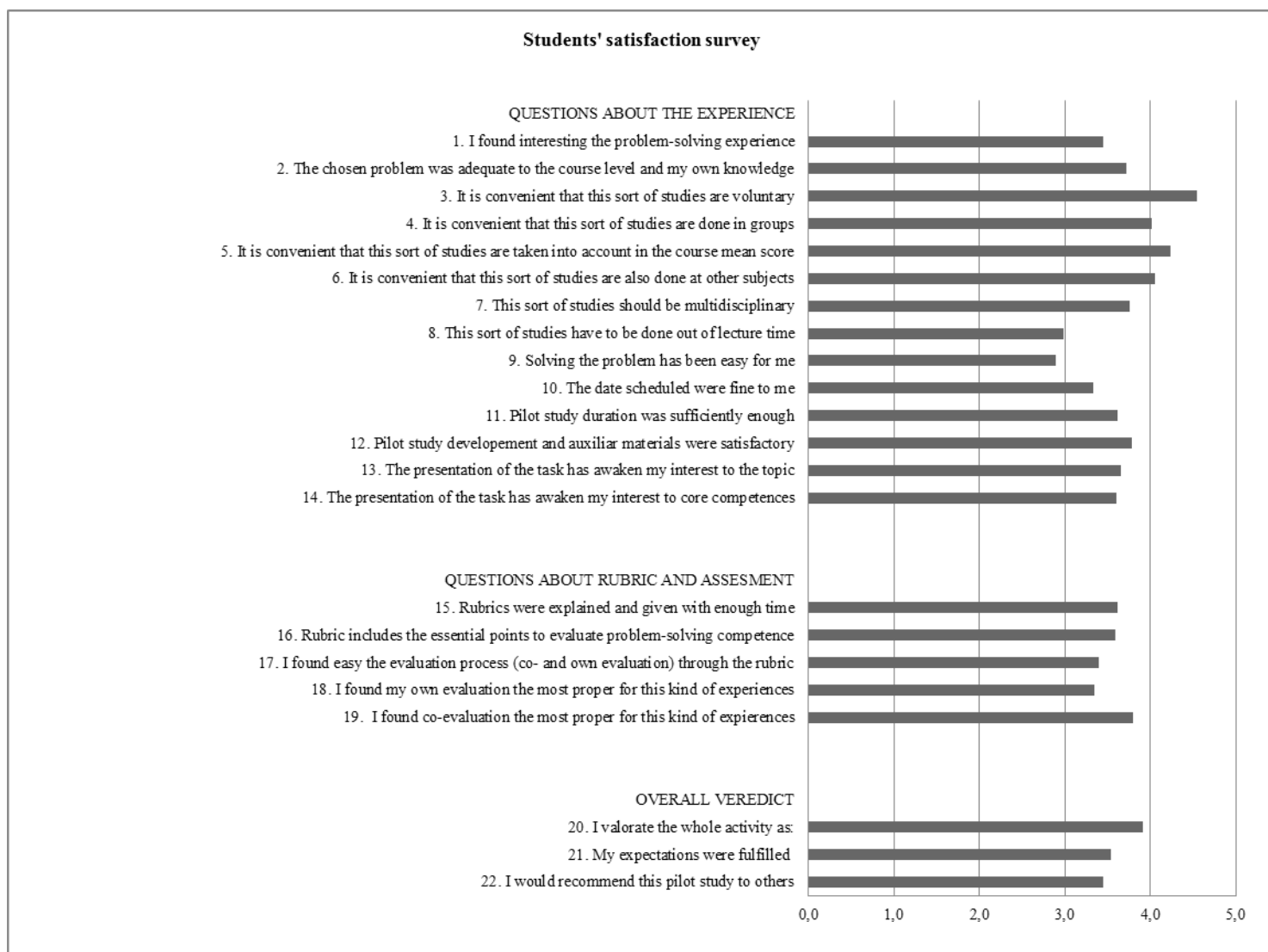
3.3.1   Students results

Once the students have taken part in pilot study and received the professor´s correction, they were asked to fulfill a questionnaire of satisfaction consisting in 22 questions. The number of responses was 70, which means two thirds of the volunteers (table 3)

Table 3: Summary of student's survey. Participants.

	Chemistry	**Math II**	**Physics II**	**Mechanisms**	**Mean/total**
number of responses	16	21	10	23	70
% of responses	64	44	91	96	65

The questionnaire was divided into three parts. The first gathered information on the experience carried out, the second on the rubric and evaluation system, and the last one collected the overall impression of the pilot study. The obtained results are presented in Table 4.

Table 4. Questionnaire of students' satisfaction. 1: totally disagree, 2: quite disagree, 3: indifferent, 4: quite agree, 5: totally agree.

Students' satisfaction survey

QUESTIONS ABOUT THE EXPERIENCE
1. I found interesting the problem-solving experience
2. The chosen problem was adequate to the course level and my own knowledge
3. It is convenient that this sort of studies are voluntary
4. It is convenient that this sort of studies are done in groups
5. It is convenient that this sort of studies are taken into account in the course mean score
6. It is convenient that this sort of studies are also done at other subjects
7. This sort of studies should be multidisciplinary
8. This sort of studies have to be done out of lecture time
9. Solving the problem has been easy for me
10. The date scheduled were fine to me
11. Pilot study duration was sufficiently enough
12. Pilot study developement and auxiliar materials were satisfactory
13. The presentation of the task has awaken my interest to the topic
14. The presentation of the task has awaken my interest to core competences

QUESTIONS ABOUT RUBRIC AND ASSESMENT
15. Rubrics were explained and given with enough time
16. Rubric includes the essential points to evaluate problem-solving competence
17. I found easy the evaluation process (co- and own evaluation) through the rubric
18. I found my own evaluation the most proper for this kind of experiences
19. I found co-evaluation the most proper for this kind of expierences

OVERALL VEREDICT
20. I valorate the whole activity as:
21. My expectations were fulfilled
22. I would recommend this pilot study to others

Although some differences in opinion were found among the different subjects, students tend to punctuate most aspects in a similar way with little variation in mean values.

More than 60% of the students admitted, not only that this pilot study had been interesting to them, but also that the difficulty of the chosen problem was adequate to their own level. In addition, most of the respondents (over 80%) were enough or totally in agreement with the following facts: these kinds of experiences should be voluntary and part of the final mark; the students would like to take part in similar pilot studies in other subjects. In addition, the majority also agreed that the given time had been sufficient, as well as the way of presenting the task attractive to them. On the contrary, students did not agree to attend to similar pilot studies out of the lectures time.

Regarding assessment criteria, half of respondents thought that the rubric was a proper manner of evaluating the pilot study, but a high number were indifferent to the question. Besides, only one third of the respondents had found the problem easy.

In general terms, two thirds of the respondents thought that the experience was positive or rather very positive, so that they would recommend other students to participate in similar pilot studies. Only ten percent of them found the whole experience negative.

3.3.2   Teacher´s opinion

From teachers' point of view, the pilot study developed satisfactorily and students were especially interested in the task, because they had to solve a problem in a different context from the usual lectures.

These kinds of experiences are to be expanded to all students in some subjects and along the semester; it is now imperative to develop transversal competences, and to be able to demonstrate that they have been practiced and evaluated in the assigned subjects.

The problem arises with the time involved in correction with rubrics, that is by far largest than classic numeric correction, as well as the analyses of results; this questions the viability of carrying out a large number of mandatory experiences distributed throughout the semester, especially considering the high number of students enrolled by subject.

In order to implement this assessment system to the full students´ sample, a careful selection of the experiences will be required. Moreover, the rubric can be simplified, reducing the number of criteria to be graded and making it more readable to the students.

Some improvements have been suggested in the survey, among which are those related to the opinion of student's score. In particular, the next two questions have been added:

- Lecturers' evaluation was fair and adequate.

- Both evaluation parts were coherent with each other.

4   Conclusions

We have design a problem-solving assessment procedure and explained in detail the first level of acquisition of the competence and have carried out four pilot studies to determine the validity of our rubric. The experiences have been used to fine tuning the procedure and we can conclude that it works fine and it is ready to be used as a problem-solving competence assessment procedure standard of the UPM. So the next step is to broaden our problem-solving procedures to other subjects and levels.

Although different knowledge fields were involved in this study, the skill of the students of the different groups is similar and the procedure and criteria used are the same, which allow us to compare the different pilot studies and generalize the results.

Basing on the students that has done the experiences we can conclude that the students of the first courses of the UPM has a basic knowledge of the problem solving competence –they have obtained a good level of achievement of the firsts assessment criteria-. But they need to progress in the acquisition of the competence to get a good level in the last criteria, especially in the critical analysis of the problem. New pilot studies will be done in the last courses of the career and in postgraduate studies to check the student improvement.

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