COMBINING CDIO AND CASE STUDY METHODOLOGIES IN FLIPPED CLASSROOM STRATEGIES

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ABSTRACT

Case Study methodology has been successfully applied in many teaching areas, as business administration, economics, law or medicine, where the implementation and operation of different solution alternatives is risky and/or expensive. It is an excellent tool for allowing students to experience real life problems, with no explicit questions and subjected to multidisciplinary restraints, letting them theoretically test different solutions through the teacher assistance. Furthermore, student activities associated to this teaching methodology (teamwork, creativity, multidisciplinary work, self-learning, class participation, presentations, etc.) greatly foster the acquisition of transversal competences, which can be enhanced through the simultaneous use of other teaching strategies as flipped classroom or gamification. A clear parallelism between the learning objectives and outcomes can be observed between case study and CDIO teaching methodologies. However, case studies usually focus on the “C”, “D” and sometimes “I” phases, rarely executing the “O” phase because of the reasons described above.

We think that case study methodology can be fully (that is, including the “O” phase) and successfully applied as component of the CDIO methodology for the teaching of specific engineering concepts and methodologies, improving the teaching outcomes reached by the students, especially those related to the acquisition of theoretical knowledge and methodologies. The use of rapid prototyping techniques allowing to develop demonstrators, in combination with the development of additional teaching and learning resources, as online tests, non-supervised study documentation, teaching guides and case texts, allows for the full integration of the case study and CDIO methodologies, taking also advantage of flipped classroom techniques, which in turn allocates more time for the discussion of alternatives in class, by transferring the teaching of theoretical concepts to out of class student activities.

We have tested this hypothesis in our “Machine Element Design” and “Vibrations in Machinery” courses. In this work, we will describe the full methodology, give examples of the demonstrators and teaching resources developed, and describe our particular thoughts about the implementation and outcomes of this combined methodology.

KEYWORDS

Case study, flipped classroom, rapid prototyping, mechanical engineering, standards: 7, 8, 10.

INTRODUCTION

In fields as computer science or electronics, the huge advances carried out during the last decades have given rise to powerful standard solutions, systems and components, with very low cost and size, and manufactured in enormous volumes. In mechanical engineering, however, the components handled have sizes, weights and costs several orders of magnitude bigger. This forces mechanical engineers to optimize weight and costs. Furthermore, due to a substantially lower level of standardization, several working principles are usually available for the same problem, which forces to complex decision making processes based on the evaluation of alternatives as a function of parameters associated to product lifecycle and the particular problem restraints. In addition, and due also to the lower standardization level, working principles must be adapted to the particular problem, which also means a complex design exercise. All the aforementioned environment implies the continuous use of creativity, problem solving, teamwork, lifelong self-learning and continuous improvement skills, which must consequently be cultivated in the mechanical engineering students.

In our experience teaching different full-course CDIO graduate subjects as “Engineering Design” or “Bioengineering” (Munoz-Guijosa 2016), (Chacón 2015), (Díaz 2013), we have realized that students, normally coming from an Industrial Technologies Engineering degree, show deep theoretical knowledge about mechanics, physics, electrical engineering and electronics. However, they are not so skilled in the application of those theoretical knowledge to real life design problems which imply a global view of the machine, as materials selection, mechanical couplings design, estimation of complex stress states, combination of different energy fields, or application of dynamic design criteria as fatigue, manufacturability, ergonomics or safety.

In our opinion, case study methodology may be a potentially effective tool to mitigate this weakness. The application of this methodology in specialized undergraduate and graduate subjects as “Machine Elements Design”, “Machinery Vibrations” or “Tribology” allows for a reduction of the time devoted to lectures by letting the student self-learn the theoretical knowledge. The available class time is then used for the application of problem solving methodologies in the mechanical design.

Usually, case studies are employed in medicine, law or business education (Edenhammar 2017) (Tripathy 2009) (Jain 2005). A problematic situation is deeply, quantitatively and precisely described, and a solution proposal -arising from the evaluation of different alternatives- as well as an implementation strategy are requested to the students. Obviously, implementation and operation of different solution alternatives is risky and/or expensive in the aforementioned fields, so case studies typically focus on the “C”, “D” and “I” stages of the CDIO process, rarely achieving the “O” one.

The Case Study Method has already been implemented in Engineering courses and Mechanical Engineering courses specifically. Whereas some authors (Runeson and Höst, 2009) put their focus on the actual implementation and creation of engaging and knowledge-wise rich Cases of Study as well as their correct assessment regarding individual and team-based skills; others (Yadav et al., 2010) have evaluated the actual impact of this methodology on Mechanical Engineering undergraduate students. The results of this implementation clearly show that students undergoing Case Study methodologies presented a higher level of attention and engagement on the problem posed while retaining the same level of understanding versus students following a classical lecture-based approach. Nonetheless, the benefits of the Case Study Method include, but not limit to the aforementioned perks. Authors (Raju and Sankar, 1999) have reported that students highly preferred a Case Study Method-based course than a traditional lecture-based, as they helped them develop their communication assets and gave them an option to apply the knowledge learned in the course. However, this methodology lacks in laboratory experiences and field work from the students, so the conclusions about the use of the case study methodology are similar to those arisen in law, medicine or business education.

However, the use of rapid prototyping technologies may allow for the execution of the “O” phase due to the substantial cost and time reduction achievable in the manufacturing of simple test benches, test coupons or mechanisms. For instance, machinery elements as springs or couplings can be rapidly obtained after a design phase, so a testing procedure can be performed in class. Similar exercises can be carried out with friction bearings or rotating disks. The successful use of case study methodologies integrated in a CDIO process could then achieve the double goal of maximizing the theoretical knowledge acquisition as well as developing the specified professional skills. Furthermore, if correctly designed, case studies can be used in different subjects by simply focusing the problem in a different way. The use of case study methodologies implies also an important teacher activity, which can trigger substantial improvements in his/her teaching style and qualify for a better teaching of full-course CDIO subjects. The CDIO standards provide a methodology foundation to be complemented with other assessment instruments. This CDIO methodology approach, combined with Case Study Method and rapid prototyping technologies, may provide the student the laboratory experience, field work and manufacturing know-how required to excel at Mechanical and Machinery Design.

REQUISITES FOR THE INTEGRATION OF CDIO AND CASE STUDY METHODOLOGIES FOR THE TEACHING OF SPECIFIC KNOWLEDGES IN TIME-RESTRAINED MECHANICAL ENGINEERING COURSES

Mechanical engineering graduate and undergraduate specialization courses have some particularities, which should be observed in order to design good case study based resources. Firstly, numerous different concepts, based on a substantially hard theoretical body of knowledge must be taught in each subject. For instance, “Machinery Vibrations” is composed of 17 sections, covering from Fourier Transform basics to vibrations in nonlinear systems and numerical methods for vibrations. “Machinery Elements Design” covers the knowledge needed for the design of a vast variety of elements, from brakes to clutches, chain-sprocket systems, or epicyclical gear trains. Whereas the acquisition of the theoretical body of knowledge must be ensured, a wide, problem solving skillset is also expected to be acquired by students. This is difficult due to the limited time available (typically 4 to 6 ECTS). The implementation of an effective case study methodology must ensure the fulfillment of both goals simultaneously. Consequently, in order to establish a methodology that can be successfully applied in practice, following considerations should be taken into account:

Need of implementation of a previously defined solution

The main goal of a full CDIO subject is the acquisition of the planned hard and professional skills through the living of a complete design experience. This does not mean that the final design level reached is the one initially planned by teachers or industry experts, with a considerable experience in design. Despite we do not have quantitative evidences about -yet-, we have realized in our 5 years of experience teaching CDIO courses that the acquisition of the desired skills is uncoupled with the design level finally reached. Excessive teacher interference in the students’ work related to design improvement proposals frequently reduces the student intellectual activity, mainly related to analysis, creativity and working principles selection, and consequently also reduces the level of acquisition of the desired skills. Errors are excellent triggers for learning and skills acquisition. Obviously, teachers must maximize the acquisition of the desired skills by allowing errors, but simultaneously must minimize the associated economical cost. In a full CDIO subject, usually with a 12 ECTS (full course) size, this strategy can be executed if teachers have enough experience. However, for teaching specialized knowledge in shorter mechanical design courses (usually 4 to 6 ECTS), where numerous, different issues must be addressed, and certain time is assigned in advance to each of them, the aforementioned strategy cannot be applied. If a CDIO methodology is desired for teaching such kind of specialized knowledge, a well-defined design goal must be established, to which students can be guided by the teachers.

Need of teachers skilled in innovative teaching methodologies

For a successful application of the CDIO or case study methodologies, teachers must be able to control unexpected class situations, associated to the confrontation to an open question, where multiple solutions exist. Teachers must also be able to guide the class to that solution previously planned, minimizing the interference with the students intellectual activity. This implies a proficiency in interpersonal skills, as well as previous experience in complete CDIO courses. Additional resources must be created if teachers lack of these characteristics.

Need of avoiding student specialization due to work-sharing

In full CDIO subjects, where complex, multidisciplinary, open problems are faced, groups of 6-8 students are usually formed. Due to the problem complexity, students spontaneously organize, defining work packages and distributing them across the team. While this specialization is advantageous in full CDIO subjects, it may not be desired in shorter subjects where very specific concepts or methodologies are expected to be acquired by all the students.

Need for the planning of the student out-of-class activity and student learning self-assessment

Case study methodology allows for reducing the time devoted to lectures by forcing the student to self-learning it out of class. However, due to the lecture time reduction, the number of questions posed by the students about the theoretical knowledge to be learned is expected to decrease, as well as the number of different methodological strategies used by teachers in lectures, as particular examples, different approaches for explaining the same concept, questioning students in class, etc. As the deep acquisition of the knowledge must be assessed in any case, additional resources must be created to assist the self-learning and the assessment of the degree of learning. These resources can consist on tests about theoretical concepts, simple numerical exercises, multimedia content, simulators, virtual labs, etc.

Cases may be designed so that they can be used in different subjects

In order to maximize the acquisition of problem solving skills, a special effort should be done for the case to have sufficient complexity and cover multiple knowledge areas. Succeeding in this goal opens a wide field of applications of each case developed. Table 1 shows an example for the use of different cases in different subjects.

Table 1. Example of use of different cases for different subjects

Cases		Subjects				
		Vibrations in machinery	**Tribology**	**Machine elements design**	**Engineering design**	**Machinery maintenance**
	Case 1: failure of a combine harvester speed reducer		Oil selection Wear rate estimation	Bearing design Gear design		Maintenance strategy
	Case 2: failure of a ski station cableway	Dynamic amplification factor Dynamic systems modelling			Redesign process	
	Case 3: excessive vibrations in a steam turbine	Rotordynamics modelling Campbell diagram Flexible rotor balancing	Hydrodynamic bearing behavior in non-nominal conditions	Bearings, seals and couplings		Predictive maintenance models
	Case 4: acceleration system for a suburban train	Dynamic systems modelling		Spring design	Concept design	
	Case 5: package design for a desktop printer	Free vibration Shock analysis			Concept design	

Cases must fulfill some requisites in order to allow for an effective learning process

As (Shapiro 2014), (Herreid 1997), (Danziger) have magnificently explained, some rules must be followed in order to achieve student excitement and attention. Storytelling is an effective tool for that, as can be seen from very young aged children. Furthermore, stories evoke feelings, so student empathy can be triggered in order to assume the real situation. A main character is then needed in the story, as well as quotes of his/her thoughts. In addition, the case must inspire students and motivate them to carry out the required problem solving process. For that, an interesting issue, involving a real situation, with a considerable challenge (for instance, high repair cost or lost profit, many possible alternatives, high technology involved…) must be used, better if it develops in a well-known environment -for instance, a multinational company-. This evidences the importance of the industrial and/or technological services experience in the teacher curriculum. A good case must also induce contradictions and force trade-offs, so that the problem solving process can be correctly performed by the students. Finally, case must force a decision making activity, which is an essential part of the problem solving process. The decision must be based in a wide alternative synthesis work, followed by a careful alternative evaluation based on relevant criteria.

Teacher personality and character are crucial for the class session (Bayona 2017), as a lead role is needed in order to correctly manage time, conduct discussions, highlight correct points of view, encourage participation, etc. Practice is the most important tool for achieving this. However, teaching guides can be written in order to assist less experienced teachers in the preparation of the class sessions.

PROPOSED METHODOLOGY

As Figure 1 depicts, the proposed Case Study-CDIO combined approach establishes two separate activities: out of class and class work. During the out of class work stage, students are expected to carry out individual study of the theoretical content -whose learning can be evaluated by means of self-assessment activities- and a subsequent teamwork in order to prepare the case discussion to be performed later in class. Certain freedom is given to the students to organize the groups. Resources for the individual work have been developed (see next section), as graphical handbooks, Matlab simulators, excel tables, videos and problem collections. For the evaluation, several Kahoot! tests have also been created. The case is also available to the students since the beginning of the course, so they can prepare it anytime.
During the class, each team will explain their solution and hold their arguments and reasoning behind their thought process, with the teacher serving the role of a moderator. In order to check the acquisition of the theoretical content, additional Kahoot! tests have been developed so that they can be done at the beginning of the class. After the case discussion, a design alternative will be decided. A prototype of this alternative will be manufactured and tested with the available lab facilities and testing devices (see next section).

SOME APPLICATION EXAMPLES

Spring design

A case has been written for encouraging the students design a spiral spring for increasing the acceleration of a three-car train. The train has initially just one electrical motor, located at the first car, so adherent mass is not enough to reach the target acceleration. The installation of additional electrical motors in the remaining cars is not possible due to size restrictions, even though this solution could be implemented with a redesign of the car, with a reduction of the number of passengers transported. Consequently, the cost of the springs must not be greater than that corresponding to the electrical motors solution. As a trade-off between energy stored in the springs and spring weight (that is, cost) and service life (that is, maintenance cost), spring materials, spring shape and stress level must be optimized. Mechanical connections, transmission and required electronic regulation are also to be designed, so this multidisciplinary problem can be taught in subjects as “machinery elements design”, “machinery maintenance”, “dynamic systems simulation” or “Systems control”. Figure 2 shows an excerpt of the case, where annexes corresponding to the results of fatigue testing of carbon fiber composites and a table showing the transient calculation of the acceleration with certain spring are shown. In order to check the spring design validity, a PLA scaled prototype must be designed and tested in a simple device created for that purpose, as Figure 3 shows. Students can manufacture the spring prototype with any 3D printers available at the lab. For the spring design, the PLA stiffness and allowable stress must be available. Simple specimen testing can be carried out in order to calculate these parameters. In order to prepare the case, different support resources have been developed for the students, as a Kahoot! 20-questions test and a tool for the calculation of the transient acceleration as well as the system parameters, which allow students to test different spring designs.

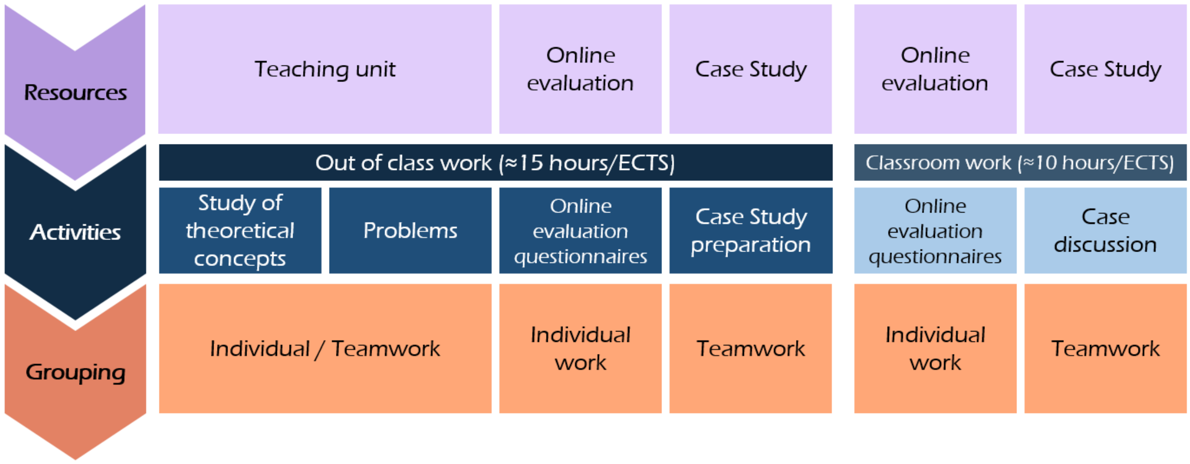

Figure 1. Proposed methodology, including resources, student activities and grouping.

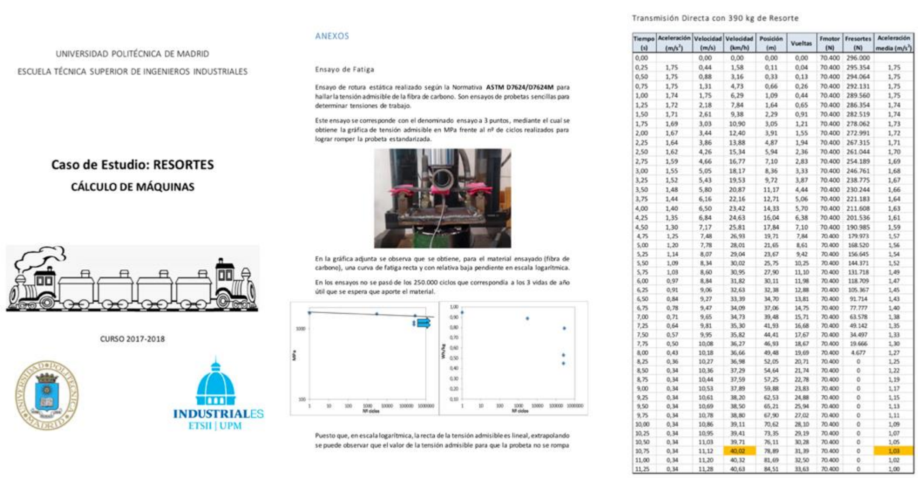

Figure 2. Excerpts from the case “Spring design for acceleration increase”.

Figure 3. Prototype spring testing device.

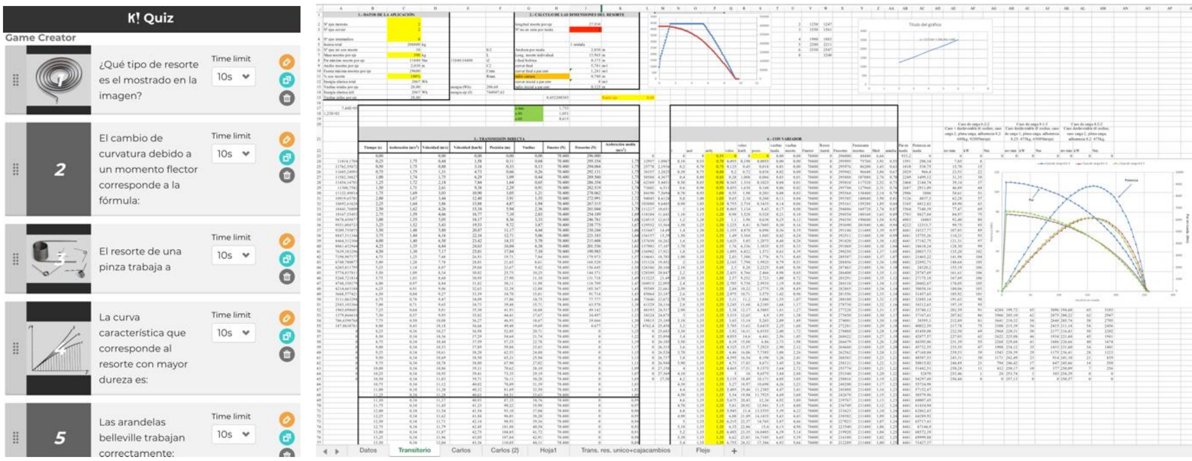

Figure 4. Self-evaluation test about spring design in Kahoot! application and helping tool for the calculation of the system transient parameters.

Vibration analysis/Design focused on vibrations

A case related to machinery failure detection by means of its vibration signature is used in the "Vibrations in Machinery" subject. It is related to a real life problem, in which a steam turbine catastrophic failure causes were analyzed by some of the Machinery Engineering Division teachers. The failure was related to rotor-stator rub due to a combination of unbalance and misalignment. A simple rotating machinery vibration simulator is used (Figure 5) to reproduce a rub and measure the vibration signal by means of a proximitor. Rotor balancing is subsequently carried out. A modal balancing spreadsheet has also been developed.

Figure 5. Rotating machinery vibration simulator.

Machinery failure analysis

A case related to the failure of a worm gear used in an elevator machinery was also prepared (Figure 6a). Some teachers of the UPM Machinery Engineering Division were involved in the failure analysis. The failure was related to an incorrect selection of the lubricant. Students must analyze the working parameters, from which the contact forces and relative speeds can be obtained. A thermoelastohydrodynamic model is then used in order to determine the operation temperatures and oil film thickness, which allows for the determination of the wear rate. The same operation can be carried out by testing different lubricants in order to select an appropriate one. The case is designed in such a way that students are conducted to the selection of a lubricant which cannot be finally used because of non-technical reasons (use of other lubricant in a different machine family).

Finally, students can check the real machine operation in a machine prepared in our lab for this purpose (Figure 6b). Surface roughness in elements operated with the correct and incorrect lubricants can also be checked by means of a surface roughness tester or a confocal microscope also available at the lab.

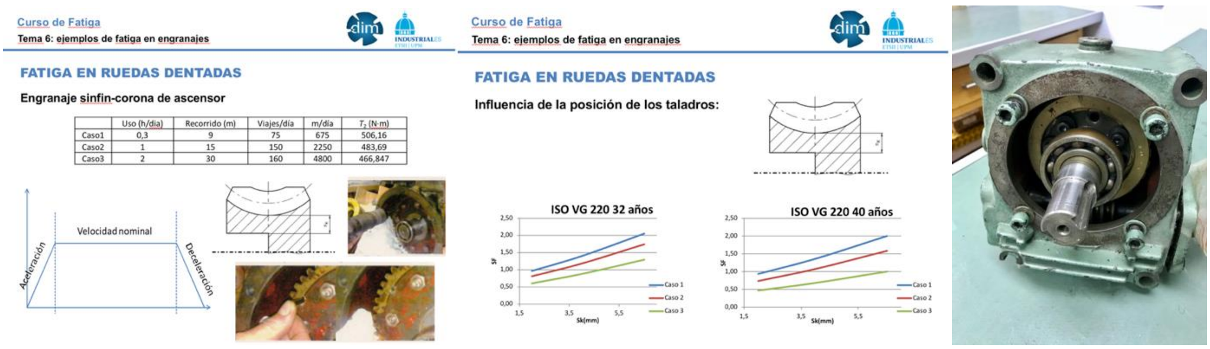

Figure 6. a) Case study, machinery wear failure. b) real machine in the laboratory.

Packaging design

A case has been written to encourage students design the packaging of a desktop printer, in the framework of the teaching of “1 degree of freedom systems” in the “Theory of Machines and Mechanisms” subject. Students must select the packaging material, thickness and surface in order to protect the printer from a free fall from 1,8 meters, corresponding to a nominal potential failure during the warehouse handling. Students are given a list of allowable materials (as bubble paper, PS foam, corrugated cardboard, folded paper, etc.). Students must perform simple tests to obtain the material stiffness and damping ratio as a function of its thickness. A mobile phone accelerometer is used for this purpose. A trade-off between stiffness (reducing maximum acceleration but increasing packaging deformation) and damping (reducing packaging deformation but increasing maximum acceleration) must be found. In addition to the case, Kahoot! tests, simple problems for autonomous study and a Simulink tool (Figure 7) for the simulation of the transient behavior have been created. In graduate subjects with a high number of students enrolled, the case study methodology may not be applied, substituting the class play with an individual or group work aimed to the design. Teacher can perform the stiffness and damping estimation in class, or encourage students to do it by themselves.

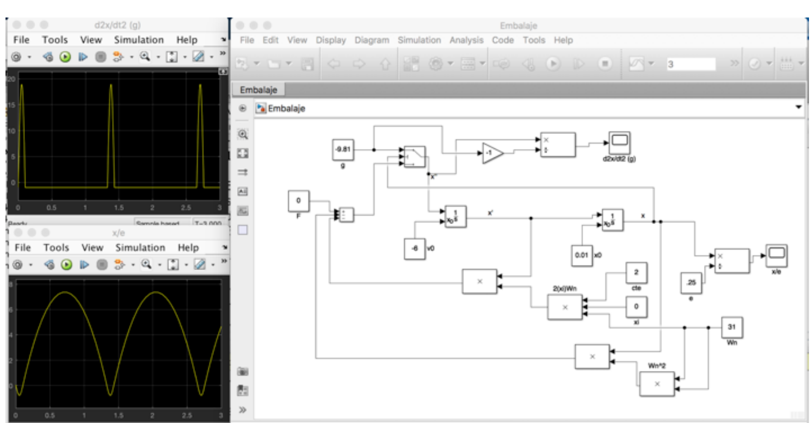

Figure 7. Simulink tool for the testing of different packaging design solutions.

CONCLUSIONS

The implementation of a combined CDIO-case study methodology allows for improvements in the quality and effectivity of the teaching-learning process:

- The acquisition of knowledge and skills related to the application of theoretical knowledge to complex integration problems in mechanical engineering, as the number of open problems solved by the students is increased.
- As a result, the acquisition level of the theoretical knowledge is increased, as students are required to a higher level of self-learning and teacher advising.
- Teachers have a better control of the student out-of-class activities, provided that information about self-assessment tests is available.
- Student motivation is improved through the inherent competition environment and the manufacturing of test setups arisen from their design work.
- Teacher motivation and skills are also improved, provided the need of managing the class discussions arisen.

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