TRANSVERSE COMPETENCE ‘CRITICAL THINKING’ IN CIVIL ENGINEERING GRADUATE STUDIES: PRELIMINARY ASSESSMENT

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Abstract

Within the framework of the new graduate degrees linked to the European Convergence, and additionally to the specific qualifications of the academic degree, a group of transverse competences to prepare students in their access to the labour market once studies finished. In several courses of the graduate degrees of Civil Engineering and Public Works 10 conceptual elements, equivalent to transverse competences, have been selected for evaluation. The transverse competence known as ‘critical thinking’ was assigned to two courses of the second year; namely Construction Techniques and Construction Typologies. This competence is crucial for the engineer as part of his analytical skills in the face to face of the professional life. The featured communication represents the students’ perception with regard to of the critical thinking during the professional practice, and based on the construction processes and typologies. Hence, an anonymous survey about the significance of the critical thinking in their skills profile has been distributed. The poll consists of 11 questions to be rated on a Likert scale. The questions relate to activities that potentially foster the acquisition of the competence ‘critical thinking’. The evaluation of the former transferable skill has become a novelty within the graduate studies at UPV, and therefore needs a continuous improvement of the evaluation work along the subsequent academic years. The methodology followed aims to extract how close the 11 activities are to one another. A factor analysis through principal components is used to identify the underlying variables or factors that explain the meaning of the correlations. A multiple regression model is proposed to explain the most correlational variables. Results have led the design of activities based on active methodologies for the assessment of the critical thinking.

Keywords: transverse competences, critical thinking, undergraduate learning, judgement analysis, graduate survey.

1 INTRODUCTION

1.1 Transverse competences assessment

The assessment of transverse competences has become a strategic objective for the curriculum framework of Universitat Politècnica de València (UPV). It is quite important for the students to gain and certify its training in competences; as similarly it is for the prospective employer and society to know the qualification level of the graduate [1]. For the UPV it entails an improvement of their university degrees, with an unquestionable added value and UPV degrees are easier certified at national and international level. The graduate studies on Civil Engineering (GIC) and Public Works (GIOP) are state Degrees offered at UPV in the Civil Engineering and Construction areas.

Within the teaching project of the construction engineering works, the group for Innovation and Quality Education (EXCELCON) of the University is constantly working toward this aim [1-9]. The group proposed a set of indicators system to manage the competences at the graduate and master levels [1,2]. Additionally, a new methodology was proposed to plan postgraduate studies leading to the construction management that considered the acquisition of competences [3]. It is worth noting the contribution in the concept of the graduate employability [10], and the highlights of using blogs and social networks in the active learning for engineering [11]. Finally, an active learning methodology for the sustainability assessment under different professional profiles was applied for students of project engineering courses [12]. The objective is the assessment of the transverse competence ‘critical thinking’, in the second year courses taught by the authors of this work are selected, namely Construction Techniques II from GIC and Construction Typologies and Techniques of Civil

ISBN: 978-84-617-8491-2

Engineering II (TPRO2) from GIOP, both belong to the teaching unit Procedimientos de Construcción at the school of Civil Engineering.

1.2 Objectives

The objectives of this communication are listed below:

1 Assessment of the undergraduate student's perception of the relevance of learning outcomes of the critical thinking within the civil engineering area.

2 Identify the underlying factors in the learning outcomes to position the assessment results.

3 Build an explanatory regression-based model of the main variables.

4 Design of activities and evaluation of learning outcomes as from the results of the distributed survey and by means of active methodologies.

2 METHODOLOGY

2.1 Development of the innovation

The applied innovation consists on the planning of activities, based on active methodologies that enable the assessment of the most significant learning results of the transverse competence 'critical thinking'. The novelty consists in compiling data from a preliminary survey that allows assessing the students' perception vis-à-vis of the learning outcomes beforehand. Such learning outcomes are deployed in the UPV university websites [13].

The results of the survey allowed to check which two underlying components best fit in the critical thinking competence, namely the following: competence related to a critical observation of the reality, through the analysis of the formulated arguments and identifying the implications of the problem against the people rights' in order to react consequently; as well as in the competence based on active involvement in debates, by argumentation of the suitability of the judgements made, based on principles and standards.

Therefore, attending to the obtained survey results, we proposed the following activities based on active methodologies for the assessment of the transverse competence:

- **Work group:** elaboration of a classwork on the subject in depth. A determined construction typology is assigned to each group of three to four students. The task is developed according to common guidelines: a) PowerPoint presentation format or similar, b) maximum number of slides, c) index of contents: 1. Definition, 2. History, 3. General features, 4. Classification, 5. Relevant or curious examples, 6. References and 7. Evaluation questions. Each group of students exhibits three to five questions -with answers-, to the audience of classmates, aware that such questions take all part in the corresponding partial test.
- **Oral presentation:** The students present the assigned construction typology in 10 minutes max. Is carried out questions from the teacher and by those students who attend, taking that respond to all them. The students are aware of the double assessment: the teacher one, and the assessment of classmates on a Likert scale 1 to 5 that judge the understanding and quality of the information, the ability to make judgements and the ability for criticism and enhanced solutions. All in all, the training on the transverse competence is empowered.

2.2 Questionnaire

A set of questions for the anonymous survey is prepared in order to know the perception of the undergraduate students with regard to the significance of the critical thinking as transverse competence. With the aim of obtaining the essential information for the investigation, the questionnaire consists of two parts: the first leads to characterize the population, by enquiry of the personal data of the individual (i.e., course inscription, sex, age, marks on the previous semester course, the second part queries 11 questions about the respondent's opinion regarding the significance of the critical thinking. These are scaled-based answers 1 to 5 as described next: 1) strong disagreement, 2) disagreement, 3) neither agree nor disagree, 4) in agreement, 5) strong agreement. Other works used a similar methodology [5]. The data mining and statistical analysis tool is SPSS 17. The variables are examined and a multivariate analysis is applied to interpret the results.

2.3 Characterisation of the survey conducted

First, a non-probabilistic convenience sampling is performed to accessible students of the Civil Engineering (GIC) and the Public Works Engineering (GIOP) degrees. The sample size was *N*=108, from which 70 (64.8%) belong to GIC and 38 (35.2%) belong to GIOP. The confidence interval is 95%, with *p*=*q*=0.5, which implies a sampling error of 15.2%, considering the sample characterises infinite population. Additionally, the liability analysis is checked by the coefficient α de Cronbach, a homogeneity indicator -consistency-, of the scale of the items involved (P1 to P11). The value delivered is α=0.799, which is high enough. Figs. 1 and 2 show the samples and results are interpreted next.

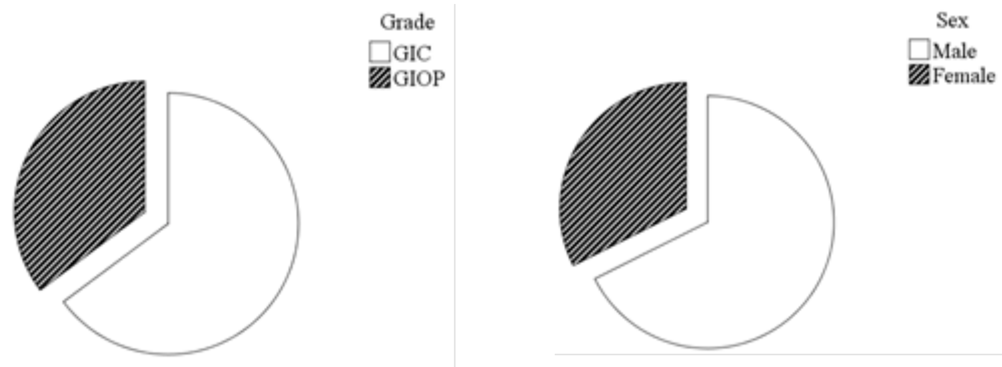

Figure 1. Characterisation of the analysed sample (1).

The respondent profile corresponds with a male student of the degree GIC, with an age of 20-21 years old, that marked ‘pass’ in the first semester course and who studied 1 to 5 hours per week. The male respondents were 73 (67.6%), while the female ones were 35 (32.4%). As regards the age groups, 39 (36.1%) fall in the range of 18 and 19 years old, 47(43.5%) in the range of 20-21 and 22 (20.4%) got over 22 years old. As for the marks, 5(4.6%) got Excellent, 25(25%) got Above average, 55 (50.9%) got Average, 15 (13.9%) got Below average and 6 (5.6%) did not present the exam. The number of hours devoted for study per week was: 29 (26.0%) less than one hour, 66(61.1%) from one to three hours and 13 (12.0%) more than three hours. The tool for statistical analysis was SPSS 17.

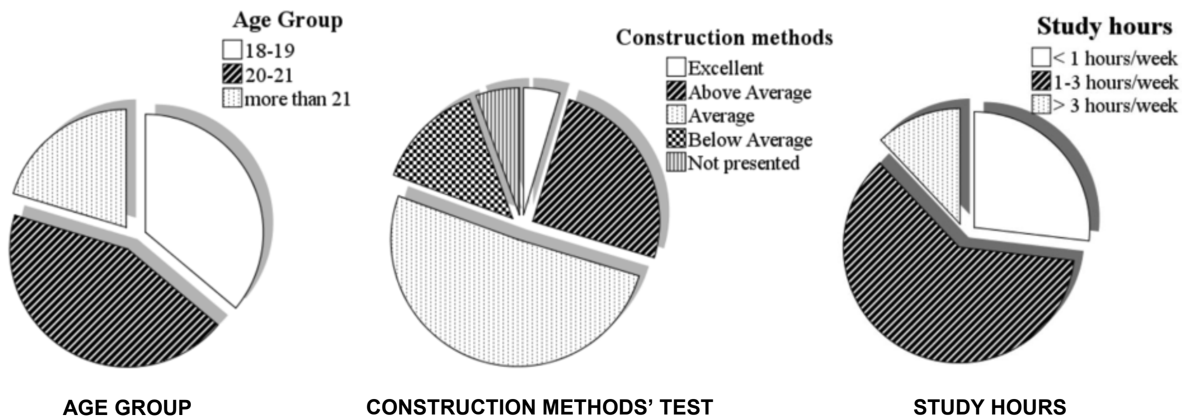

Figure 2. Characterisation of the analysed sample (2).

2.4 Basic analysis of the sample

We stablish a relationship between the study hours devoted and the mark obtained (Figure 3). The most remarkable of the figure is:

- As expected, there is not Excellent mark for the range of fewer devoted hours.
- There is not Below average mark for the range of more devoted hours. This means that the students who most work at home do perform better.

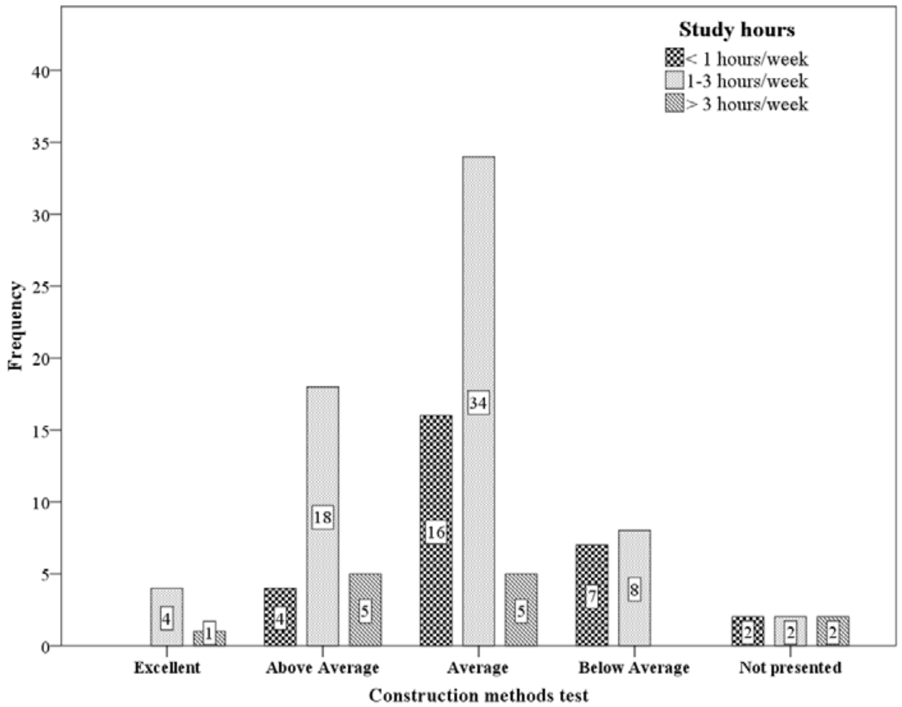

Figure 3. Relationship between hours of study and final course marks.

Another sample correlation between sex and final course marks might be of interest (Figure 4):

- All women got mark, while some men did not present the test, so no mark was possible.
- The number of Above average and Average marks among the female sex was the same, while for men sex the Average marks is almost three times the Above average marks.
- The rate of Excellent in the female sex group is three times higher than for the group of men.

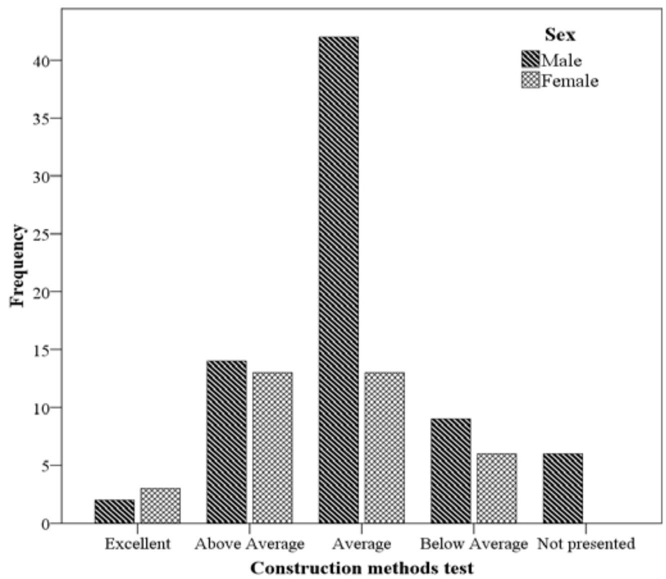

Figure 4. Relationship between sex and final course marks.

An interest point is how the exam marks of the GIC undergraduates differs from GIOP ones. Fig. 5 presents the percent distribution of the five ranges '*Excellent', 'Above average', 'Average', 'Below average'* and '*Not presented'*. It can be observed that more students of GIOP obtained excellent results than GIC students. Similarly, the rate of GIC students with lower marks increased steadily with lower mark ranges. It is of interest for the course evaluation to further analyse this phenomenon. However, one hypothesis states that the leading cause might lay on the expectations of the evaluator in the assessment of exams and academic work. He is expected to subconsciously grade lower marks to the students in GIC, as part of a long lasting degree (4+2 years). There is an underlying idea that the short term studies such as GIOP require less effort.

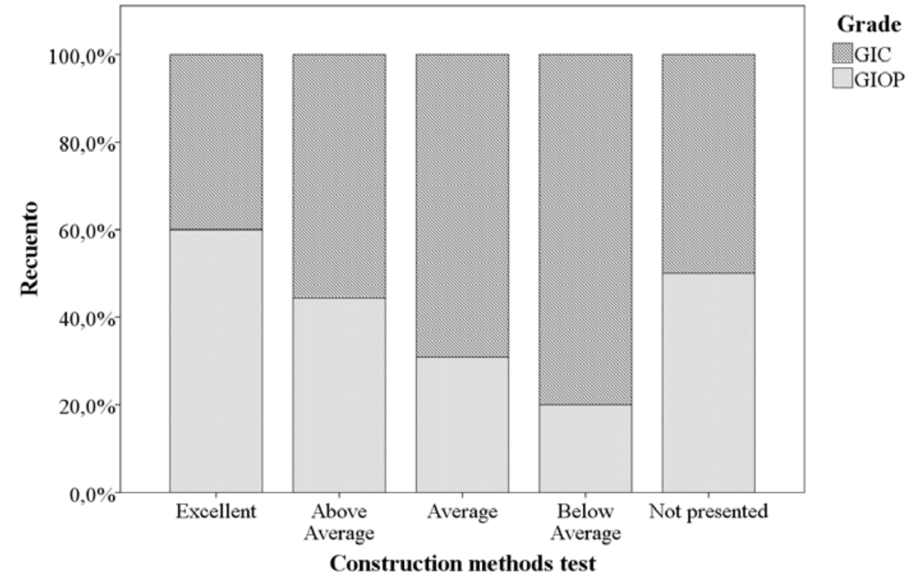

Figure 5. Distribution of marks for GIC and GIOP grades

3 RESULTS

3.1 Descriptive statistical analysis

Table 1 shows the average and standard deviation values of each of the 11 questions in the poll. It can be observed that the best valued and agreed learning outcomes are (1) act coherently and responsibly in decisions and behaviour, (2) the critical thinking is a key competence for the civil engineer training, and (3) demonstrate a critical attitude towards society. There is a higher distance from the first to the second of the learning outcomes (0.24), than between the second and third (0.08).

Table 1. Average and standard deviation of the poll answers.

Nº	Question	Average	Stdev.
P10	Act coherently and responsibly in decisions and behaviour	4.56	.752
P11	The critical thinking is a key competence for the civil engineer training	4.32	.783
P1	Showing a critical attitude to reality	4.24	.668
P4	Reflection of the consequences and effects of people' decisions have over another	4.16	.751
P7	Identify the implications of a problem or proposal regarding the rights of people	4.15	.759
P2	Differentiate facts from judgements, interpretations and valuations in someone else's arguments	4.14	.803
P6	Evaluate the practical implications of decision making and proposals	3.90	.710
P8	Identify ideas, principles, models and underlying values in the critical judgements	3.81	.716
P3	Actively take part in debates	3.64	.859
P5	Made judgements according to internal criteria	3.55	.847
P9	Make judgements according to external criteria	3.42	.877

On the other hand, the learning outcomes with less agreement are (1) make judgements according to external criteria and (2) actively take part in debates. The learning outcome with less importance is to make judgements.

After the analysis of correlations of the questions, the strongest correlation (Pearson 0.475, with pairwise significance 0.000) corresponds to (P1) showing a critical attitude towards the reality and the critical thinking is a key competence for the civil engineer training. Following, the next strongest Pearson correlation, 0.467 (with pairwise significance 0.000), corresponds to (P7), identify the implications of a problem or proposal as to people rights with (P4) reflection on consequences and effects that their decisions have on the rest of the people. Finally, (P2) differentiate facts from judgements, interpretations and valuations in someone else's arguments is correlated to (P10), act with coherence and responsibility on decisions and behaviour (Pearson correlation 0.442, with pairwise significance at 0.000 level).

3.2 Applied Multivariate analysis

Following the correlations' analysis, a factor analysis (FA) through principal components, as previously used [4,9] is carried out to identify the variables or factors explaining the configuration of correlations within the group of variables of study. Ultimately, we seek to identify the 'constructs' or underlying variables that allows to explain the observed variables. Furthermore, a multiple linear regression analysis will be performed to describe to the limit the assessment of (P4) reflection on consequences and effects that their decisions have on the rest of the people and (P7) identify the implications of a problem or proposal as to people rights).

3.2.1 Principal components analysis

The analysis of principal components (PC) examines the interdependence among variables to reduce the dimension of an original group of variables to a new subgroup consisting of unobserved variables. Briefly, PC computes factors that are linear combination of the original variables and which are also independent of each other. The first principal component is chosen so that it explains the majority of the possible variance of the original variables, and so on. Within this technique, dependence among the variables is not taken for granted beforehand, so the PC analysis is applied before a multiple regression [15]. To avoid the unit of measure affects the results, the correlations matrix is used instead of the covariance's one. This way the average value of the principal components is 0 and its standard deviation is 1.00. Furthermore, a criterion to determine the number of principal components is deemed (the eigenvalue of the PC is greater than 1.00). Likewise, the Varimax method is used for ease of understanding, as it assumes an orthogonal rotation that minimizes the number of variables that present severe saturation in each factor [16].

Before extracting principal components (PC), each variable becomes explained a 100% by itself. However, once the PC are extracted, these do not explain all the variability of each variable, so some information is missing. Table 2 shows the standard deviation after the extraction, i.e., the commonalities, that measure the level of information available after such extraction. The question P5 is the one that best explains the model (made judgements in terms of internal criteria), and P8 (identify ideas, principles and underlying values in the critical judgements) explains less the model.

Table 2. Communalities.

Nº	Question	Extraction
P5	Made judgements according to internal criteria	.591
P10	Act coherently and responsibly in decisions and behaviour	.558
P9	Make judgements according to external criteria	.536
P2	Differentiate facts from judgements, interpretations and valuations in someone else's argument	.531
P1	Showing a critical attitude to reality	.527
P7	Identify the implications of a problem or proposal regarding the rights of people	.449
P6	Evaluate the practical implications of decision making and proposals	.448
P11	The critical thinking is a key competence for the civil engineer training	.445
P3	Actively take part in debates	.376
P4	Reflection of the consequences and effects of people' decisions have over another	.372
P8	Identify ideas, principles, models and underlying values in the critical judgements	.334

With the exposed criteria, there are two underlying PC that explain the 47% of the variance (Table 3) of the 11 questions of the poll. The components are related to the following underlying features:

- Component 1: Competences related to the critical observation of the reality, analysis and assessing the formulated arguments and identifying the implications of the problem towards the rights of people to react in consequence.
- Component 2: Competence based in the active involvement in debates, by argumentation of the suitability of the judgements made, by fundament on principles and standards.

Table 3. Total variance explained.

	Initial Eigenvalues		
Component	**Total**	**% of the variance**	**% cumulative**
1	3.232	29.383	29.383
2	1.935	13.263	46.970

Table 4 contains the matrix of the rotated factorial components, which indicates the existing correlation between each of the PC and the original variables. These values represent the weighting of each variable in the linear relationship of each PC with the different variables.

Table 4. Matrix of rotated components.

	Components		
Nº	**Question**	**1**	**2**
P10	Act coherently and responsibly in decisions and behaviour	.743	
P2	Differentiate facts from judgements, interpretations and valuations in someone else's arguments	.729	
P1	Showing a critical attitude to reality	.700	
P6	Evaluate the practical implications of decision making and proposals	.669	
P7	Identify the implications of a problem or proposal regarding the rights of people	.612	
P11	The critical thinking is a key competence for the civil engineer training	.601	
P4	Reflection of the consequences and effects of people' decisions have over another		
P5	Made judgements according to internal criteria		.769
P9	Made judgements according to external criteria		.732
P8	Identify ideas, principles, models and underlying values in the critical judgements		.512
P3	Actively take part in debates		
	Extraction method: Principal Components analysis. Rotation method: Kaiser Varimax Normalisation. Values lower than 0.5 were removed.		

3.2.2 Models of multiple regression

This section we carry out a regression analysis of all the variables to stablish models that explain the dependent variables we choose. For this purpose, inferences on simple or multiple linear models are drawn, and quantitative measures of the level of correlation of the variables are obtained through the coefficient R. The linear models adjust by least squares so that the dependent or response variables are explained to the limit by a group of independent or explanatory variables. The goodness of fitness is evaluated by a determination coefficient R^2, deduced as the proportion of variation of the response variables explained through the linear regression model [17].

First, we try to explain each response variable according to the explanatory variable to which it is more correlated. It is about increasing the regression coefficient by adding independent explanatory variables. To that end, the *stepwise* method [18], consist in introducing the variables at a time and check if each variable remains or exits of the model. As an inclusive criterion, an increment in the explained variance significant at 5% (F=0.050) is deemed, while for the exclusion of a variable a drop of 10% (F=0.100) is taken. The first variable introduced is the one with a higher correlation coefficient R. Subsequently, all the correlations are again computed by removal of the influence of the variable already into the model. Then the next variable with greater *R* enters the model, in such a way we get the variables entering independent from the ones already in the model.

As a result of the multiple regression computed (see Table 5 and 6, and Figures 5a and 6a), it is observed that, on the one hand the variable (P5); 'making judgements based on internal criteria in the training of the civil and public works engineer', can explain only a 11.5% of the actively take part in debates. On the other hand, (P1); 'showing a critical attitude to reality' and (P7); 'identify the implications of a problem or proposal regarding the rights of people' can explain the 24.6% of (P4); "reflection of the consequences and effects of people' decisions have over another". It is then clear that more factors occur than explain the variability and are not included in the model. This strengthens the value of the rubrics to assess the relevance of the critical thinking in the training of engineers.

Table 5. Multiple regression models. Response variables: P3 Active involvement in debates.

Modelo		**Coef.**	**Revised R^2**
1	(Constant)	2.378	0.115
	P5 Made judgements according to internal criteria	0.356	

Fig. 5b depicts the predicted vs. observed residuals plot shows how the values distribute along the diagonal without substantially distance, so it is considered that residuals represent a Poisson distribution, and therefore, standardized residual.

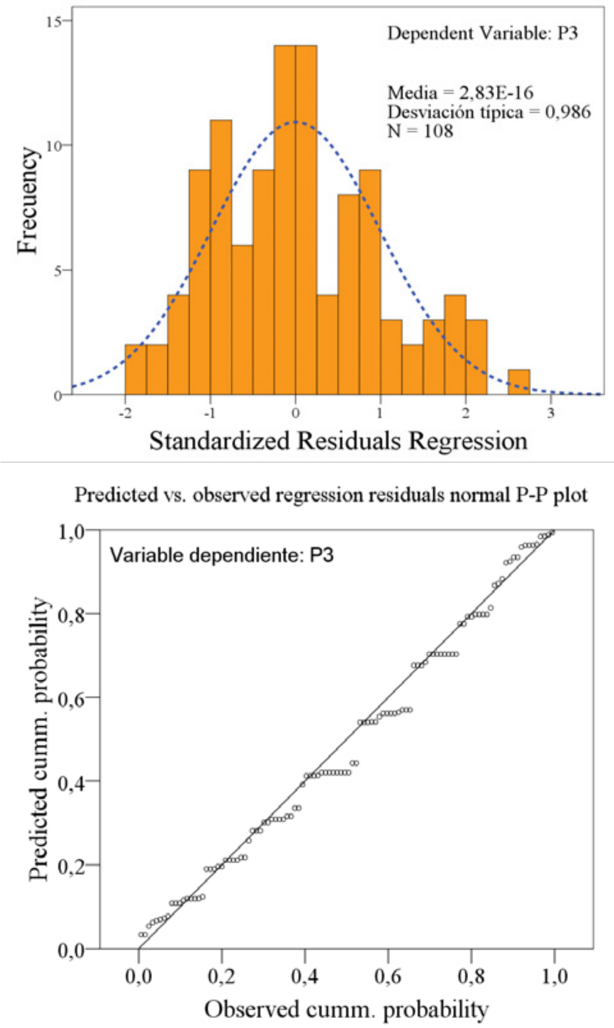

Fig. 5. Diagram of standardized residuals and normal distribution probability plot for variables P3.

Table 6. Multiple regression models. Response variables: P4 Reflection on the consequences and effects that people' decisions have over another.

Model		Coef.	Revised R^2
1	(Constant)	2.240	0.211
	P7 Identify the implications of a problem or proposal regarding the rights of people	0.462	
2	(Constant)	1.535	0.246
	P1 Showing a critical attitude to reality	0.250	
	P7 Identify the implications of a problem or proposal regarding the rights of people	0.376	

Fig. 6b shows the predicted vs. observed residuals plot. As for P3 in Fig. 5b, it can be observed that the values distribute along the diagonal without substantially distance, so it is also considered that residuals represent a Poisson distribution.

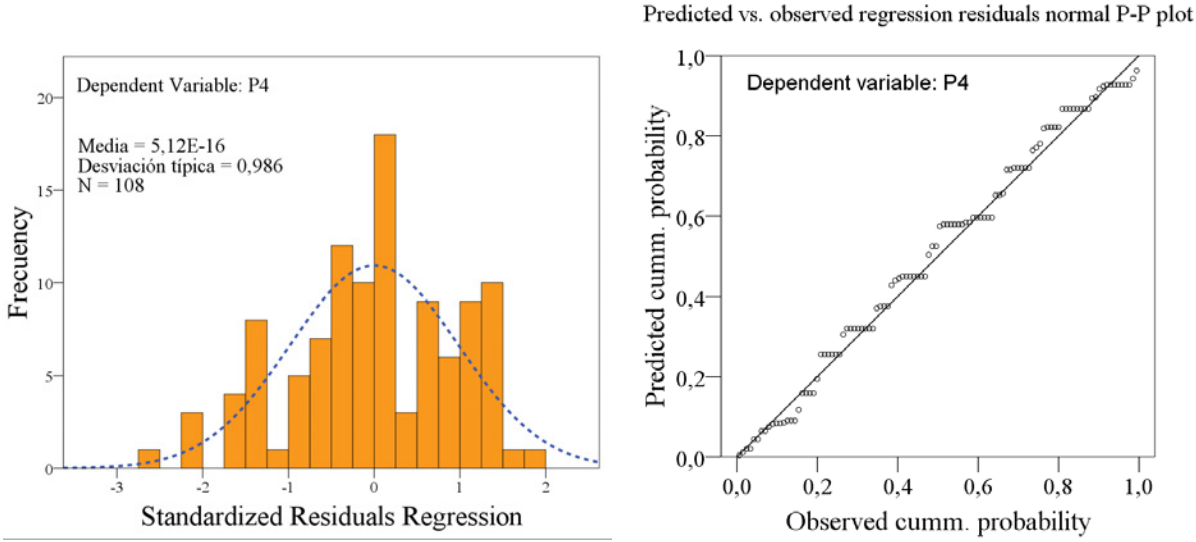

Figure 6. Diagram of standardized residuals and normal distribution probability plot for variables P4

4 CONCLUSIONS

It may be concluded that the learning outcomes deemed greater relevance and most agreed were (1) act coherent and responsibly in decisions and behavior, (2) the critical thinking is a key competence for the civil engineer, and (3) show critical attitude towards reality. On the other hand, learning outcomes with greater divergence are (1) make judgements based on external criteria, and (2) actively take part in debates. The outcomes result with lesser relevance is to make judgements based on external criteria. Two components relate with the following underlying aspects:

- Component 1: Competences related to the critical observation of the reality, analysis and assessing the formulated arguments and identifying the implications of the problem towards the rights of people to react in consequence.
- Component 2: Competence based in the active involvement in debates, by argumentation of the suitability of the judgements made, by underpinning on principles and standards.

In view of the findings, active methodologies -deepen work group, exhibition in class, pose alternative proposal or enhancement, critics to colleagues and suggest exam questions-, are deemed coherent. Thus, all of them can help to evaluate learning outcomes of the transverse competence critical thinking.

ACKNOWLEDGEMENTS

The authors acknowledge the support from the Ministry of Competitiveness and FEDER funding (Project BIA2014-56574-R), the Group of Innovation and Quality Education EXCELCON at UPV and the European Institute of Innovation and Technology (Project nº 20140262/ APEC0093_2016-1.5.1-093_P066-0 - Overcoming Barriers Towards a Low-Carbon Strategy in the Construction Industry).

REFERENCES

[1] V. Yepes; E. Pellicer; J.A Ortega. 'Designing a benchmark indicator for managerial competences in construction at the graduate level', in *Journal of Professional Issues in Engineering Education and Practice ASCE*, vol. 138, issue 1, p. 48-54, 2012.

[2] V. Yepes; S. Segado; E. Pellicer; C. Torres-Machí. 'Acquisition of competences in a Master Degree in Construction Management', in: *10th International Technology, Education and Development Conference INTED 2016*. March, 7-9th, Valencia, pp. 718-727, 2016.

[3] E. Pellicer; V. Yepes; A.J. Ortega. 'Method for planning a graduate program in construction management', in *Journal of Professional Issues in Engineering Education and Practice ASCE*, vol. 139, issue 1, p. 33-41, 2013.

[4] E. Pellicer; C.L. Correa; V. Yepes; L.F. Alarcón. 'Organizational improvement through standardization of the innovation process in construction firms', in *EMJ-Engineering Management Journal*, vol. 24, issue 2, p. 40-53, 2012.

[5] J.R. Martí-Vargas; J.F. Ferri; V. Yepes. 'Prediction of the transfer length of prestressing strands with neural networks', in *Computers and Concrete*, vol. 12, issue 2, p. 187-209, 2013.

[6] J.L. Ponz-Tienda; V. Yepes; E. Pellicer; J. Moreno-Flores. 'The resource leveling problem with multiple resources using an adaptive genetic algorithm', in *Automation in Construction*, vol.29, p. 161-172, 2013.

[7] T. García-Segura; V. Yepes; J.V. Martí; J. Alcalá. 'Optimization of concrete I-beams using a new hybrid glow-worm swarm algorithm', in *Latin American Journal of Solids and Structures*, vol. 11, issue 7, p. 1190-1205, 2014.

[8] L.A. Sierra; E. Pellicer; V. Yepes. 'Social Sustainability in the lifecycle of Chilean public infrastructure', in *Journal of Construction Engineering and Management*, vol. 142, issue 5, p. 05015020, 2016.

[9] V. Yepes; E. Pellicer; L.F. Alarcón; C.L. Correa. 'Creative innovation in Spanish construction firms', in *Journal of Professional Issues in Engineering Education and Practice*, vol. 142, issue 1, p. UNSP 04015006, 2016.

[10] C. Torres-Machí; A. Carrión; V. Yepes; E. Pellicer. 'Employability of graduate students in construction management', in *Journal of Professional Issues in Engineering Education and Practice ASCE*, vol. 139, issue 2, p. 163-170, 2013.

[11] V. Yepes. 'El uso del blog y las redes sociales en la asignatura de Procedimientos de Construcción', in: *Jornadas de Innovación Educativa y Docencia en Red IN-RED 2014*. July 15-16th, Valencia, pp. 1-9, 2014.

[12] E. Pellicer; L.A. Sierra; V. Yepes. 'Appraisal of infrastructure sustainability by graduate students using an active-learning method', in *Journal of Cleaner Production*, vol. 113, p. 884-896, 2016.

[13] Universitat Politècnica de València. Project 'Competencias Transversales UPV'. Available online at <https://media.upv.es/player/?id=c3aa2800-5572-11e6-8b81-dd635e3abea5>. Last accessed in 04.10.2016.

[14] V. Yepes; J. Díaz, F. González-Vidosa; J. Alcalá. 'Statistical Characterization of Prestressed Concrete Road Bridge Decks' in *Revista de la Construcción*, vol. 8, issue 2, p. 95-109, 2009.

[15] P.J.A. Shaw. Multivariate statistics for the environmental science. *London: Hoddeer-Arnold,* 2003.

[16] H.F. Kaiser. 'The Varimax criterion for analytic rotation in factor analysis', in *Psychometrika*, vol. 23, issue 3, p. 187-200, 1958.

[17] N. Draper; H. Smith. Applied regression analysis. *New York: Wiley*, 1999.

[18] R. Hocking. 'The analysis and selection of variables in linear regression' in *Biometrics*, vol. 32, p. 1-49, 1976.