Evaluation in High Education Based On a Multi-Criteria Methodology: Application to a Course on Power Systems

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Abstract

After the adoption of the Bologna Plan by European Universities, the classical method used to evaluate students by traditional exams has changed, so that a wide typology of evaluation mechanisms have appeared. By means of those mechanisms, students may be evaluated according to the specific and transversal competences they have acquired during their degree. In this contribution, the authors present a methodology, based on a multi-criteria procedure, which could be used to evaluate University students from different perspectives so as to obtain an objective assessment about the level of achievement of such competences. The proposed methodology has been applied during the last four years to the course on Power Systems that is taught in the Master Degree in Industrial Engineering at the Polytechnic University of Valencia, Spain, whose results are also presented here.

Index Terms— evaluation; methodology; multi-criteria; objective prove; power; problems; self-evaluation; system.

1. Introduction

Before the implementation of the Bologna Plan in 2010, the acquisition of learning result in university education was usually evaluated, almost exclusively, by means of a final exam, which could be oral or written [1]. However, the Bologna Plan meant an inflexion point for evaluation methods and a wide variety of them has appeared in the last times. Nevertheless, is true that none of them has managed to dethrone the traditional exam and the percentage of teachers who use them effectively is meager [2].

For the specific case of Spain, universities have addressed evaluation based on multi-criteria mechanisms in their operating rules. Accordingly, the new Regulations for the Academic Regime and Student Evaluation of the Polytechnic University of Valencia, which is in the review phase, considers in Article 15 the condition that no act of evaluation can exceed 40% of the final grade of the course [3]. This condition has been already implemented in some schools, such as the College of Industrial Engineering.

Multi-criteria methods have been extensively used to evaluate programs and projects [4]. In general, multi-objective decision models allow a balanced type of analysis to be carried out in all the aspects that affect the planning of a project [5]. In the particular case of evaluating university students, using a multi-criteria method allows for analyzing the students' learning with a greater degree of independence concerning the evaluation technique used. Indeed, some students could find it easier to solve an objective test (multiple-choice test) while others may prefer an open development test, without necessarily implying that they have a higher level of knowledge. Also some students could find it easier to transmit their understanding orally, while a writing test will be preferred by others. In consequence, the choice of one type of test or another may be biasing the ability of students to be evaluated as objectively as possible. The application of a multi-criteria method may help to solve this problem because students would be subjected to a wide variety of evaluation techniques, which may help to alleviate potential deficiencies of the evaluation system. In this way, students could express their degree of learning in the mode they feel most comfortable, compensating the students' skills and assessing the knowledge and skills acquired based on various criteria. Consequently, this procedure will require greater involvement and effort on the part of the professor, who will have to design balanced evaluation tests through which students can demonstrate the degree of real learning they have achieved.

There are few examples about previous experiences of professors applying a multi-criteria evaluation method in the bibliography [6]. Therefore, this article presents an experience of evaluation based on a multi-criteria method designed and applied to the course of Power Systems taught in the second year of the Master Degree in Industrial Engineering at the Polytechnic University of Valencia (UPV), Spain.

The article is structured as follows: Chapter 2 presents the objectives of the work carried out, which will be developed in detail in Chapter 3, where the designed methodology is described. Chapter 4 shows the results of the practical case of application to the course on Power Systems. Finally, the conclusions of this work are summarized in Chapter 5.

2. Objectives

The general objective of this work focuses on developing a multi-criteria method for the evaluation of students of university technical education, which is applied to the particular case of the course on Power Systems of the Master Degree in Industrial Engineering of the UPV. In this area, the specific objectives of the work are:

1) Designing an evaluation method to allow the level of student learning been assessed as objectively as possible, not being linked to a specific type of evaluation technique.
2) Helping students, by means of the designed method, to learn through their mistakes, offering continuous feedback throughout the course, leading to a more reliable learning process [7].
3) Evaluating students in a continuous way throughout the whole course, which would make assume students greater responsibility to favor their learning process [8].

3. Methodology

The methodology proposed in this article to design a multi-criteria evaluation system is depicted in Fig. 1. The first step would be the selection of the learning objectives to be evaluated by means of each of the evaluation techniques. It is assumed that these objectives have been adequately established, using appropriate educational taxonomy principles [9]. Before, it is necessary to choose the most appropriate evaluation technique for each of the learning objectives that will be evaluated. Some examples of these techniques have been summarized in Table 1, as collected in [10]. Depending on the kind of information offered by each type of test, they have been classified.

Table 1. Evaluation techniques [10].

Technique	Knowledge	Abilities	Attitudes
Oral exam or oral presentation	••	••	••
Open-ended written test	••	•	
Multiple choice objective test	••		
Conceptual map	••	•	
Academic assignment	••	•	
Minute questions	••	•	
Diary		••	••
Portfolio	••	••	••
Project	••	••	••
Problem	••	••	••
Case	••	••	••
Essay	••	•	•
Discussion	•	••	••
Observation	•	••	••

Once the technique is chosen, the evaluation factors that are considered most suitable will be analyzed. For example, for the case of an objective test, a "True/False" model or a multiple-choice one will be chosen. Other factors to be considered are the number of questions, the grading for each question or group of questions, the penalty to be applied in case of error, etc. Following, it will be necessary assess the constraints that may make the test successful or not, depending on the learning outcome to evaluate. Thus, if the chosen test does not comply with the identified constraints, the identified factors should be re-adjusted or, if necessary, a different technique should be chosen. In case of compliance, the characteristics of the chosen technique will be specified, repeating the previous steps for the rest of evaluation techniques.

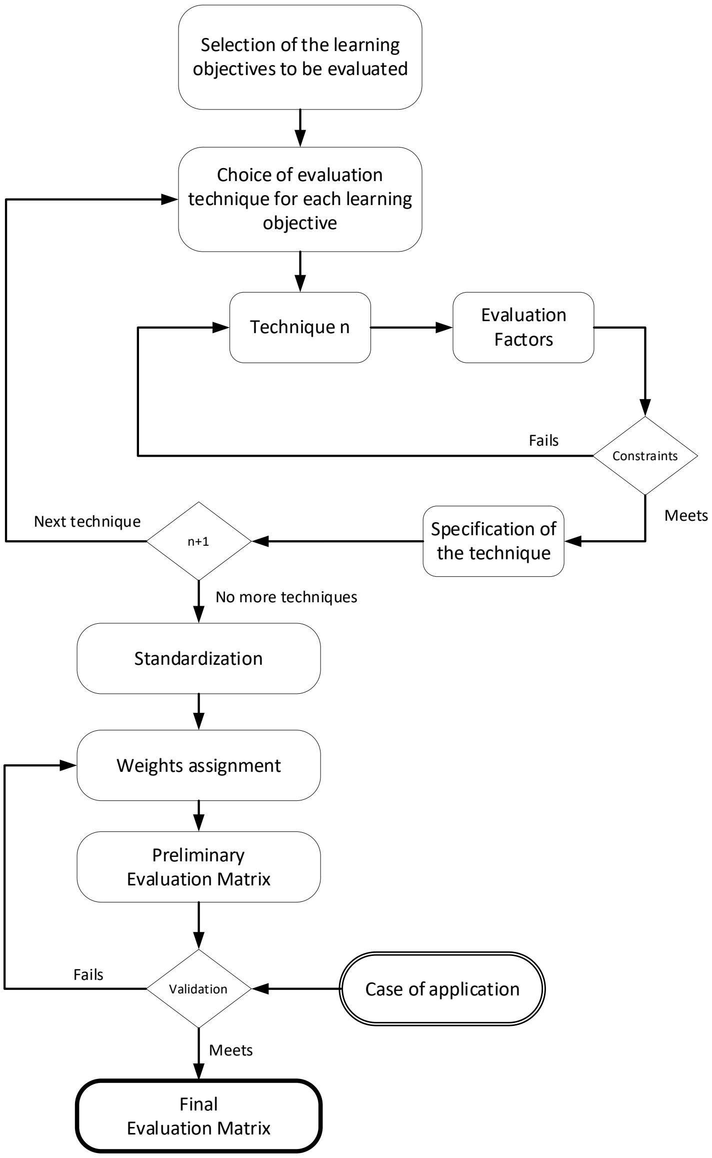

Fig. 1. Methodology for the design of a multi-criteria evaluation system.

Once all the selected evaluation techniques have been specified, their grading has to normalized, making that the different evaluation tests are graded from 0 to 10. Next, a weight will be assigned to each evaluation technique according to the significance that each of them will have in the course's final grade, given that some criteria will have more relevance than others according to the professor's experience [5]. The weights will be expressed as a percentage, so that the sum of all of them is 100%. In some cases, it could be appropriate to have some evaluation technique with additional credits, which permit students to retake some extra points to improve their final grade. In that case, the grading related to such techniques will be considered, as additional mark," and its weight will not be included in the previous sum.

The last step consists of the design of the Evaluation Matrix, where the quantitative mechanism related to the student's evaluation will be depicted. This matrix is a double-entry table, where each of the rows includes a learning result, and each of the columns corresponds to one criteria (assessment techniques). Within the matrix, the weights related to each criteria for each learning outcome has to be entered. The structure of the Evaluation Matrix, designed from [5], is shown in Table 2.

Table 2. Evaluation Matrix.

Learning Result (i)	Evaluation Technique (j)				
	1	2	3	...	j
Result 1	W_{11}	W_{12}	W_{13}	...	W_{1j}
Result 2	W_{21}	W_{22}	W_{23}	...	W_{2j}
Result 3	W_{31}	W_{32}	W_{33}	...	W_{3j}
⋮	⋮	⋮	⋮	⋱	⋮
Result i	W_{i1}	W_{i2}	W_{i3}	...	W_{ij}

The first time that the methodology is applied to a course, making adjustments will be necessary according to the obtained results. Therefore, based on the first case of application and the successive ones, the Evaluation Matrix will have to be updated according to such results.

4. Case of Application

The methodology described in the previous section has been applied to the design of the multi-criteria evaluation system for the course on Power Systems corresponding to the Master Degree in Industrial Engineering taught at the College of Industrial Engineering of the Polytechnic University of Valencia. The syllabus of said subject and the learning outcomes associated with each of the topics are shown in Table 3.

Table 3. Learning results of the course on Power Systems

Educational Unit	Lesson	Learning Results
Unit 1. Structure and elements of Power Systems	1. Introduction. Structure of Power Systems	LR1. Identify the elements that take part in power systems
		LR2. Describe the operation strategies in power systems
	2. Review of basic elements: Loads	LR3. Identify different types of load in power systems
		LR4. Build the mathematical model of different kinds of load
	3. Review of basic elements: Transmission lines	LR5. Build the mathematical model of a power line (pi model)
		LR6. Calculate the transmission capacity of a power line
	4.Review of basic elements: Transformers	LR7. Build the mathematical model of a three-phase transformer
		LR8. Calculate the rate of control transformers
	5. Review of basic elements: Generators	LR9. Build the model of a synchronous generator

Educational Unit	**Lesson**	**Learning Results**
		LR10. Analyze the operation of a generator connected to a single load
		LR11. Analyze the operation of a generator connected to an infinite bus
Unit 2. Power Systems in Steady-State	6. Interaction P-f and Q-V	LR12. Identify the relation between the balance of real power and the frequency
		LR13. Identify the relation between the balance of reactive power and the voltage of a bus
	7. Power flow: Method of Newton-Raphson	LR14. Calculate the admittances matrix of a power system
		LR15. Calculate the power flow of a power system by the method of Newton-Raphson
	8. State Estimation	LR16. Describe the matrixes to calculate the state estimator of a power system
		LR17. Calculate the state estimator of a linear system
		LR18. Calculate the state estimator of a real (non-linear) power system
Unit 3. Operation strategies in Power Systems	9. Economic Dispatch	LR19. Identify the main characteristics of the optimization method of Economic Dispatch
		LR20. Model the function cost of a power generator
		LR21. Calculate the economic dispatch neglecting the power losses
		LR22. Calculate the economic dispatch of a power system considering power losses
	10. Transactions and energy exchanges	LR23. Distinguish between regulated and competitive power markets
		LR24. Calculate the energy transactions between areas in regulated markets
		LR25. Calculate the energy transactions between areas in competitive markets
	11. Units Commitment	LR26. Build the complex model of a power generator
		LR27. Calculate the units commitment by priority list
		LR28. Calculate the units commitment by the method of dynamic programing

Educational Unit	Lesson	Learning Results
Unit 4. Power Systems in Transient-State	12. Transient Stability	LR29. Build the dynamic equation of a generator
		LR30. Calculate the critical angle by the method of areas
Unit 5. Control of Power Systems	13. Voltage control	LR31. Build the transfer function for primary voltage control of a generator
		LR32. Calculate the primary voltage control system of a generator
	14. Frequency control	LR33. Classify the different types of frequency control of a power system
		LR34. Build the transfer function for primary frequency control of a generator
		LR35. Calculate the primary frequency control system of a generator
		LR36. Calculate the secondary frequency control in multi-area systems

The techniques chosen to evaluate the course's learning outcomes are included in Table 4.

Table 4. Evaluation techniques in the course on Power Systems

Technique	Knowledge	Abilities	Attitudes
Open-ended written test	••	•	
Multiple choice objective test	••		
Academic assignment	••	•	
Portfolio	••	••	••
Problem	••	••	••

As stated in the methodology, the set of tests chosen allows the evaluation of different aspects related to the students' knowledge, skills, and attitudes in an appropriate way. The indicated evaluation techniques are used as follows:

1) Open written test: there are two open-response written tests, one at the middle of the course and one more at the end. Each written test weighs 30% of the final grade of the course. They are used to assess learning outcomes related to application, analysis, synthesis, and evaluation.

2) Multiple-choice objective test: three multiple-choice tests are carried out during the course. Each test consists of 20 multiple-choice questions with four possible answers, only one of which is correct. According to the methodology presented in [11] for the design of multiple-choice tests, each correct answer adds 1 point to the test; a wrong answer subtracts 1/3 point; and unanswered questions neither add nor remove points.

Each multiple-choice test weighs 5% of the course's final grade. They are used to assess learning outcomes related to knowledge and understanding in continuous evaluation.

3) Portfolio: this test is used to evaluate laboratory practices. Students have to keep a portfolio with the follow-up of their activities during the practices, which they have to document and solve correctly. Four laboratory practices are carried out in a computer lab. The portfolio is evaluated at the end of each practice, so that students have 10 days to deliver the corresponding part of the portfolio. It weighs 15% of the final grade.

4) Problem: during the course, students have to solve four problems corresponding to the different units (except the last one), which they must solve. The parameters to solve the problems are different for each student since they are calculated from each student's ID number (National ID, Passport, etc.). Problem statements are posted on a specific date, which is notified to students on the first day of class. From the statement's publication to the delivery deadline there are ten days (like for the portfolio), within which students have to deliver the solved problem. If any student is late in the delivery, he receives a penalty of 0.1 points per day of delay. To do so, they are provided with an electronic template where they must indicate the results. Within 1 or 2 days from the delivery, the student receives by e-mail the obtained grade, as well as some feedback with the correction of the exercise. To do this, the professor uses an electronic tool designed explicitly for that, detailed in [12]. Problems weigh 10% in the final grade.

5) Academic Assignment: in addition to the previous tests, whose resulting grade is 100%, students have the possibility of doing a voluntary academic assignment, though they could obtain up to 5% of extra points to complement their final grade. Being an additional test, it is not part of the Evaluation Matrix. The topic to carry out the academic work is agreed between the student and the professor at the beginning of the course and it is related to one of the topics studied during the course. This assignment is monitored during the whole course by the professor through tutorials.

The resulting Evaluation Matrix with the weights related to each of the techniques used for each learning outcome is shown in Table 5. Finally, the time schedule for carrying out each evaluation technique throughout the course is shown in Figure 2.

Table 5. Evaluation Matrix of the course on Power Systems

Learning Results	**Evaluation Techniques**			
	Open-ended written test	Multiple choice objective test	Portfolio	Problem
	60%	*15%*	*15%*	*10%*
LR1		0,5%		
LR2		0,5%		
LR3		0,5%		
LR4		0,5%	0,5%	

Learning Results	Evaluation Techniques			
	Open-ended written test	Multiple choice objective test	Portfolio	Problem
	60%	*15%*	*15%*	*10%*
LR5		1,0%	1,5%	
LR6	3,0%			
LR7		1,0%	1,0%	
LR8	4,0%			1,0%
LR9		1,0%	1,0%	
LR10	3,0%	0,5%		
LR11	3,0%	0,5%		
LR12		0,5%		
LR13		0,5%		
LR14	3,0%		0,5%	1,5%
LR15	4,0%		2,0%	2,5%
LR16		1,0%		
LR17	3,0%			
LR18	4,0%			
LR19		1,0%		
LR20	2,5%	0,5%	0,5%	
LR21	4,0%		1,5%	1,0%
LR22	2,5%		1,5%	
LR23		0,5%		
LR24	4,0%		1,0%	1,5%
LR25	4,0%		1,0%	1,0%
LR26		1,0%		
LR27	2,0%			
LR28	2,0%			
LR29		1,0%	0,5%	
LR30	4,0%		2,5%	1,5%
LR31		1,0%		
LR32	3,0%			
LR33		1,0%		
LR34		1,0%		

Learning Results	Evaluation Techniques			
	Open-ended written test	Multiple choice objective test	Portfolio	Problem
	60%	*15%*	*15%*	*10%*
LR35	3,0%			
LR36	2,0%			

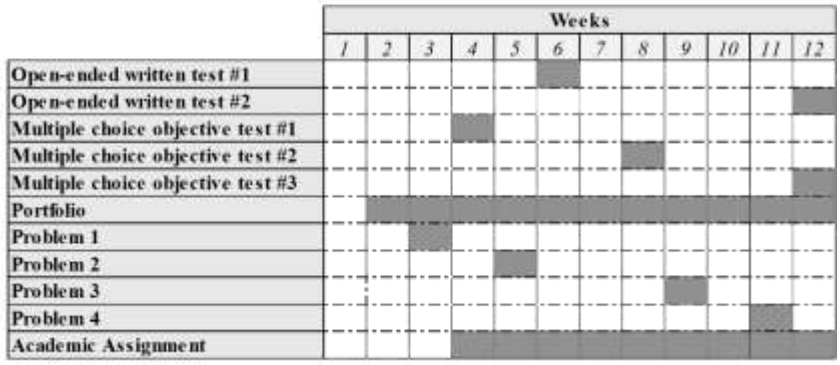

Fig. 2. Schedule of evaluation techniques during the course

5. Conclusions

The article highlights the advantages of using a multi-criteria assessment system since, among other reasons, it allows students to be assessed without being tied to a specific technique. This aspect guarantees that students will be evaluated more objectively, given that they feel frequently more comfortable with some specific evaluation technique. Therefore, some students could be harmed if the evaluations is limited to a single type of test, as usually done in high education.

Usual evaluation techniques, such as open-response exams or objective tests, could be combined with other types of tests by means of a multi-criteria method, facilitating the continuous evaluation of the students. In this manner, the combination of several types of test allows a more exhaustive assessment of the degree of development of the learning objectives of the course, while allowing the professor to choose a higher or lower weight of each of them in the final grading of the course. This choosing would be done according to the significance of the different learning results in the curriculum of students based on the professor's teaching experience, as well as considering some key performance indexes that could be defined and will be objective of future research.

The methodology shown in this paper has been designed and successfully applied to the course on Power Systems of the Master Degree in Industrial Engineering taught at the UPV, where students and professors have valued its implementation positively, based on the advantages that it means when compared to the method used before, basically based on the traditional exams.

This methodology has been also applied to other courses taught by the authors, and it is in the process of being applied to different undergraduate and graduate courses at the College of Industrial Engineering, where similar satisfactory results are expected.

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