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ASSESSMENT OF CRITICAL THINKING WITHIN A SUBJECT RELATED TO MECHANICAL ENGINEERING

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Abstract

The international accreditation of the programmes for the masters' and bachelors' degrees offered at our university, together with the demands of the employers, have made it clear that the students' curricula should specify not only what they have studied, but also what they are actually able to do. Although, in the recent years the competence based curricula approach has been used in the development of the new masters' and bachelors' degree programmes within the European Higher Education Area, the assessment of the generic competences is still a pending matter. This work presents an 'outcomes' approach for the assessment of the capacity for critical thinking within subjects related to mechanical engineering. In particular, this paper proposes a methodology in order to quantify the level of achievement and shows one tool developed for that purpose. The tool is based on the evaluation of some learning outcomes that can be observed by asking the students about different issues related to the contents of the course. Conclusions about preliminary results and the difficulties found to create this tool are also described here.

Keywords: competence assessment, learning outcomes, critical thinking.

1 INTRODUCTION

Within the European Higher Education Area, a huge effort is being done in reorienting the learning process towards the generic competences, the importance of which in the students' curricula is out of discussion. Most frameworks of higher education in the world include generic competences in their programmes [1,2]. These skills are recognised to be critical in order to prepare the students for increasing social prosperity and their own individual wealth [3,4]. They permit to evaluate the technical, professional and teamwork skills beyond the subjects studied during the degree, what is highly valued by the employers to assess the adequacy of their candidates [5]. In addition, these generic competences are also of great interest for universities to promote students' mobility on the basis of comparable evaluation criteria and methodologies [6]. However, this assessment is still a topic under research [7].

Therefore, as a part of this European educational framework, the Polytechnic University of Valencia (UPV) has developed special programmes in order to clearly define the specific and generic competences for each of its bachelors' and masters' degrees as well as for the particular subjects along them [8]. Although the competence-based curricula approach has been used in the development of new study programmes, the assessment of generic competences is still a pending task. In this regard, the use of learning-oriented active methodologies is being introduced in new programmes in contrast to the lecture-based teaching method in which the university system has been traditionally subtended. In this way, the development of the competences is favoured by means of evaluation activities where the students have to put their skills into play.

With this background, it is evident the need of tailoring the competence evaluation methodologies depending on the academic discipline in which they will be applied. The UPV has defined 13 key generic competences [8] that integrate different instrumental and interpersonal competences, using Tuning project name convention [9]. In this work, a developed methodology has been implemented for the assessment of the generic competence number 9: “Critical Thinking”. It is a competence difficult to define, whose denomination can vary from “Self-critical Capacity” [10] to “Critical Reasoning” [11,12]. This competence was tested in one subject dealing with Mechanics within the second year of Aerospace Engineering Bachelor Degree.

In order to make the evaluation of the generic competences easier, our university has established three different levels of development for every competence, from first and second years in bachelors’ degree (Level 1), through third and fourth years (Level 2), to last year in Masters’ degree (Level 3). The complexity of the learning outcomes associated to these competences increases with these levels [8]. For Level 1, corresponding to our subject, the main learning outcome defining critical thinking competence is expressed as follows: *Shows a critical attitude to reality, being able to analyse and question information, results, conclusions and other points of view.*

The corresponding indicators are: 1) shows a critical attitude to reality: ask the why of things; 2) deepens a topic with logic and impartiality, contrasting information in reliable sources; 3) differentiates facts from opinions, interpretations or evaluations; 4) forecasts the consequences (practical implications) of the decisions. Table 1 below gathers the indicators and descriptors of the rubric developed by the Institute of Education Sciences (ICE) of the UPV [8].

As seen, this competence is connected with the ability to apply logical and rational processes to analyse the components of an issue, and think creatively to generate innovative solutions. According to the definition adopted in the institutional project of the UPV, it is a matter of developing a critical thinking interested in the foundations on which the ideas, actions and judgments, both their own and those of others, are based. Critical thinking goes beyond the skills of logical analysis, since it involves questioning the underlying assumptions in our habitual ways of thinking and acting and, based on that critical questioning, be prepared to think and do differently. Critical thinking is the thought of the questions: why things are like this? Why cannot things be otherwise? Why do you think they are like this? Consequently, we will say that the student has developed it to the extent that she/he questions herself/himself about things and is interested in the foundations of the ideas, actions, assessments and judgments.

2 METHODOLOGY

In line with the previously explained situation, the authors considered that the computer labwork sessions of the practical part of the subject were a good scenario to evaluate the competence under study. Along these sessions, the students had to learn about how to use ADAMS/View©, a dynamic simulation software for the design and implementation of mechanisms as well as for the analysis of their dynamics and stresses.

In each session, the students work in pairs developing different applied cases from which they have to extract kinematic and dynamic results. Each pair solves a different exercise with particular geometrical and inertial data different from the reference problem developed and solved in the manual of the session. Since the requested results are numerical, the automated correction of the exercise is carried out, assuming a tolerance margin of 5% with respect to the solution previously calculated by the teacher. The average of the marks of the seven sessions determines the evaluation of this part of the subject.

The authors believe that checking if the students are able to confront expectation versus reality, and to understand the potentialities and limitations of the software employed will provide a good opportunity to assess the development of this competence on “Critical Thinking”.

Table 1. Learning outcomes: show a critical attitude to reality, being able to analyse and question information, results, conclusions and other points of view and achievement levels in the domain level 1 for the competence of Critical Thinking [8].

LEARNING OUTCOMES	D. Not reached	C. Developing	B. Good / adequate	A. Excellent / exemplary	EVIDENCES
He/she shows a critical attitude towards reality: the student wonders why things are happening	The student does not manifest any kind of critical spirit: he never questions the situation or the reality in which he lives. It assumes as true any information it receives	The student questions certain situations of the reality in which he lives. But it is incapable of issuing judgments and valuations of its own. Need the help of others to get answers	The student asks the question of things and investigates to get answers autonomously. But it is influenced by issuing its own judgments and assessments	The student reflects and investigates the why of things, and is able to find answers and argue them objectively	In exercises or problems with real proposals, include questions that invite the student to question: Is the result obtained in the previous section coherent (units, physical sense)? Could it have been solved in another way?
Detects inconsistencies or contradictions in other people's speech or in a text	The student is not able to detect inconsistencies or contradictions in a speech or text	The student is able to detect some inconsistencies but does not know how to explain why	The student detects inconsistencies and contradictions, and provides arguments to demonstrate the same	The student detects inconsistencies and contradictions, provides arguments, and coherently reformulates contradictory statements	To evaluate solving problem process; to suggest problems with multiple solutions; to justify the methodology and data used
Differences made from opinions, interpretations or valuations	The student shows a reflective attitude towards other people's discourse. Does not distinguish facts from opinions	The student normally distinguishes facts from opinions, but can accept judgments or decisions based on opinions	The student differences facts from opinions, interpretations or assessments in the arguments of others	The student questions judgments or decisions based on opinions, evaluations, etc. and detects fallacies and ambiguities	From press news or texts related to the subject, ask students to differentiate between objective facts, and interpretations of the author
Delves into a topic with logic and impartiality, contrasting information in reliable sources	The student is not able to delve into a subject. It uses a single source and does not contrast the information	The student resorts to diverse sources, but it does not verify the reliability of the same ones	The student consults different sources and contrasts the information of them to verify their reliability	The student consults reliable sources, contrasts the information and provides his personal assessment	Ask the students to do brief documentation work on a topic related to the subject, and to contribute the bibliography

2.1 Assessment tool proposed: Questionnaire

For the evaluation of the mentioned competence in this context, it was proposed to carry out a questionnaire with open questions. These questions are designed to stimulate the critical thinking, trying to give rise to the student to make value judgments and own impressions as a result of handling the software used in the labwork sessions. They intend to stir the originality of the answers beyond the technical knowledge acquired, also proposing new cases and the advantages and disadvantages to implement them in the dynamic software. The students had 15 minutes to complete the questionnaire, enough to calmly answer each of the questions. The questionnaire was delivered in the last session, following the format presented in Table 2:

Table 2. Assessment tool: open questionnaire.

1. *"As the world's most famous and widely used Multibody Dynamics (MBD) software, ADAMS improves engineering efficiency and reduces product development costs by enabling early system-level design validation. Engineers can evaluate and manage the complex interactions between disciplines including motion, structures, actuation, and controls to better optimize product designs for performance, safety, and comfort. Along with extensive analysis capabilities, ADAMS is optimised for large-scale problems, taking advantage of high performance computing environments."* With which affirmations of the text belonging to the ADAMS' brochure do you agree more and with which disagree? Argue your reasons.
2. Explain which, in your opinion, are the advantages and disadvantages of using ADAMS/View© to solve a parabolic shooting problem with air friction.
3. Which parameters do you consider most important to carry out a correct dynamic analysis? Why?
4. What are, from your point of view, the factors that can cause the numerical results to move away from the real measures?

Once the activity and the evaluation tool are described, thereafter the followed methodology to determine the achievement level of such competence is detailed. The design of the previous 4 items has been based on the learning outcomes provided by Table 1, as justified below.

Item 1. The first question requires evaluating a promotional text of the software brochure, indicating with what statements students agree and with which they disagree based on their experience. This item involves questioning the underlying assumptions and asks students to differentiate between objective facts and interpretations.

Item 2. The second question raises the problem of parabolic shooting considering air friction, a question solved analytically in the theoretical sessions. This permits to evaluate solving problem process for a problem with multiple solutions, requiring the justification of the methodology used.

Item 3. In the third question, the students are asked to choose the key parameters for solving dynamic cases, especially the ones that they consider crucial for the analysis.

Item 4. The last question focuses on the causes of divergences between the numerical results and the actual measurements, encouraging the students to take a critical perspective in the assumptions considered during the modelling process.

Each item is evaluated from 0 to 10 points, averaging them with the same weight to get the total mark of the questionnaire, scored as 10 points maximum.

2.2 Additional assessment based on observation

Previous to the design of the questionnaire described above, it was experienced the assessment based on observation. The labwork session 4 required as intermediate step a decision taken by the student about the initial condition that should be set in the proposed exercise. To make that decision, students had to think and argue about the prescribed motion introduced in the problem and its influence in the kinematic relationships involved. Based on the decision that each pair took and, in particular, how they argued and exposed their reasoning, the professor took notes and rate the competence from 0 to10 points. It is important to note that there was no rubric for its evaluation, marks were just based on the criteria of the professor, who was the same for all the labwork groups of the subject.

3 RESULTS

3.1 Comments to the answers of the questionnaire

Item 1. The question has generated answers questioning the ease of use and flexibility of the software in some specific circumstances and, especially, those that explain that they cannot assess their performance for large-scale problems since they have not been seen in any of the cases studied in the sessions, have been positively valued.

Item 2. Some students question whether, for a preliminary study, the time invested in a model in the software is profitable, being able to solve the problem analytically with a shorter procedure. On the other hand, some of the answers consider that the modelling of friction with air is not simple and escapes their knowledge acquired in the subject. The question opened a debate about the most optimal way to address a problem in which the aerodynamic forces completely condition the trajectory of the body under study.

Item 3. Although the rigor and completeness of the answers have been taken into account, the authors consider that this question has not managed to put the focus on the competence under study. Almost all of the students limit themselves to listing the parameters that are useful in the *entities tree* of the software, beyond an assessment of their importance. Hence, no many answers that imply any type of valuation or differential criterion are found. For the next courses, this question will be reconsidered.

Item 4. The last question has generated a greater diversity in the answers compared to the previous ones when evaluating the factors that may cause divergences between the numerical results and the actual measurements. Although some students have focused on the numerical precision of the software in the temporal integration, most have stated that the real energy dissipation is difficult to adjust to software implementable models, understanding that the results will be an approximation to the real behavior of the modelled system. There was a remarkable variety of answers in this regard, with very interesting specific reasoning.

3.2 Discussion

Fig. 1 gathers the average obtained for each item, corresponding with average of 6.74 for the total questionnaire as indicated below in Table 3. This value is closer to the theory and global mark compared to the observation indicator, which adjusts better with the labwork average.

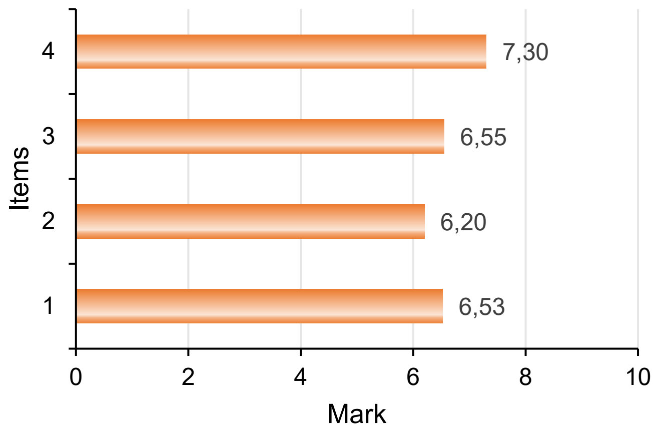

Figure 1. Average marks for the different items of the questionnaire.

Table 3. Average and deviation values corresponding with the competence assessment tools (observation and 4-items questionnaire) and the marks of the labwork sessions, theory exams and global grade of the subject.

	Observation	Questionnaire	Labwork	Theory	Global
Average	7.56	6.74	7.67	4.76	5.56
Deviation	*1.93*	*1.59*	*1.66*	*2.11*	*1.82*

In order to delve deeper into the adequacy of the assessment tools, the results of the questionnaire and the evaluation based on observation have been compared to analyse whether both assessment tools show or not similar rates per student. As shown in Fig. 2, the correlation between both is poor as expected, with significant differences higher than 2 points for a 41% of the students. Furthermore, there is not a clear trend in the density of points that permits us to have a conclusion, which is confirmed by the low determination coefficient R^2 of 0.011 captured.

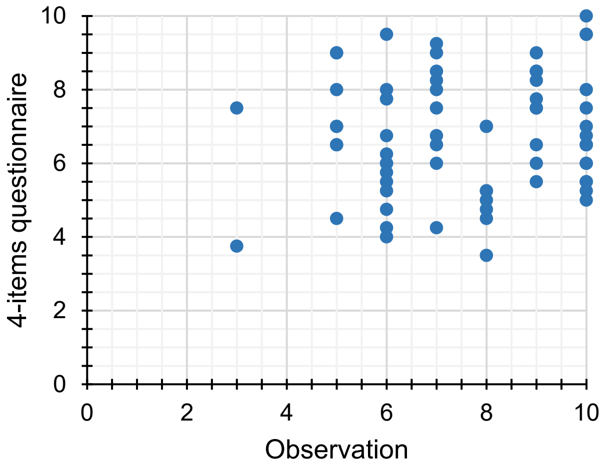

Figure 2. Comparison between questionnaire and observation assessment.

It has to be taken into account the hurries with which students usually work to complete the labwork exercise within the given deadline, totally different from the case of the questionnaire. This could be an important factor to explain the divergences, together with the lack of individualized attention by the professor during the course of the session that could had disturbed his observations during the sessions. Nevertheless, this observation seems to work quite well compared with the labwork marks, as indicated above. As shown in Fig. 3(a), only 8 of the 68 cases analyzed fall out the 2-points range depicted in the figure, observing a clear trend in which observations of 10 points correspond to labwork marks higher than 8 points. This evidence permits to infer a necessary correlation in the degree of performance of the labwork tasks by students and how the professor perceives this ability, although he has tried to evaluate exclusively the competence of critical thinking. In fact, its correlation with the theory marks are very unsatisfactory as observed in Fig. 3(b), with a determination coefficient R^2 of 0.021. Therefore, observation could be more recommended for the evaluation of other competences more related to practical skills.

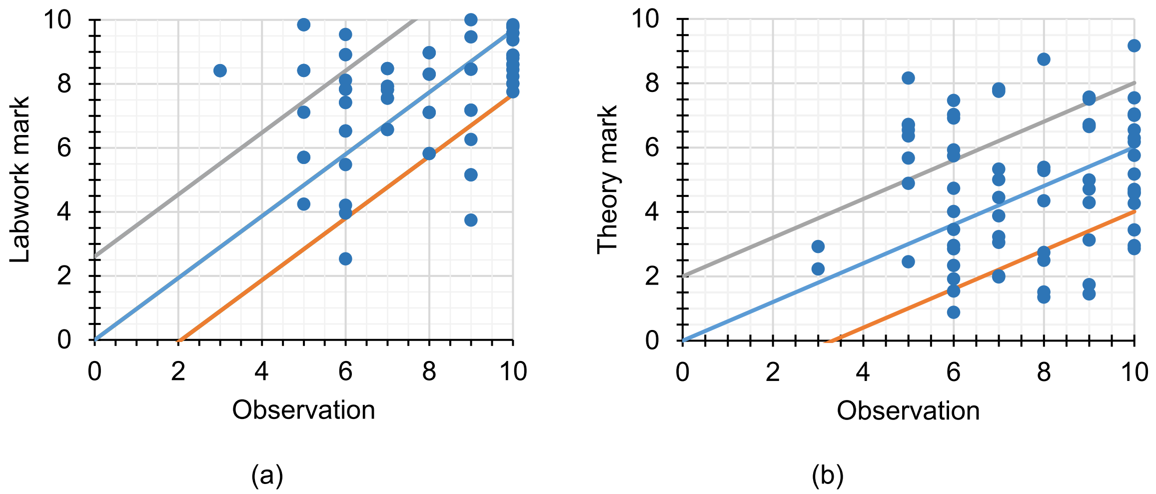

Figure 3. Comparison between observation assessment tool and: (a) labwork, (b) theory marks.

The previous results led us to focus on the questionnaire to evaluate the competence under study since the four open questions have been designed exclusively for the evaluation of the critical thinking competence. The results from the questionnaire have been analyzed and compared with the mark of 116 students corresponding to the labwork sessions and, as third significant element, the score of the two partial theory exams of the subject.

It is observed that scoring high in the questionnaire is indicative of a good performance in the labwork sessions and the exam, as shown in the trends gathered in Fig. 4. The correlation is clearer between the questionnaire and the theory exam as evidenced by the percentage of 27% of students out of the 2-points range traced in the Fig. 4(b), which is lower than the 35% achieved for the labwork mark as shown in Fig. 4(a). This satisfactory correlation with the theory marks brings up to infer that critical thinking is an important skill to approach the subject, although not the only one, since it requires a calm process and continuous acquisition and internalization of the complex concepts developed within the subjects. Other competences such as “Comprehension and Integration”, “Application and Practical Thinking” and “Analysis and Problems Solving” play a fundamental role to prepare the subject and to acquire the abilities required in the theory exam, in which complex dynamic problems with a strong mathematical content are faced. In these types of problems, the practical thinking is more important than the critical one. Nonetheless, a significant correlation with the critical thinking is observed.

It is important to note that some anomalies are found in Fig. 4(b), in which the highest rates in the theory exam had poor results in the questionnaire (lower than 5), and some students above 7.5 in the questionnaire obtained less than 2 points in the exam.

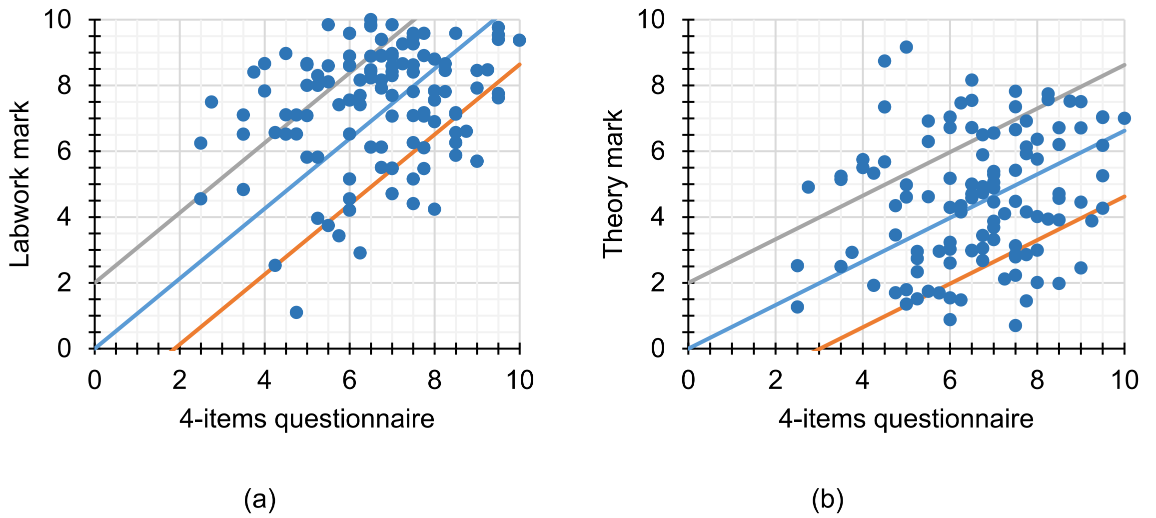

Figure 4. Comparison between questionnaire assessment tool and: (a) labwork, (b) theory marks.

4 CONCLUSIONS

A methodology has been defined to carry out the assessment of the critical thinking competence achieved by bachelors' degree students in Mechanics subject. Due to the mathematical and procedural nature of this subject, it leads to guess that competences that affect practical thinking and the analysis and resolution of problems seem more appropriate to establish a correlation with the students' marks. Hence the need for an appropriate design of the assessment tool for the specific evaluation of the competence under study, in a way as isolated as possible, without considering any direct extrapolation with the labwork or theory marks is necessary.

A 4-items questionnaire has been adopted as evaluation activity, where the student must go beyond the technical skills acquired during the labwork sessions questioning the underlying assumptions and generating differentiated answers from several perspectives. This questionnaire has been designed to cover the learning outcomes through the indicators and descriptors of the rubric developed by the UPV, scored from 0 to 10 points. An evaluation based on observation has also been tested, given unsatisfactory correlation with the results of the questionnaire.

These results show a certain correlation (greater than expected) between the competence and the labwork and theory rates, indicating that critical thinking plays a significant role in the skills that the students need to achieve on the subject. Nevertheless, the trend found is not sufficient to infer the grade of this competence from the marks of the subject, concluding that specific methodologies carefully designed are needed to assess this particular skill.

For the next course, it is proposed to perform a similar open questionnaire in the first session and see the evolution of students by comparison with a second questionnaire delivered in the last session.

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