PBL+, A TAILOR-MADE LEARNING-TEACHING METHODOLOGY FOR STEM, BASED ON A COMBINATION OF PROBLEM BASED LEARNING (PBL) AND OTHER THREE INNOVATIVE METHODOLOGIES

B. Urbano[1], X. Gómez[2], M.E. Sánchez[2], M.I. San-Martín[2], R. Mateos[2], C. Fernández[2], E.J. Martínez[2], O. Martínez-Morán[2], A. Morán[2], F. Gonzalez-Andres[2]

[1]*Teaching Innovation Group INGENIAQ. Universidad de Valladolid (SPAIN)*
[2]*Teaching Innovation Group INGENIAQ. Universidad de León (SPAIN)*

Abstract

PBL+, acronym of "Problem Based Learning Plus", is a combination of teaching-learning innovations, designed and tested for practical credits in Engineering subjects, in order to completely achieve the competences described in the educational guide to practical activities. In brief, students working in small groups of two to three members, get in contact with a company needing a solution to a problem. These students, in close relation with a commissioned person, look out for a solution to the current problem affecting the company. PBL+ has been successfully applied to subjects associated with Agricultural Engineer, Mining and Energy Engineering and Pharmaceutical Industries Engineering. The other methodologies used in PBL+ were flipped classroom, rubrics-based evaluation of the activity, and in some cases service learning. Regarding the flipped classroom, this activity was proposed to the students at the beginning of the course, before studying the theoretical basis, which are subsequently presented as the necessary tools to solve the problem. In order to evaluate the achievement of competences proposed in PBL+, specifically designed rubrics were used. The rubrics were managed with the complement of Google-Suite CoRubrics. The use of rubrics improved the understanding of the practical activity by students. Moreover, another key aspect for the success of PBL+, was the normalization of correspondence between the competence to be evaluated, and the dimension or dimensions established in the rubric designed to evaluate such competence. The normalization encompassed 11 different subjects from the Engineering degrees included in the pilot program. In such a way, when the same competences applied in different subjects, these were evaluated using the same dimensions in the rubric, which facilitated understanding the activities proposed to fulfil the practical competences by students. The normalization generated a table publicly accessible, with the standardized dimensions intended to evaluate them. At the same time, competences were also standardized at the National level (the basic competences) or at the University level (transversal and general competences), and thus the creation of standardized indicators to evaluate competences improved students' self-evaluation, and achieved a better understanding of the practical activity by students. In some other cases, PBL+ was also used a service learning activity, as long as problems to be solved were related with social problems or small self-directed companies, particularly in the Agrarian sector. The relevance of small companies in the business world is undeniable, and to help such kind of companies in improving their competitiveness is a first-class service to the community. PBL+ has proved to be an optimal methodology to fulfil practical competences of STEM degrees in engineering specialities.

Keywords: Problem based learning plus, flipped classroom, flipped learning, service learning, rubric, CoRubrics, STEM.

1 INTRODUCTION

Problem Based Learning (PBL) is a teaching-learning methodology initially created for medical education at McMaster University (Canada) by Barrows [1]. Its main characteristics are the following [2]: i) learning is student-centered; ii) learning occurs in small student groups; iii) problems form the organizing focus and stimulus for learning; iv) problems are a vehicle for the development of clinical problem-solving skills; v) new information is acquired through self-directed learning. This methodology has evolved because it has been adapted to the particular needs of different disciplines in which it has been adopted. In essence, the methodology starts with the description of a real problem, thus the student needs to find out what is needed to be learned in order to solve the specific problem; this is called “self-directed learning”. Therefore, the methodology essentially consists on learning in the context of the need for solving problems [3].

In a previous work, Urbano et al. [4] recognized as a priority in the STEM studies at the University, the alignment of the higher education with the labor market, promoting the entrepreneurial spirit, and enhancing the links between education, research, and enterprise, which is supported by the European Commission [5] and the Spanish National Agency for the Higher Education Quality [6].

Starting from 2016, Urbano et al. [4], [7], [8], [9], [10] and González-Andrés et al. [11], [12] developed a methodology to re-design student practical work (associated with specific subjects) in STEM studies at the University, in particular Engineering. The practical work consists in solving a real case or problem affecting a company, getting into direct contact with a commissioned person from this company. The methodology developed was named PBL+, because it is based on the original PBL methodology, but combined with other innovative methodologies, namely i) the flipped classroom, ii) the service learning, iii) the use of rubrics for evaluation. The PBL+ was constructed in several stages testing each one with the students before moving on to the next one. The PBL methodology showed the particularity of allowing direct contact between students-company whenever it was possible. The following stage consisted on the combination of PBL with flipped classroom [7], starting the practical activity at the beginning of the course, before theoretical lectures are given, because this endows students with the need for learning the necessary theoretical basis to look for a solution. Although combining PBL and flipped classroom resulted successful, it was detected that such uncommon practical activities pose the threat of finding a suitable way to perform its evaluation, proving as inadequate the traditional evaluation systems [7]. To avoid this problem in the subsequent stage, Urbano et al. [8] and Gonzalez-Andres et al. [11] developed an evaluation system, based on rubrics, that provided the students, from the beginning of the course, with the necessary information regarding the expectations from the activity proposed, and indicating in a clear way the evaluating criteria. Simultaneously, Urbano et al. [8], [9], converted the activity in a service learning one, in some specific subjects in which the problem to be solved has a social interest or is associated with self-directed micro-companies, which due to their small size were not able access consultancy services. The validation with students of the evaluation process using rubrics [8] showed that depending on the teacher, a weak point of this system may be the great variety of approaches that can be given for the same competences in different subjects. Urbano et al., [9], [10], demonstrated that, even with this mentioned drawback, the use of rubrics for evaluation was still successful since it helps students to understand the main objective of practices as well as the components of the evaluation process. The rubrics must be organized in dimensions and indicators, with several levels per indicator so it is clear for students the performance expected from them [13].

The general objective of the present work was to address the last stage of development of PBL+ methodology. The specific objectives were: i) to standardize rubric indicators to evaluate general, transversal and basic competences of STEM studies, that are covered by PBL+; the indicators were arranged by dimensions. The indicators were uploaded into a repository, in Spanish language, along with a correspondence between competences and indicators; ii) to validate PBL+ in 11 STEM subjects from 5 different degrees and 5 different Masters, using the software CoRubrics for the rubric application

2 METHODOLOGY

PHASE 1. Standardization of dimensions, indicators and levels for the rubric corresponding with competences to be evaluated.

This was achieved in a panel with participating professors responsible of 11 subjects (Table 1) which are included in the present work. The procedure followed by the experts' panel consisted firstly in selecting basic, general and transversal competences associated with practical work susceptible to be evaluated using PBL+. Afterwards, the experts selected the pool of dimensions, indicators and levels to be used in the evaluation of each competence.

In a second round, the proposal was critically analyzed by other stakeholders as the coordinators of the Masters and Degrees having subjects included in this program, and by the commissioned person from the participating companies. Finally, a database matching competences to be evaluated and dimensions and indicators was uploaded to a digital repository.

PHASE 2. For each of the 11 subjects (Table 1) those rubrics approved in phase 1 were transferred to CoRubrics, which is a freeware for Google Sheets [14].

Table 1. List of subjects included in the validation of the PBL+ methodology. Six of these subjects correspond to Master level and five of them to Degree level.

Degree/Master	Subject	Acronym
Degree in Agrarian Engineer	Ornamental crops	DAgE
Degree in Biotechnology	Biotechnological processes	DB
Master in Agronomic Engineering	Crops systems	MAE
Master in Production in Pharmaceutical Industry	Innovation in the pharmaceutical industry	MPPI-1
Master in Agronomic Engineering – University of Valladolid	Business administration and agri-food marketing	MAE_UVA
Master in International Cooperation for Development	Agricultural and rural development	MICD
Master in Mining and Energy Resources Engineering	Processes in carbochemical and petrochemical industry	MMERE
Degree in Electrical Engineering	Environmental technology	DEE
Degree in Environmental Science	Energetic resources management	DES
Degree in Aerospace Engineering	Aerospace sustainability	DAeE
Master in Production in Pharmaceutical Industry	Chemical reactors and fermenters	MPPI-2

PHASE 3. Implementation of practical work by the students, in each of the 11 subjects using PBL+ methodology. Activities were evaluated using rubrics and their management was performed using CoRubrics.

PHASE 4. Evaluation of the PBL+ methodology during practical work.

The first stage of the evaluation process corresponded to academic results, and consisted on comparative analyses of results obtained from the evaluation performed by the teacher and from the self-evaluation by the students, using the corresponding rubric. As the rubrics were managed with the software CoRubrics, the results were automatically processed by the software, and were accessible in the form of a worksheet.

The data mining consisted on a graphical analysis of mean values. Two different comparisons were carried out between evaluation and co-evaluation, by rubric dimensions on one hand, and by subjects on the other.

The second stage of the evaluation corresponded to professors' satisfaction regarding the use of PBL+. With this purpose, the panel of professors was gathered together again for discussing on results.

3 RESULTS

3.1 Standardization of rubric indicators to evaluate practices in STEM subjects

A total number of 60 competences belonging to categories: general, transversal and basic were fulfilled with the practical work. The rubrics for evaluating competences were created, and indicators standardized. After this standardization process, the number of indicators was reduced to 20, belonging to five dimensions (Figure 1). The description of the 20 indicators and dimension to which they belong, are in Table 2, whereas the database containing the matching information between competences and indicators can be accessed (written using Spanish language) at https://ingeniaq.unileon.es/ SMARTRUBRIC/Materiales Generados/Tabla_CINE. The database was called "*Tabla CINE Competencias e INdicadores Estandarizados*". In some cases, several competences were evaluated by the same indicator, particularly when competences are quite similar but belonging to different subjects. On the contrary, on small cases, one competence was evaluated by different indicators.

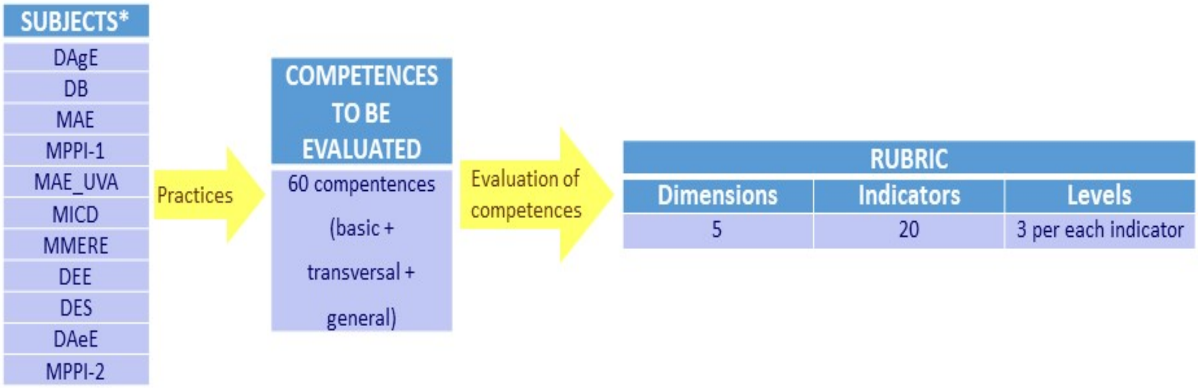

Figure 1. Standardization of the rubric indicators to evaluate practical work of STEM subjects with PBL+ methodology. Subjects codes according to Table 1.

Table 2. Selection of rubric indicators to evaluate practical activities based on PBL+ in STEM university studies.

Indicator		***Dimension***
No.	***Description***	
I0001	Oral presentation: Understanding and knowledge of the work content	Oral communication skills
I0002	Oral presentation: Adequacy of student's answers to teacher's questions	Oral communication skills
I0003	Technical-scientifically quality: Theoretical-practical contents	Technical knowledge and skills
I0004	Oral presentation: Audio-visual material prepared for presentation	Oral communication skills
I0005	Quantity and quality of the documentary sources	Synthesis capability
I0006	Level of understanding of the business problem to be solved	Synthesis capability
I0007	Capability of searching scientifically and technically sound information about the problem to be solved	Synthesis capability
I0008	Excellence of the innovations provided to solve the problem	Critical thinking
I0009	Level of interaction between the students and the company	Critical thinking
I0010	Technical viability of the alternatives presented to solve the problem	Technical knowledge and skills
I0011	Economic viability of the solution	Technical knowledge and skills
I0012	Formal aspects of the written document: Structure and skilful in writing	Written communication skills
I0013	Formal aspects of the oral presentation: Structuration and skilful in the transmission of ideas	Oral communication skills
I0014	Formal aspects of the written document: Length and formatting	Written communication skills
I0015	Formal aspects of the oral presentation: Time duration	Oral communication skills
I0016	Aspects related with the active participation in the classroom	Oral communication skills
I0017	Possibility of exploitation of the innovative results obtained and social-economic impact	Critical thinking
I0018	Social approach of the project	Technical knowledge and skills
I0019	Proper use of social media	Critical thinking
I0020	Scientific and technical capabilities for R&D activities, and capability to fulfil technical-economical requirements of the projects	Technical knowledge and skills

The selection process was based on 11 different subjects from Degree and Master level at Universities of León and Valladolid (Spain) (see Table 1). Indicators have been arranged by Dimensions. Further details on competences and their correspondence to each indicator can be obtained from https://ingeniaq.unileon.es/ SMARTRUBRIC/Materiales Generados/Tabla_CINE

3.2 Implementation of the PBL+ system and evaluation of its performance

PBL+ was implemented for different 11 subjects, with a total number of 50 students. During the first evaluation stage, performed by the panel of professors, the main highlights were the following: i) PBL+ was adequate for evaluating practical work, but direct contact between students and companies is difficult when technological companies are to be addressed due to confidentiality issues; ii) in some cases, the practical work was exerted as a service learning regarding the subjects of Ornamental crops and Crops systems (DAgE and MAE in Table 1); iii) the software CoRubrics facilitates the use of rubrics and it is the preferred option by professors compared with other software; iv) the evaluation of PBL+ using rubrics increases the objectivity when evaluating students, but involves an additional work for the professor to elaborate such methodology, when applied for the first time.

In the second stage, the use of rubrics with the software CoRubrics was analyzed, in order to evaluate the PBL+ activity in 11 subjects. Table 3 shows average values obtained by subject and rubric dimension in two different set of evaluations, self-evaluation and professor's evaluation. In general, higher scores were achieved from students' self-evaluation, except for two specific cases having opposite results, namely the written communication skills in the subject: Energetic resources management (DES) and synthesis capability in the subject: Biotechnological processes (DB). Regarding three other dimensions – technical knowledge, oral communication and synthesis capability – from the subject Energetic resources management (DES), the average score of students' self-evaluation and the one performed by the teacher were coincident (codes according to Table 1).

Table 3. Average scores obtained using rubrics for evaluating PBL+ methodology in 11 subjects, for two different evaluations: Students' self-evaluation, and evaluation by the professor. Data are arranged by subject and by rubric dimension. Scores are from 0 to 5.

Degree (D)/Master (M) subjects*	Dimension									
	Technical knowledge and skills		Written communication skills		Oral communication skills		Synthesis capability		Critical thinking	
	Self	Professor	Self	Professor	Self	Professor	Self	Professor	Self	Professor
DES	3.0	3.0	2.0	3.0	3.0	3.0	3.0	3.0	3.0	2.0
DB	4.0	3.5	3.5	3.0	3.5	3.0	3.0	3.5	4.0	2.5
MAE-UVA	3.8	2.9	3.8	3.1	3.4	3.0	3.6	3.3	3.8	2.9
MPPI-2	4.0	3.0	4.0	3.5	4.0	3.3	4.0	3.4	4.0	3.7
DEE	3.7	3.1	3.3	3.1	2.0	1.9	3.4	3.3	3.7	2.8
MICD	3.8	3.0	3.7	3.2	3.1	2.7	3.7	3.3	3.8	3.1
MAE	3.7	3.1	3.4	3.2	3.2	2.8	3.5	3.3	3.7	2.8
MMERE	3.8	3.0	3.6	3.3	3.1	2.7	3.6	3.3	3.8	3.1
MPPI-1	3.7	3.1	3.4	3.2	3.2	2.8	3.5	3.3	3.7	2.9
DAeE	3.4	3.1	3.6	3.2	3.1	3.0	3.5	3.4	3.8	3.0
DAgE	3.4	3.1	3.6	3.2	3.1	3.0	3.6	3.3	3.8	3.0

**Codes according to Table 1, D at the beginig means Degree and M means Master*

Figure 2 shows the average evaluation obtained by subject, for the five rubric's dimensions, comparing self-evaluation scores with professors' scores. In general, self-evaluation scores are higher than those given by professors, with the modal difference being 0.5 points out of 5 (approximately a 10%). For two subjects, Biotechnological processes (DB) and Business administration and agri-food marketing (MAE-UVA), this difference was higher (0.6 and 0.7 respectively). As an exception, for the subject Energetic resources management from the Degree in Environmental Sciences (DES), the professor's evaluation was slightly higher (3.5%) than the average obtained from the students' self-evaluation.

The differences between self-evaluation and professor's evaluation for the 11 subjects is presented in Figure 3, where it was arranged by rubric's dimension. The higher differences was for the critical thinking, followed by the technical knowledge and skills (Figure 3). Critical thinking is generally a weak point at University education level [15], and our results demonstrate that students are not aware of their shortcomings regarding this issue. In relation to technical knowledge, our results indicate that students' technical knowledge is still insufficient and therefore they have not capabilities in many case to understand their own limitations.

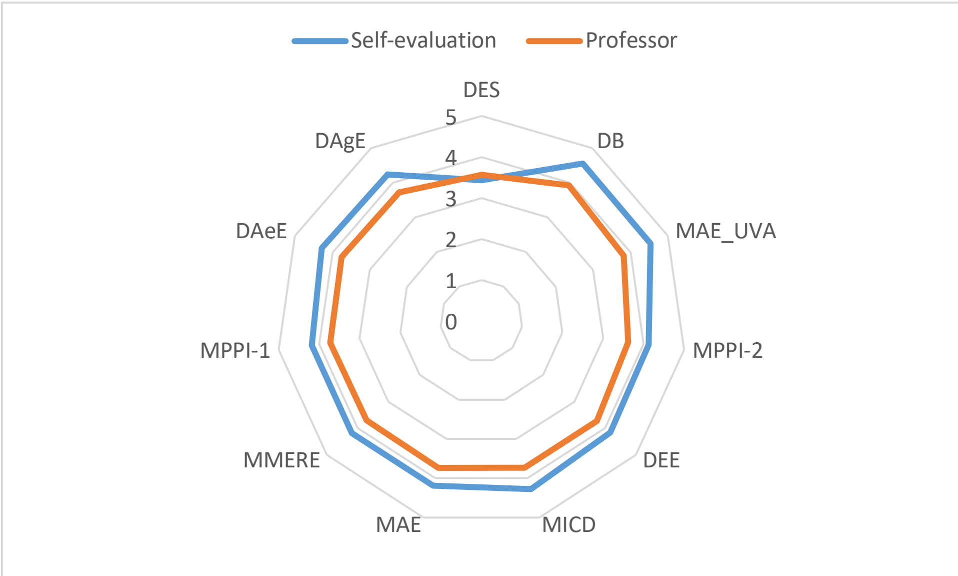

Figure 2. Average evaluation values for PBL+ activity in each of the 11 subjects, comparing self-evaluation scores with professors' scores.

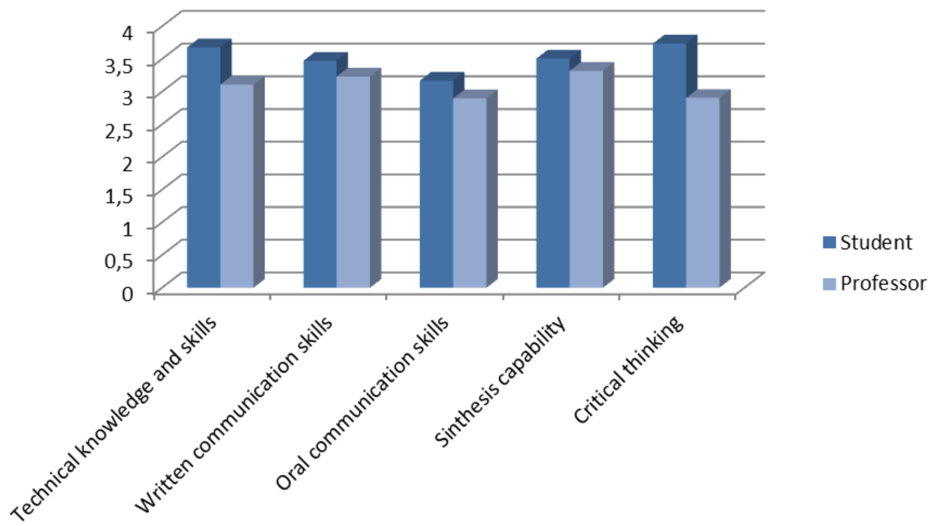

Figure 3. Average values of self-evaluation and professor's evaluation in PBL+ applied on 11 subjects. The evaluation was carried out using rubrics, and data were grouped by dimensions associated with the rubric. Scores are from 0 to 5.

4 CONCLUSIONS

PBL+ was developed by the teaching innovation group INGENIAQ from University of León (Spain), with the purpose of establishing contact between students and real case problems affecting companies. This experience was carried out in practical work activities included as a part of the practical credits of technology subjects at University level in STEM education. PBL+ combines several methodologies thus being a modified version of PBL, including flipped classroom, the use of rubrics for evaluation, and in some cases also service learning methodologies.

PBL+ is a good tool for fulfilling general, basic and transversal competences at University level in STEM education. Taking into account scores given by professors, competences related with "critical thinking" reached the worse scores, but surprisingly, students' perception was, by contrary, that they had achieved this competence in a high level. More efforts must be done to increase the students' critical thinking capability.

The use of rubrics for the evaluation process is essential in the success of PBL+, because rubrics improve the students' understanding of competences to be covered by the activity. This improvement has been demonstrated by the similarity between students' self-evaluation scores and that given by professors, with a modal difference of about 10% which was considered as a low difference. It can be concluded that students are conscious of what it is expected from them thanks to the use of this type of methodology. The software CoRubrics was useful for rubric management, and greatly simplifies professors' work, being especially useful for automatic compilation of data.

ACKNOWLEDGEMENTS

This work was supported by the "Escuela de Formación" from the University of León (Spain). The project granted was SMART-RUBRIC from the call PAGID-2018.

REFERENCES

[1] H. S. Barrows, *Simulated (Standardized) Patients and Other Human Simulations.* Chapel Hill, N.C.: Health Sciences Consortium, 1987.

[2] E. Mazur, "Farewell, Lecture?," *Science*, vol. 323, 50-51, 2009.

[3] M.A. Díaz Fondón, M. Riesco Albizu, "De la lección magistral al aprendizaje activo: diseño de una actividad basada en PBL," *XIV Jornadas de Enseñanza Universitaria de la Informática, JENUI*, Granada, 2008

[4] B. Urbano, X.A.; Gomez-Barrios, O. Martinez-Moran, M.E. Sanchez-Moran, A. Moran, F. Gonzalez-Andres, "The use of ICT and the flipped learning methodology to close the subject's practices to the labour market," *ICERI Proceedings*, vol. 2016, 2113 – 2119, 2016.

[5] EACEA: Education, Audiovisual and Culture Executive Agency, European Commission. Modernization of Higher Education in Europe, "Access, Retention and Employability, Eurydice Report," Luxemburg: European Commission Publications, 2014. Retrieved from: http://bookshop.europa.eu/is-bin/INTERSHOP.enfinity/WFS/EU-Bookshop-Site/en_GB/-/EUR/ViewPublication-Start?PublicationKey=EC0214422

[6] Spanish National Agency for the Higher Education Quality. *Informe final de renovación de la acreditación del Grado en Ingeniería Agrícola y del Medio Rural de la Universidad de Valladolid.* 2016.

[7] B. Urbano, F. Gonzalez-Andres, "Assessment of the use of ICT and flipped learning methodology in the subject's practices: closing the students to the labor market," *INTED Proceedings,* vol. 2017, 5550-5557, 2017

[8] B. Urbano, X. Gomez, M.E. Sanchez-Moran, R. Mulas, M.I. San-Martin, R. Mateos, C. Fernandez, O. Martinez, A. Moran, F. Gonzalez-Andres, "The use of rubrics for the evaluation of the subjects' practices in engineering studies, consisting in solving real cases in direct contact with companies: the case of the project EVALUA-PRACTIC," *INTED Proceedings,* vol. 2018, 4062 – 4068, 2018.

[9] B. Urbano, X. Gomez, M.E. Sanchez, M.I. San-Martín, R. Mateos, C. Fernandez, E.J. Martinez, O. Martínez-Morán, A. Moran, F. Gonzalez-Andres, "The use of rubrics for the evaluation of student practice in engineering subjects improves the teaching-learning process and the students' understanding of the evaluation process," *INTED Proceedings,* vol. 2019, 2301 – 2311, 2019a.

[10] B. Urbano, D. Carpio, F. Gonzalez-Andres, "Validation of rubrics to assess competences in agricultural engineering higher education," *INTED Proceedings* vol. *2019*, 1593 – 1600, 2019b.

[11] F. Gonzalez-Andres, B. Urbano Lopez de Meneses, "The use of rubrics to assess competences," *INTED Proceedings* vol. 2018, 4255 – 4261, 2018.

[12] F. González-Andrés, O. Martínez-Morán, M.E. Sánchez-Morán, X.A. Gómez-Barrios, A. Morán, B. Urbano-López-de-Meneses, "Evaluation of an innovative teaching methodology for engineering involving companies and ICTs in a flipped classroom," *Infancia, Educación y Aprendizaje (IEYA)*, vol. 3, 536-543, 2017.

[13] M. Romeo, M. Yepes-Baldó, S. Burset, V. González, J. Gustems, L. Sánchez, A. Besolí, "Evaluación de competencias profesionalizadoras en los estudios de grado de comunicación audiovisual," *REIRE. Revista d'Innovació i Recerca en Educació*, vol. 10, no. 1, 57 – 74, 2017.

[14] J. Feliu. "CoRubrics" *Technocentres.org*, 2018. Retrieved from https://corubrics-es.tecnocentres.org/home

[15] R. Sternberg, "Chapter 13 - Critical Thinking in STEM Disciplines," in Critical Thinking in Psychology (R. Sternberg and D. Halpern, eds.), pp. 309-327, Cambridge: Cambridge University Press. 2020.