

Methodology to evaluate transversal competences in the master's degree in industrial engineering based on a system of rubrics and indicators

Carlos Llopis-Albert¹ , Francisco Rubio¹ 

¹Centro de investigación de Ingeniería Mecánica (CIIM). Universitat Politècnica de València –
Camino de Vera s/n, 46022 – Valencia, Spain

Corresponding author: Carlos Llopis-Albert, e-mail address: cllopisa@upvnet.upv.es

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Abstract

This paper presents a methodology to evaluate transversal competences in the context of the subject “Design and application of industrial equipment” in the Master's Degree in Industrial Engineering at Universitat Politècnica de València (Spain). The competency-based education implies several activities, such as a project-based learning that must be eventually defended in public by students in groups. Evidence of learning is collected based on a well-defined system of rubrics and indicators, which are known in advance by students. We have observed that the use of such techniques improves the students learning on the contents of the subject, allows to acquire the transversal competences related to the analysis and problem solving, and enhances the ability to understand concepts intuitively. Moreover, results clearly show a positive influence on the use of such tools for improving the professional and ethical commitment to the issues raised.

Keywords: Transversal competences; Project-based learning; Innovation; Creativity and entrepreneurship; Knowledge of contemporary problems

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1. Introduction

This paper presents a methodology to evaluate transversal competences in the context of the subject “Design and application of industrial equipment” in the Master's Degree in Industrial Engineering at Universitat Politècnica de València (UPV) in Spain. This master qualifies for the Industrial Engineering profession.

The degree of Industrial Engineer has been accredited by the American ABET (Accreditation Board for Engineering and Technology) agency, which recognizes it as equivalent to the master's degree studies taught in the United States. It also has the EUR-ACE international seal of excellence, which certifies that these studies meet the professional requirements of engineering (Table 1).

Table 1. Indicators in the Master's Degree in Industrial Engineering at UPV.

Academic year	2015/2016	2016/2017	2017/2018	2018/2019
Degree performance rate	91,71 %	89,76 %	88,05 %	88,62 %
Degree drop-out rate	-	1,84 %	1,41 %	2,09 %
Graduate efficiency rate	98,5 %	96,94 %	94,1 %	94,16 %
Graduation rate	-	73,36 %	73,72 %	67,25 %
Supply-demand rate	161 %	172,33 %	194,67 %	199,67 %
Registration rate	99,67 %	100,67 %	102,33 %	106,67 %
PhD rate for academic staff	85,49 %	82,22 %	83,16 %	81,52 %
Full time academic staff rate	77,25 %	72,22 %	69,7 %	67,66 %
Number of students enrolled	505	701	827	864
Number of students graduated	89	154	236	235

This Degree provides the students with a deep professional and scientific background and with a great variety of knowledge about industrial technologies like mechanics, electricity, electronics, automation, materials, industrial building, projects, environment, energy and industrial organization and management. All of this implies a multidisciplinary education that makes graduates able to develop their professional work in industries, companies, professional practice of industrial engineering and public organizations.

This teaching innovation project is in line with the UPV objective to accredit the transversal competences (TC) to graduate students in any of the official degrees taught at the university (UPV, 2020). The TC are intended to ensure that students acquire the necessary skills to be able to have an

adequate labor insertion. This training must be seen from a broad perspective, linked to the integral training cycle of students, which includes both undergraduate and postgraduate degrees. In this regard, this research evaluates for the subject “Design and application of industrial equipment” the transversal competences CT-04 and CT-10, which are explain in detail in the next section.

2. Evaluation of transversal skills

2.1. Transversal competences at UPV

This research aims to develop a teaching innovation project to evaluate the transversal competences (TC) as defined by the UPV. TC are intended to synthesize a competency profile for its graduate students, ensuring a reference framework of all degrees. These cover a set of cognitive skills and metacognitive and instrumental and attitudinal knowledge of great value for the knowledge society. They are related to a set of attitudes and values (know-how to be) and procedures (know-how to do / act) and can be translated from one specific professional field to another. Furthermore, they are key and transferable in relation to a wide variety of personal, social, academic, and work contexts throughout of the life. Thirteen transversal competences are defined at UPV (UPV, 2020):

- TC-01. Comprehension and integration. Demonstrate understanding and integration of knowledge both from own specialization and in other broader contexts.
- TC-02. Application and practical thinking. Apply theoretical knowledge and establish the process to follow the achievement of certain objectives, carry out experiments and analyze and interpret data to draw conclusions.
- TC-03. Analysis and problem solving. Analyze and solve problems effectively, identifying and defining the significant elements that constitute them.
- TC-04. Innovation, creativity, and entrepreneurship. Innovate to respond satisfactorily and in an original way to personal, organizational, and social needs and demands with an entrepreneurial attitude.
- TC-05. Design and project. Design, direct and evaluate an idea effectively until it is concretized in a project.

- TC-06. Teamwork and leadership. Work and lead teams effectively for the achievement of common objectives, contributing to the personal and professional development of themselves.
- TC-07. Ethical, environmental, and professional responsibility. Act with ethical responsibility, environmental and professional to oneself and others.
- TC-08. Effective communication. Communicate effectively, both orally and written, adequately using the necessary resources, and adapting to the characteristics of the situation and the audience.
- TC-09. Critical thinking. Develop critical thinking by taking an interest in foundations on which ideas, actions, and judgments, both own and others, are based.
- TC-10. Knowledge of contemporary problems. Identify and interpret problems contemporaries in their field of expertise, as well as in other fields of knowledge, paying special attention to aspects related to sustainability.
- TC-11. Permanent learning. Use learning strategically, autonomously, and flexible, throughout life, depending on the objective pursued.
- TC-12. Planning and time management. Adequately plan the time available and program the activities necessary to achieve the objectives in academic, professional, and personal terms.
- TC-13. Specific instruments. Use techniques, skills, and the necessary updated tools for the practice of the profession.

The development of each competence is staggered on a continuum that can be called curve of learning, in which partial results that provide information to students, teachers and tutors. It must consider the reference level of development that will be required at the end of the training process to accredit students' achievement.

2.2. Transversal competences CT-04, TC-05 and CT-10 at UPV

In the subject "Design and application of industrial equipment" taught in the Master's Degree in Industrial Engineering at UPV the transversal competences TC-04, TC-05 and TC-10 are assessed.

2.2.1. Transversal competences CT-04

The transversal competence CT-04 is named “Innovation, creativity and entrepreneurship” and refers to the students’ capability to innovate and respond satisfactorily and in an original way to personal, organizational, and social needs and demands with an entrepreneurial attitude. Innovation is understood as the ability to respond satisfactory to personal, organizational, and social needs, modifying processes and / or results to generate new value. The development of this competence requires both the thinking of another way to bring different perspectives (creativity) and committing certain resources on their own initiative, to explore an opportunity, assuming the risk that it implies (entrepreneurship). The procedure to detect advances in the development of the competence entails three levels of domain, which are based on what learning outcomes would be desirable to reach at the end of master's course by the student. For each of these three learning outcomes, we will define a series of indicators, which are the concretions of those, of helping to focus attention on the issues that have been to analyze to detect progress (UPV, 2020).

Level 1:

- Learning outcome: questioning reality, identifying needs of improvement and ideas that can generate value.
- Indicators:
 - Question reality.
 - Come up with ideas.
 - Express ideas formally.
 - Identify results.

Level 2:

- Learning outcome: come up with original ideas and approaches that add value through creativity strategies and techniques.
- Indicators:
 - Identify opportunities and / or aspects for improvement.
 - Come up with ideas and original approaches.

- Employ creative strategies and / or techniques to capture formal ideas and solutions.
- Control results.

Level 3:

- Learning outcome: propose an action plan, including a global analysis of the innovation value.
- Indicators:
 - Integrate knowledge from other disciplines.
 - Adopt creative approaches to contents and development of classes.
 - Propose an action plan.
 - Analyze the value of innovation.

2.2.2. Transversal competences CT-05

The transversal competence CT-05 is named “Design, direct, develop and evaluate an idea effectively until concretize it in a service or product”. The development of this competence favors the student learn by doing and integrating knowledge and skills from different disciplinary areas, developing high-level intellectual skills, promoting learning and autonomous work, teamwork, and self-assessment. Three levels of mastery are specified in which it is intended that students reach certain learning outcomes. For each of them, a series of indicators are defined to detect progress (UPV, 2020).

Level 1:

- Learning outcome: design a working project at the draft level (without get to its execution).
- Indicators:
 - Reasonably justify the need for the project.
 - Establish clear objectives of the project.
 - Propose actions to achieve the objectives (and assign responsible in the case of group work).

- Assign the necessary deadlines to complete the planned actions (and assign responsible in the case of group work).
- Develop actions to achieve the objectives.
- Identify possible risks inherent to the project.

Level 2:

- Learning outcome: planning projects in collaboration with others in situations poorly structured, anticipate incidents and risks (planning without execution).
- Indicators:
 - Identify the causes that have led to the current situation of a problem.
 - Identify the social, economic, cultural, and diverse consequences of the problem in the context of their professional field.
 - Distinguish the parts that make up a problem and relate them to each other, identifying the main actors in their different dimensions (economic, social, ethical, technological...).
 - Reason (critically) the solutions already proposed for a problem.
 - Propose new solutions to the problem that has arisen based on one's own experience and available information.

Level 3:

- Learning outcome: assess and become aware of contemporary problems that affect their professional field and related fields.
- Indicators:
 - Propose solutions to certain important contemporary problems in their professional field and related fields.
 - Evaluate the proposed solutions to the most important contemporary problems in your professional field and related fields.
 - Prioritize the best solution to the problem raised based on own experience and available information.
 - Reframe the problem in terms of a new scenario.

- Evaluate the consequences and implications of the proposed solutions to the problem in terms of a new scenario.

2.2.3. Transversal competences CT-10

The transversal competence CT-10 entails to “Identify and interpret contemporary problems in your field of expertise, as well as in other fields of knowledge”. This competence refers to the need for students to understand contemporary political, social, legal, and environmental issues and values, as well as the mechanisms of expansion and dissemination of knowledge. It is about developing the ability to "stay up-to-date" with current events in their field of knowledge and in society in general.

To work on this competence, formative scenarios should be raised in which students discuss these types of issues in depth, being able to summarize the most relevant aspects and defend a position on it. In the same way, it is very important that they learn to evaluate complex situations using different approaches, such as: economic aspects, quality of life, environmental repercussions, local and national policies, etc. Again, several levels of student's command and indicators are defined:

Level 1:

- Learning outcome: recognize contemporary issues that affect your professional field.
- Indicators:
 - Identify what contents of the subject are related to a contemporary problem.
 - Identify contemporary problems related to your professional field.
 - Describe the problem and its main characteristics with an appropriate vocabulary in different contexts, orally or in writing.
 - Identify valid sources of information related to the assigned problem (reliable, independent, recognized sources...).
 - Identify solutions to the problem based on the information available

Level 2:

- Learning outcome: planning projects in collaboration with others in situations

poorly structured, anticipate incidents and risks (planning without execution).

Indicators:

- Support the context and the need for the project with evidence and data.
- Formulate the objectives of the project with coherence regarding the needs

detected in context.

- Plan actions effectively (achieve objectives).
- Plan actions efficiently (use resources optimally).
- Establish monitoring mechanisms for planning.
- Identify possible risks inherent to the project.
- Review expected results.

Level 3:

- Learning outcome: designing projects in unstructured contexts by part of the professor on global scopes, contemplating the execution of the same.
- Indicators:
 - Assess the needs in a real context of intervention.
 - Specify the operational objectives of the project and establish deadlines.
 - Plan actions and foresee contingencies.
 - Properly manage available resources.
 - Track the implementation of the project.
 - Properly manage the risks of the project.

3. Implementing the TCs in the framework of “Design and application of industrial equipment” subject.

The subject “Design and application of industrial equipment” is framed in the field of industrial constructions and mechanical engineering, which is taught in the first year of the Master's Degree in Industrial Engineering at UPV. It basically deals with the design of machine components (materials

in the design of machines, transmission elements, elastic elements, cams and unions, etc.), and about indoor transport systems and maintenance. Students must have the skills, knowledge, and abilities to carry out the verification and control of facilities, processes, and products, as well as knowing the methods and techniques of transport and industrial maintenance. This trains students to work in different types of companies in the industrial field. Therefore, in addition to learning to design and calculate elements and components of machines that are common to the different types of industrial equipment (brakes, clutches, springs, screw connections, power screws, bearings, etc.), the students will be able to apply the methods and techniques of indoor transport and material handling systems in any type of industrial facility. For instance, problems of movement of light or heavy loads arise, either in a discrete way (level change systems, lifting devices, overhead cranes, handling trolleys, etc.) or continuous (conveyor systems by belts, rollers, wheels, splints, chains, paternosters, aerial, etc.).

The subject comprises 11 evaluation acts, none of which individually exceed 40% of the final grade. The evaluation will be carried out through two objective tests with multiple choices, two open-response written answers, mark of three academic works, a project-based learning carried out in groups or 2-3 students and orally defended in classroom and a case study (Table 1).

Table 1. Evaluation system.

Description	Number of acts	Weight (%)
Objective tests (multiple choice)	2	35
Open-response written answers	2	25
Academic work	3	7,5
Case study	1	7,5
Project	1	25

The activities carried out for the acquisition of the competences entails carrying out an academic work in groups of 2-3 students, solving different problems, the use of several techniques for generating ideas, and a SWOT analysis. This analysis is a strategic planning technique that helps students to identify strengths, weaknesses, opportunities, and threats related to subject. In this sense, students must carry out in groups of 2-3 components a series of classroom and laboratory practices, with a weight of 17.5% in the final grade. In the practices they must analyze the indoor transport and maintenance of products in industrial facilities of any type of activity. Each group must carry out the

analysis of the problem raised, trying to find technically viable solutions, as well as proposing creative and innovative solutions that improve the systems currently on the market, with respect to the characteristics of the equipment and facilities proposed in practice.

In one of the practices students will apply a technique for generating ideas, innovation and creativity of new concepts and technical solutions, applied to proposals for the design of equipment and industrial facilities. For example, the SCAMPER technique could be applied (Eberle, 1996). This technique is an activity-based thinking process that consists of the application of a checklist used to create new ideas about improvements or new products / services while avoiding leaving out concepts that may be interesting. It is an acronym for the words / terms that define each of its letters and that identify the following ideas:

- Substitute comes up with another topic that is equivalent to the present topics.
- Combine adds information to the original topic.
- Adjust identifies ways to construct the topic in a more flexible and adjusted material.
- Modify, magnify, minify creatively changes the topic or makes a feature/idea bigger or smaller.
- Put to other uses identifies the possible scenarios and situations where this topic can be used.
- Eliminate removes ideas or elements from the topic that are not valuable
- Reverse, rearrange evolves a new concept from the original concept.

Therefore, this technique as a teaching strategy helps the students to analyze the knowledge in its creative form and helps the teacher to make teaching creative and interesting.

With regard the academic work, it will consist of carrying out an analysis of facilities for indoor transport of goods and materials in a real company. The students must justify the proposals leading to improvements regarding the current situation of the industrial plant. For instance, the topics of the academic work include:

- Docks for loading and unloading goods, with their maneuvering areas.
- Storage and transportation facilities that use load level compensation equipment.
- Facilities for the production, storage, or dispatch of materials where handling equipment supported on the ground is used.

- Freight transport facilities that use motorized load lifting equipment.
- Automated freight transport facilities between production areas.
- Facilities with automated cargo palletizing systems.
- Robotization of industrial facilities.

After the completion of the academic work, students should be able to answer the following questions:

- How is the system / facility currently implemented?
- What could be done to improve its performance, reliability, or security?
- What element or mechanical system of the equipment or installation can students design and calculate?

The analysis of the industrial activities of the company, and the proposal to improve the selected facilities, will allow the development of the CT-10 competence. The teachers who evaluate the evidence of compliance of CT-10, will apply to justify its achievement, the rubric shown in the following shown in Table 2.

Table 2. Rubrics for evaluating CT-10

Indicators	Descriptors		
	0. Not reached	1. Adequate	2. Good / Excellent
Proposes solutions to the problems treated according to the subject of the work	Does not propose viable solutions appropriate to the problem posed	Proposes few solutions or little elaborate solutions	It proposes solutions with an optimal or satisfactory level of detail. Demonstrates good application of the contents of the subject
Evaluate the proposed solutions	Does not evaluate the feasibility of the proposed solutions	Evaluate solutions superficially	Evaluate the solutions with an optimal or satisfactory level of detail, as discussed in the subject
Relate any of the objectives of the sustainable development goals or challenges 4.0 as a contemporary problem	It does not relate the proposal to any of the SDGs or challenges 4.0	Little does the proposal relate to the SDGs or challenges 4.0	Relate the proposal with an optimal or satisfactory level of detail with the SDGs or challenges 4.0

The use of the rubric will offer a grade between 0 and 4, with the following scale:

- Grade between 0.00 and 0.99: Not reached (D)
- Grade between 1.00 and 1.99 In development (C)
- Grade between 2.00 and 2.99 Adequate (B)
- Grade between 3.00 and 4.00 Excellent (A)

Among the different teachers of this subject are the authors of this paper, professors Llopis-Albert and Rubio, which have an extensive experience in this field. To be able to transmit knowledge effectively, especially at the master's level, it is important that teachers keep up to date with technological advances in the subject. For instance, they have published articles closely related with the subject: Llopis-Albert et al., 2015; 2018; 2019; 2019a; 2020; 2020a; Rubio et al., 2015; 2016; 2019; 2019a; 2020; and Valero et al., 2017; 2019; 2019a.

4. Results and discussion

There are 300 students enrolled in the subject of subject “Design and application of industrial equipment” in the Master's Degree in Industrial Engineering at UPV for the 2019-2020 academic year. The results obtained have been very satisfactory given the great acceptance by the students, which have actively participated in all activities. Regarding the activities related to the competences, all students but seven have passed the evaluation activities based on the aforementioned indicators and rubrics. Furthermore, most of students reached a high grade in the competences, i.e., an A or B mark. This shows that the evaluated competences were widely addressed in classroom. Although the academic works were less guided activities and student should work autonomously, they did them correctly. Further improvement for the next academic year includes to better fit in the calendar the different installments of the academic works, considering the workload of the students, and the elaboration of improved indicators and rubrics for their evaluation.

The main indicators of success of the activities carried out are the excellent pass rate and the high correlation that exists among the evaluation of the academic works, the open response written answers, the objective tests, the case studies, and the final grade of the subject.

4. Conclusions

This paper presents a teaching innovation project based on applying a system of rubrics and indicators to evaluate several transversal competences as defined at UPV. The proposed evaluation activities have been proven to be a valid tool for the achievement of such competences, and to improve both the students' performance in a mechanical engineering subject, and their level of satisfaction. In fact, the student's satisfaction survey regarding the subject, evaluation activities and teachers are very positive. Results have shown an excellent pass rate and a high correlation among the evaluation of academic works, the open response written answers, the objective tests, the case studies, and the final grade for the subject.

As future enhancements for next academic years it is expected to better fit in the calendar the different installments of the academic works and the elaboration of improved indicators and rubrics for the evaluation.

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