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Use of technical computing systems in the context of engineering problems

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Abstract

This paper presents a teaching innovation project based on applying technical computing systems as a resource to improve learning in the classroom and as a way of evaluating transversal competences (TC). By these means, students analyze complex kinematic and dynamic mechanical systems in the context of the subject Dynamics of Mechanical Systems of the Master's Degree in Mechatronics Engineering at Universitat Politècnica de València (Spain). We have observed that the use of such tools improves the students learning on the contents of the subject, allows to acquire the transversal competence related to the analysis and problem solving, and enhances the ability to understand concepts intuitively. Furthermore, 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 competencies; technical computing systems; ethical responsibility; professional responsibility; dynamics of mechanical systems.

1. Introduction

This paper aims to assess a transversal competences (TC) through a teaching innovation project based on applying technical computing systems in the context of a mechanical engineering subject, which is taught at Universitat Politècnica de València (Spain). This teaching innovation project is in line with the UPV objective to accredit the transversal competences to graduate students in any of the official degrees taught at the university.

The UPV focuses on science and technology and has more than a century of history. It is intended to advance towards training models that ensure that its 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 sense, the fundamental objectives of the university are (UPV, 2020):

- Establish a strategy for the systematic evaluation of transversal competences (TC), defining where they are acquired and how they should be evaluated.
- Prove the acquisition of such skills.

For that end, the specific objectives are focus on:

- Define what is a transversal competence, taking into account the different approaches collected in national and international references.
- Determine which are the thirteen transversal competences of the UPV.
- Incorporate transversal competences to the traditional training of students using different strategies.
- Design processes for the evaluation and accreditation of transversal competences that are flexible and innovative.
- Implement the processes of evaluation and accreditation of TC in all the degrees taught at our university.
- Give visibility of the results acquired by students to society.

With this strategy the university will achieve several objectives:

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- Provide their graduates with added value that can differentiate them from other graduates and, consequently, make the studies offered more attractive compared to similar offers from other universities.
- Value the training of our graduates in the face of employers.
- Make the acquisition of competences explicit for international accreditations.

2. Teaching, learning and assessment of transversal competences

2.1. Transversal competences at UPV

The motivation for the implementation of a teaching innovation project based on applying technical computing systems lies in the need to evaluate the transversal competences (TC) as defined by the UPV. TC seek to synthesize a competency profile for its graduate students, ensuring a reference framework of all degrees. Here is a brief description of the 13 transversal competences defined:

- 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 and evaluate an idea effectively until it is realized 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.

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- 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.

Transversal competences are related to a set of attitudes and values (know-how to be) and procedures (know-how to do / act). TC can be translated from one specific professional field to another. When curricula are designed, two types of competences are specified that students must develop: the specific and the transversal competences.

- The specific competences are those related to a specific scientific field or academic degree and are oriented to the achievement of a specific profile of the graduate.
- The transversal competences, denominated in various ways and under different perspectives (generic competencies, core competencies, key competencies, transferable competencies, soft skills, etc.), respond to those that are key and transferable in relation to a wide variety of personal, social, academic and work contexts throughout of the life. In this sense, they constitute a fundamental part of the professional profile of the degrees. These are competencies that include a set of cognitive skills and metacognitive and instrumental and attitudinal knowledge of great value for the knowledge society. The transversal competences are characterized by being:
    - Integrative, since they favor the integral formation of students.

- Transferable in academic and work, personal, and social contexts.
- Interdependent, since when a certain TC is worked it is usual that other related transversal competences are also dealt.
- Multifunctional, that is, versatile and capable of responding to different types of problems.
- Assessable, since they must be broken down into learning outcomes to be able to accredit the level reached in them by each student.

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.

To establish these mastery levels, it is essential to determine how to develop each one of the competences progressively. In this regard, it play a major role to take into account the experience of teachers and professionals who are working on it.

The CT UPV institutional project establishes three levels of mastery for each competence:

1. First level: it is developed in the 1st and 2nd grade courses
2. Second level: takes place in the 3rd and 4th grade courses
3. Third level: developed in the master courses.

To develop and evaluate the acquisition of competences, three ways are established complementary to each other: through study plans, the Bachelor's Degree Final Project, the Master's Degree Final Project and considering extracurricular activities.

2.2. Transversal competence CT-03

In the subject Dynamics of Mechanical Systems taught at the Master's Degree in Mechatronics Engineering at UPV the transversal competence TC-03 is worked. The transversal competence CT-03 refers to the students' capability to analyze and solve problems effectively, identifying and

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defining the significant elements that constitute them. Problems are new situations that require students to respond with new behaviors. Solving a problem implies performing tasks that require reasoning complex processes and, in many cases, not simply a routine activity.

The objective of this transversal competence is for the student to be able to apply structured procedures to solve problems, promoting thus their ability to learn, understand and apply knowledge of autonomous way. Three levels of domain are established, which define what learning outcomes it would be desirable that the student had achieved at the end of the second-degree course, the fourth degree and master, respectively. For each of these three learning outcomes, a series of indicators are defined, which are the concretions of the former, so that help to focus attention on the aspects to be analyzed to detect progress.

- Level 1: Learning outcome: analyze a problem applying the methods learned. The indicators of this level are:
  - Define the problem by describing clearly and concisely the aspects more important.
  - Use indicated information sources and select the correct data.
  - Use a learned method to solve the problem proposed.
  - Analyze the coherence of the solution/s obtained.

- Level 2: Learning outcome: develop your own criteria to solve problems effectively and efficiently through reflection and experience. The indicators of this level are:
  - Identify a complex problem, transform it into a several parts easier to solve and argues it.
  - Contrast the sources of information and handle rigorous data.
  - Use the most appropriate methodology, based on their experience, to solve the problem efficiently and justifiably.
  - Choose an optimal solution using justified criteria.

- Level 3: Learning outcome: solving problems individually and / or in team, in different contexts and in depth, from different approaches. The indicators of this level are:
  - Analyze the causes and effects of problems from a global perspective long-term.
  - Apply advanced information search criteria for the problem solving and evaluating the quality of the information.

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○ Organize in a systematic way the work for the decision-making process (individual / group).

○ Evaluate possible solutions according to their scientific-technical feasibility and according to its difficulty of implementation.

In addition to the transversal competence CT03, several specific competences are also worked in this subject. They are related to a specific scientific field or academic degree and are oriented to the achievement of a specific profile of the graduate. They are subsequently presented:

- Ability to model and solve dynamic problems in complex mechanical systems
- Ability to work in a team.
- Ability to apply acquired knowledge and to solve multidisciplinary problems. Decision-making, initiative, creativity, and critical reasoning.

2.3. Evaluation systems of CT

The recommended evaluation proposed by the university is by means of active methodologies and instruments. They are the most compatible and coherent in a training by competencies focused on student learning. In this sense, the type of activities that are used most frequently are, among others, those that start from learning based on problems, project-oriented learning, collaborative learning (formal and informal), contextualized learning or learning through case studies.

Most of these methodologies rely on teamwork and collaboration but also, they seek ways of working that promote critical thinking and creativity. Moreover, they are intended to assess the previous knowledge acquired.

These types of initiatives are more likely to attract attention and maintain the interest of students. Complex tasks that come close to the real context are meaningful tasks that allow the mobilization of knowledge, since they lead students to question, to recognize and reorganize relevant knowledge before it can be solved. The integration is the essential principle in the competency training. The activities for monitoring and integrating learning can take various forms, but they involve a formative evaluation. That is, it is about giving regularly feedback to students so that they can situate their current learning with respect to the expectations of the program and to their own

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development. In this way, the process of development of students' competencies and the growth of their professional self-regulation is boosted.

It is of the utmost importance to design complex activities that integrate both transversal and specific competences, which must be framed in the contents of the subjects. Teachers must evaluate and collect evidence from the evaluation of both types of competences. It is worthwhile mentioning that all the subjects are part of the curriculum and that the competences are acquired throughout it. Hence the Dynamics of Mechanical Systems subject is not the only option to develop the TC-03, but what it does is contribute to the acquisition of a part of it.

The evaluation of the CT-03 in this subject is performed through rubrics. In the evaluation rubrics several elements are differentiated:

- Three levels of mastery are defined which refer to the learning outcomes that the student must acquire at each stage.
- The indicators, which are concretions of the learning results that defines that level of domain.
- Descriptors, which define the student's behavior with respect to the indicator that is evaluated.
- An assessment scale of 4 values: D, C, B, A; which refer, respectively, to score a level of development not reached (D), in development (C), adequate (B) or excellent (A) of the competence.

The result of the evaluation will be based on the weights that the teacher assigns to each one indicators and descriptors. Each student will obtain a final A, B, C, D assessment as a result of the evaluation rubric.

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3. Implementing the TC-03 in the framework of Dynamics of Mechanical Systems

The syllabus of the Dynamics of Mechanical Systems subject taught at the Master's Degree in Mechatronics Engineering at UPV is structured in five didactic units:

1. Introduction to modeling in kinematics and machine dynamics.
   - Introduction.
   - Objectives of computational mechanics.
   - Applications.
2. Kinematic analysis of mechanisms - Vector methods.
   - Equation of the velocity/acceleration field.
   - Kinematic relations in kinematic joints.
3. Kinematic analysis of mechanisms - Analytical methods with numerical resolution.
   - Coordinate systems.
   - Constraint equations.
   - Mobility analysis.
   - Formulation of the position problem.
   - Analysis of the velocity in 2D mechanisms with various degrees of freedom.
   - Analysis of the acceleration in 2D mechanisms with various degrees of freedom.
   - The dynamic problem.
4. Dynamic Problem Types – Definitions.
   - Newton's Laws.
   - Principle of Virtual Works.
   - Principle of Virtual Powers.
   - Lagrange Equations.
   - Force analysis.
   - Motion analysis.
5. Introduction to mechanical design: SolidWorks.

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This subject is taught by professors Rubio and Llopis-Albert, which have an extensive experience in this field, as shown for instance in Llopis-Albert et al., 2015; 2018; 2019; 2019a; 2020; 2020a; Rubio et al., 2015; 2016; 2019; 2019a; and Valero et al., 2017; 2019; 2019a.

As stated, the CT-03 is implemented using technical computing systems, while it provides a way to develop students' engineering capabilities. The software used to work this transversal competence is Wolfram Mathematica, which is a technical computing system; and SolidWorks, which is a solid modeling computer-aided design (CAD) and computer-aided engineering (CAE) computer program.

The evaluation will be carried out through two objective tests with multiple choices, mark of three academic works, and oral presentations in classroom of the work done during the course (Table 1). These tests are focused on aspects that have been detected as critical in the evaluation of the students. The contents and the level of the tests are adapted for students of a master's degree. Regarding the academic works the students are intended to solve the kinematics and dynamics of a mechanism subject to external forces using the software Wolfram Mathematica, and to model it using SolidWorks. For instance, a certain mechanism from the series of books of Artobolevski (1975) are assigned to the students (Fig. 1). In SolidWorks they must design all pieces, provide the assembly model, the dimensioned drawings, a motion study, and a finite element analysis (Fig 2). The academic work related to the resolution of the dynamics of a mechanism and the modelling using SolidWorks are carried out individually by each student, while the academic work related to the kinematics of a mechanism is performed in groups of two. In addition, a second-chance exam will be performed.

Table 1. Evaluation system.

Description	***Number of acts***	***Weight (%)***
Objective tests (multiple choice)	2	40
Academic work	2	30
Co-evaluation	1	7,5
Case	1	15
Portfolio	1	7,5

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A co-evaluation procedure has also been implemented in the evaluation system, which is carried out among students based on predefined criteria. The performance and quality of the three academic works are evaluated by the classmates, as well as the level of achievement in relation to the learning objectives. The co-evaluation procedure has several advantages from both the teachers and student's perspective. For teacher's point of view, co-evaluation can save time, while students learn to value the processes and performance of their peers. In addition, responsibility is encouraged, students understand the peculiarities of an evaluation process, collaborative work is favored, they develop skills for analysis, and it represents an opportunity to share learning strategies together. Moreover, a double benefit is obtained, since on the one hand feedback is given to the partner who is being evaluated, but simultaneously the evaluated student will obtain feedback from her own work. In this sense, the professional and ethical commitment of the students is encouraged and worked in this subject. Moreover, they are related to other transversal competences as defined at UPV (TC-07). In short, co-evaluation leads to obtain cognitive gains and favor the achievement of Bloom's taxonomy of educational objectives, which is a set of three hierarchical models employed to classify learning objectives into levels of complexity (Bloom, 1956).

With the oral presentations and written reports, the TC-08 is also worked, since the effective communication both orally and written is confronted in front of an audience. By means of the academic work performed in groups of two the TC-06 is dealt, which is related to teamwork and leadership.

As a result, several TC are worked, although in the curricula of the Master's Degree in Mechatronics Engineering at UPV for the subject Dynamics of Mechanical Systems only the CT-03 is mandatory to be assessed.

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1359 Artobolevski's mechanism.nb - Wolfram Mathematica 12.1

Archivo Edición Insertar Formato Celda Gráficos Evaluación Paletas Ventana Ayuda

```
In[75]:= ClearAll;
          borra todo

1. Variable definition

In[76]:= q = {x[1], y[1], x[2], y[2], theta[2], x[3], y[3], theta[3], theta[1]};
         qp = {xp[1], yp[1], xp[2], yp[2], thetap[2], xp[3], yp[3], thetap[3], thetap[1]};
         q2p = {x2p[1], y2p[1], x2p[2], y2p[2], theta2p[2], x2p[3], y2p[3], theta2p[3], theta2p[1]};

2. Constraint equations

phi = {x[1] - L1 / 2 * Cos[theta[1]],
                        coseno
   y[1] - L1 * Sin[theta[1]] / 2,
                seno
   BE * Cos[theta[2]] + L1 * Cos[theta[1]] / 2 - x[2] + x[1],
        coseno              coseno
   BE * Sin[theta[2]] + L1 * Sin[theta[1]] / 2 - y[2] + y[1],
        seno                seno
   x[3] - AC,
   y[3],
   theta[3] - theta[2],

   -y[2] * Cos[theta[3]] - (AC - x[2]) * Sin[theta[3]]
           coseno                        seno
  };

In[80]:= Phiq = D[phi, {q}]
              deriva
```

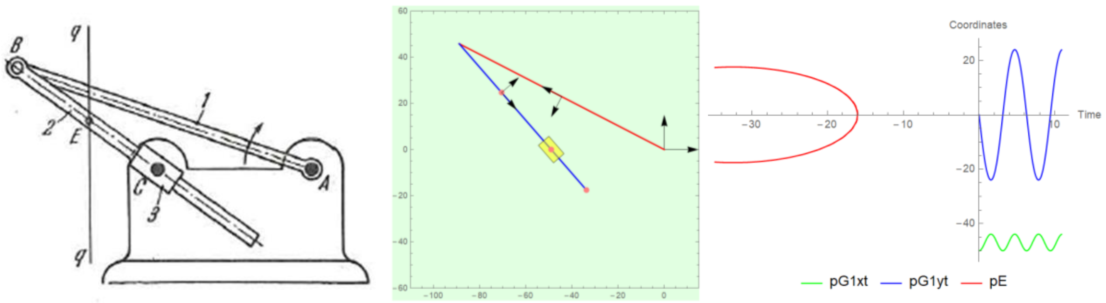

Figure 1. Kinematics resolution using Wolfram Mathematica of the four-bar link-gear conchoidal approximate straight-line mechanism, which correspond to the 1359 Artobolevski's mechanism.

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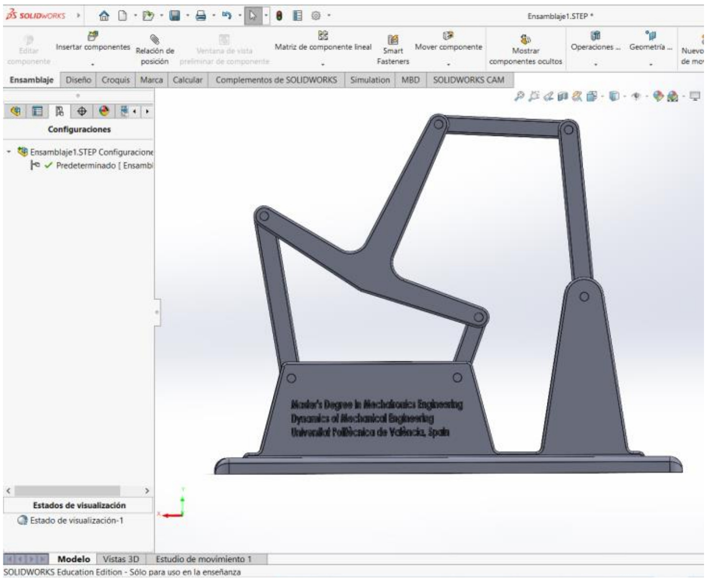

Figure 2. SolidWorks assembly of an Artobolevski's mechanism.

4. Results and discussion

There are 37 students enrolled in the subject of Dynamics of Mechanical Systems belonging to the Master's Degree in Mechatronics 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 the activities. Regarding the activities related to TC-03, all students but one have passed the objective tests. Furthermore, most of them reached a high grade in the exam (with an average of 7.1 on a scale of 1 to 10), since the questions were widely addressed in classroom. Although the academic works were less guided activities and student should work autonomously, they did them correctly. As aspects to improve for the next academic year, it is proposed, on the one hand, to better fit in the calendar the different installments of the academic works, taking into account the workload of the students and, on the other hand, the elaboration of improved 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 objective tests, and the final grade for the subject.

4. Conclusions

This paper presents a teaching innovation project based on applying technical computing systems to evaluate the transversal competence of the UPV TC-03. Furthermore, the use of technical computing systems has been proven to be a valid tool to improve both the students' performance in a mechanical engineering subject, and also, their level of satisfaction. Results have shown an excellent pass rate and a high correlation among the evaluation of academic works, the objective tests, 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 rubrics for the evaluation.

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