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A learning environment to stimulate the development of competencies for mechanical design

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ABSTRACT: The objective of the research discussed in this article was to identify the educational and technological factors that favourably affect the learning of mechanical design by engineering students. A Web site was created to assemble educational materials; namely, notes, videos, widgets and on-line examinations. To study its effect, a qualitative exploratory research case methodology was followed. The impact of technological factors was assessed, viz. ICT management, connectivity and usability; and educational factors assessed included use of real situations, creative thinking, collaborative work. A final competency assessment was made. It was found that this combination improves the speed of calculation, promotes the optimisation of the designs, takes the cognitive process to higher levels in the development of disciplinary and transversal competencies and increases the interest of the student in mechanical design.

Keywords: Engineering learning environments, competency-based learning, challenge-based learning, mechanical design, higher education

INTRODUCTION

In the 21st Century, the greatest challenge in history facing the discipline of engineering is to sustain civilisation while the population grows and resources are depleted. The National Academy of Engineering (NAE) in Washington D.C., has published since 2008 a list of the main challenges for engineering in the 21st Century. These include the generation of renewable clean energy, access to potable water, advances in computer science, and the design of tools to support scientific development and personalised learning [1].

These challenges bring the necessity to apply new approaches to the training of engineers. In this context, universities must adapt and evolve, change their educational models, incorporate digital technologies and accept there are no borders in a global world. One of the most recognised and accepted tendencies is education by competencies [2]. Competency-based university education integrates the knowledge and processes of a discipline with the attitudes and values that make it possible to be a participative professional [3].

When it comes to the learning of engineering, this approach is particularly valuable because it focuses on the student and their command of these competencies. This assures a learning based not just on knowledge but also on the ability to apply knowledge. It helps students to understand what is expected of them and promotes self-management of learning and flexibility. It allows employers to know if a candidate matches their needs [3][4].

Among the most important engineering competencies is design, which is a highly iterative and creative problem-solving process. The design engineer's abilities in terms of creativity and problem-solving skills are linked to knowledge of technology and its principles [5]. Design in mechanical engineering is the process of giving shape, dimensions, materials and technology to a machine, and this normally involves all the areas of this discipline [6]. Although when the design of machines or machine components is mentioned it refers to conceiving the mechanical, electrical and hydraulic elements that make up a machine.

A useful educational approach to the acquisition of mechanical design competencies is challenge-based learning. In this practical problem-solving approach, the student works collaboratively with peers, professors and experts to solve challenging engineering problems. This promotes a more profound knowledge of the thematic contents of design [7]. Students are confronted with situations that demand real solutions. The use of ICT tools and the pedagogical approach based on challenges greatly facilitates the learning of design methodologies and the acquisition of new knowledge.

One of the fundamental reasons for the development of computers and the advancement of the digital age is the need to expedite calculations of complex equations, and the need for continuous consulting of data, tables and graphs that engineering requires [8][9]. With respect to the matter of ICT support for the learning of mechanical design, there are few didactic options. Apple and Android systems have applications that illustrate in an elementary way the factors of basic mechanics for gear sets or pulley transmissions. But, these do not involve the integration of a design process, per se. On the other hand, there are some applications (apps) for sale at a professional level that are directed to the selection of machine components from the manufacturer with details of operation and installation.

These apps are not specifically didactic, nor do they seek to explain design or operation. They only allow a choice of a machine item from a vendor under specific conditions and nothing else. There exists also professional software, such as SolidWorks, Ansys or KISSsoft which, despite their calculating power, are not much of a didactic aid for learning the design of machine elements.

For the creation of effective didactic design tools, *Mathematica* software deserves special mention. It has great capacity for numerical and symbolic calculation with image processing. It is also a powerful programming language with widespread use in the fields of physical-mathematical sciences and engineering [10]. Also, calculation widgets can be created using the Wolfram development platform (WDP), i.e. content apps that run on a Web page [11]. These can be backed up in the Wolfram cloud. From there, the widgets can be accessed on the World Wide Web using their URL.

Free-access educational resources (REA) are digital materials (widgets, apps and Web sites) that are in the public domain of the Internet and allow free use for learning. They are important in the academic field of engineering for the promotion of free and democratic access to knowledge by teachers, researchers and students [12]. The REAs are digital repositories of files and tools dedicated to sharing knowledge over the Web. The REAs are revolutionising the academic world through their availability to a greater number of people. Thus, engineering education needs to provide a broader educational alternative for today's society.

METHOD

A case study was included in this research. A group of students of engineering at a university was the subject of an investigation of the effect of an enriched learning environment on the development on mechanical design learning [13]. A repository of mechanical design material was available on an open-access Web site. It consisted of four thematic sections corresponding to the principle themes of design, viz.:

a) Gear transmissions;
b) Belt transmissions;
c) Chain transmissions;
d) Selection of bearings.

Provided on this site was a variety of educational materials, including theoretical summaries, videos, calculation widgets and on-line examinations, to support the learning of mechanical design. Figure 1 shows the learning environment. The taxonomy of Marzano and Kendall was used as a frame of reference to explain the cognitive progression of the learning trajectory through mechanical design (declarative and procedural) to a superior level that implies the use of acquired knowledge in specific situations of decision making and problem solving related to mechanical transmissions [14].

For the evaluation of the impact of these resources on the learning of mechanical design, a qualitative exploratory research methodology was chosen [15]. The research was based on a descriptive case study focused on a group of engineering students in a rich learning environment for the development of competencies in mechanical design and how this affects learning [16][17]. The indicators observed and measured were favourable to learning design beginning with the analysis of the effectiveness of the educational resources and the pedagogical approach. They were exploratory, both in the findings and in the conclusions.

The population studied were students who took the course *Machine Design and Development* during the semester August-December (AD) of 2017. For several local administrative reasons, the population was a single group of 20 students, men and women, aged between 18 and 22, who attended the 7th or 8th semester of engineering in automotive design, electrical mechanics and mechatronics.

To identify the factors that favourably influence the learning of mechanical design, two procedures of collection and interpretation of data were established [15]:

a) Self-directed, individual questionnaires with mainly closed, multiple-choice questions but with several open-ended questions. These surveys covered two factors: namely, the technological and educational factors that affected the learning process.
b) Tests of knowledge of each of the mechanical components, a final examination of the course material and rubrics for the development of disciplinary and transversal competencies [18] in mechanical design engineering.

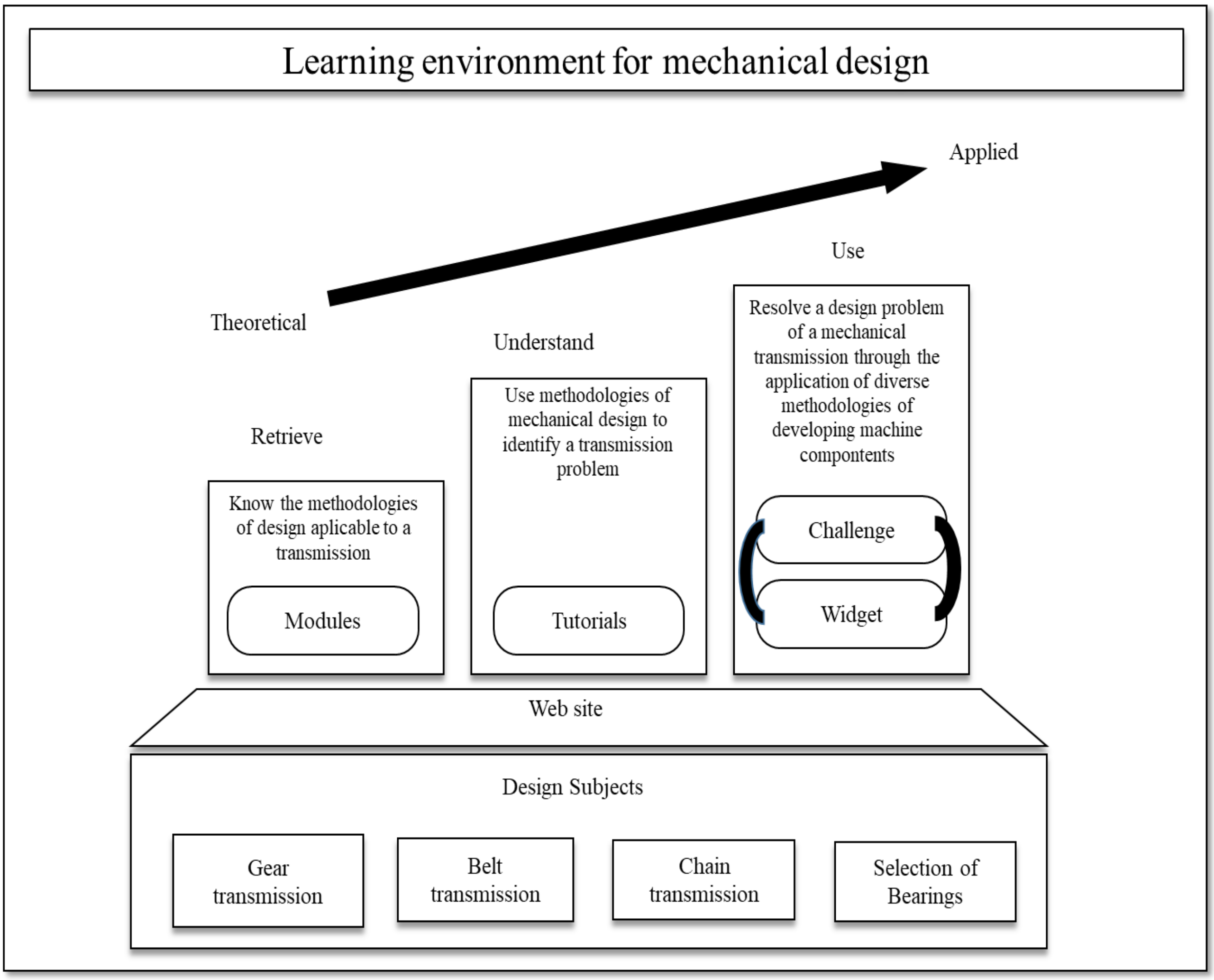

Figure 1: Learning environment.

RESULTS

The learning environment is structured around a Web site (https://aprendisenomec.weebly.com) as a repository of educational resources for design learning:

a) description of the Web site;
b) the use of the Web site in mechanical design;
c) description of the machine elements for analysis;
d) references to the authors;
e) contacts page.

The contents of each of the thematic sections of the site were:

a) Modules to provide the theoretical background and the bases for the corresponding calculations, class notes in digital format, a pair of comprehension exercises linked to the *Nearpod* platform to do in class, various videos and links of interest.
b) Tutorial section of short videos prepared by the authors in Mix format, with the instructions on how to use the class material to perform step-by-step the complete calculations of the transmission in question.
c) Challenge section describes a problem in design that needs to be solved, with a scenario and the instructions for its development and documentation.
d) Webapp section has a digital on-line calculator - a widget of *Mathematica* that allows the student to design the machine elements set out by the Challenge and that later would be used for homework, examinations and other class exercises. The mechanical calculation widgets were programmed in *Mathematica* and stored in the Wolfram cloud in the .wdp format. The widgets could be accessed via the Internet using the URL of the widget.
e) Quiz, a summative evaluation built on the *Schoology* platform that permits the student to verify their learning.

As mentioned above, the results were divid*ed* into two factors of influence, and their evaluation corresponded to the student's perception of the effect they had on their learning of mechanical design. Figures 2 and 3 summarise students' views on the technological and educational factors that helped them learn more and/or better.

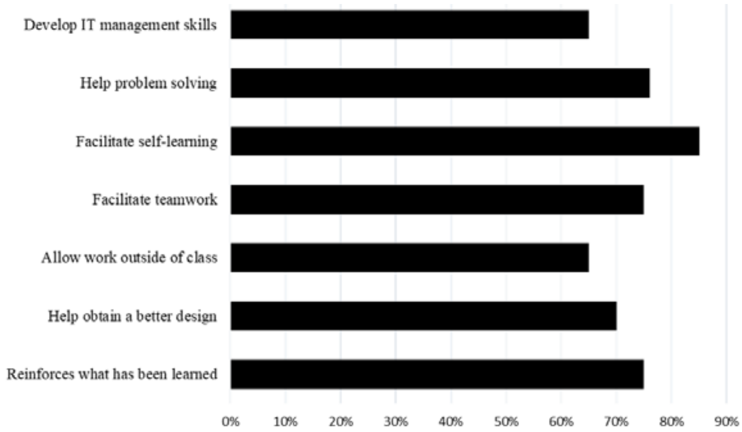

Figure 2: Technological factors.

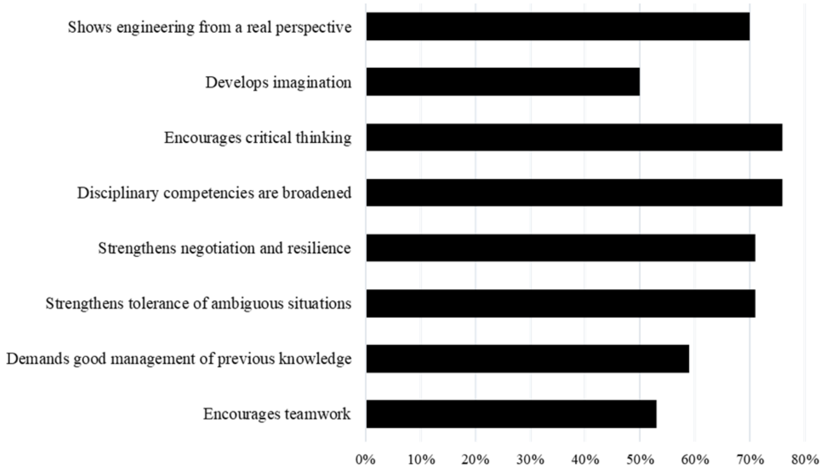

Figure 3: Educational factors.

Tables 1 and 2, as well as Figure 4, show the results of the summative evaluations, the final examination and the final rubric for the development of competencies. More information may be found in Vargas-Mendoza et al [18].

Table 1: Final grades of the semester of evaluation (2017-AD) with the previous three semesters.

Subject		2017-AD	2017-JM	2016-AD	2016-JM
Gears	Average	80	71	84	87
	Median	79	70	80	90
Belts	Average	79	93	89	(*)
	Median	85	95	100	(*)
Chains	Average	75	(*)	91	84
	Median	70	(*)	95	85
Bearings	Average	84	(*)	85	100
	Median	92	(*)	76	100
Final average**		94.12	87.02	88.73	79.32

p = average; m = mode; (*) = the subject was not evaluated in an independent manner
AD = semester August - December; JM = semester January – March;
**The final average was generated based on the individual topic grades (45%), the entire semester design project (15%), the written final examination (25%) a one-week *impromptu* project (5%), and others

Table 2: Results of the final evaluation of competencies in the mechanical design (disciplinary) and engineering (transversal) material. The numerical values correspond to the levels of medium-superior command of material (3 = analysing) and higher (4 = using knowledge) on a Marzano scale [14].

Competency	Design of gears	Design of belts	Design of chains	Selection of bearings	Problem solving	Critical thinking	Teamwork	Management of IT
Key	D1	D2	D3	D4	T1	T2	T3	T4
Expected value	4	4	4	4	4	4	3	3
Measured value	3	3	3	4	4	3	3	3

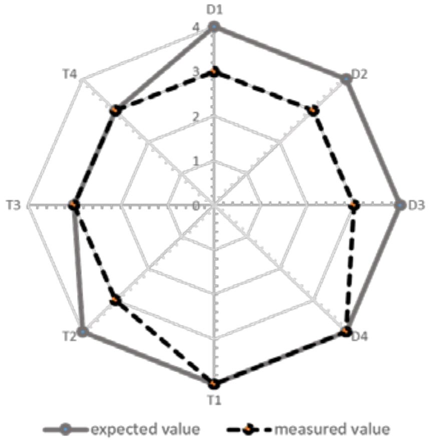

Figure 4: Radar of final evaluation of the development of mechanical design competencies (D) and the transversals of engineering (T).

Student Perceptions

As reported in Figure 2, in general, students perceive in a positive way the use of all the technological resources of the Web site as tools to help to learn mechanical design, especially the widgets. They recognise the worth of the Web site resources in aspects, such as obtaining a good design, improving it through iteration processes that would otherwise take too long, helping in the processes of problem solving, reinforcing what was learned in class and the support for self-teaching. [18].

Surprisingly, to the question about the computational resource most used to solve the designs, 85 percent responded that they preferred the personal computer to the mobile devices, arguing the ease of reading and operation of these compared to the small screens and keyboards of the tablets and phones. This highlights an important inconvenience of using the latter devices considering the care that is required in managing the tables and the reading of the graphics inherent in the required computations. This finding is consistent with the results of previous research work confirming that there are some operational difficulties when using mobile learning for engineering that require reading minuscule text/figures, constant interaction with the device and great care in the calculations [19].

To the final question in this section, *Do you think using the technology resources from your mobile device somehow favours your learning of mechanical design?*, the students responded favourably, despite the inconvenience, with viewpoints, such as *giving another perspective to design work*, *helps to make the iterations faster*, *because nowadays the work of an engineer is more about designing than learning the formulas* or *performing iterations in these apps helps a lot to achieve better results*. These answers are consistent with the approach of leaving the main decisions of design to knowledge and the creativity of the designer, and leaving to the digital tools the execution of long and repetitive calculations.

The educational factors shown in Figure 3 are favourable as well, although, comparatively, their acceptance values are lower. The opinions on this aspect focus more on the handling of the challenges and the theoretical support, both written and in video form. Among the aspects that, in the judgment of the students, are the most valuable in learning design are freedom to take on the challenge, self-learning, presentation of real engineering situations and the benefit of a face-to-face evaluation versus a written examination. They recognise that with this way of learning, broader disciplinary competencies are acquired, which is precisely one of the main reasons for using this modality and which is mentioned in the introductory methodology manual [7].

Using challenges as a pedagogical approach is an experience that substantially motivates the learning of design. The challenges and their widgets provide a more complete experience to delve into the themes of machine elements, making the student more curious to know what happens, making them see the problem as a whole and elevating their expectations to learn more about the particular. It helps to encourage curiosity; it allows exploration of many versions of solutions to find the best; all of which helps their experience and self-confidence.

Competency Assessment

The final assessment of competencies shows that this learning approach particularly favours the development of some highly useful transversal competencies in engineering, such as the ability to solve problems, and the ability for collaborative work and leveraging ICT resources to optimise long and repetitive calculations required by mechanical design.

It is also evident that the challenges (which are challenges as much intellectual as executory with which the student is not accustomed) and computational tools carry the student to the middle and upper levels of cognitive dominance of the disciplinary competencies required in the subjects of mechanical design [18]. Only one series of challenges-widgets is not available for the highest levels of command; rather, they are used in the fourth attempt (selection of bearings) in which the student already arrives with experience in this mode of work.

The use of these ICT tools and the challenging cognitive approach requires practice and sustained effort (which would be desirable in more than one subject) so that it can bear fruit more promptly and protractedly. Although the higher levels of proficiency were not achieved in all the disciplinary competencies of mechanical design, the test could be considered successful. The student continues to become familiar with this didactic approach through more occasions of similar work.

In qualitative terms, the main benefits provided by this way of learning design are:

- The digital tools and cognitive resources are specifically designed to meet the learning needs of mechanical design.
- The software and its didactic approach does not compete with other digital developments. In addition, it is commonly used in engineering and science, it is hosted in the cloud, it can be used on any computational device and does not require a software licence.
- This way of working supports creative freedom for design and improves student self-confidence to address complex engineering problems.
- A notable improvement in the speed of the calculation for machine components is obtained, and thus, the student can explore more than one solution by repeating their calculations with new data until they find the best.

CONCLUSIONS

This research was aimed at identifying the ways in which the use of a cognitive approach based on challenges and the employment of calculation tools for mobile learning promote the development of competencies for mechanical design. This was achieved, and leads to the conclusions:

- A good use of digital resources can improve the design process of machine components and the provision of optimal solutions, both faster and safer.
- The educational and technological factors of the process have a favourable impact on the learning of mechanical design. Motivational factors were found that stimulate curiosity and enthusiasm to achieve the best possible design.
- Widgets were an interactive resource well liked on the course. They are useful in design optimisation, and thus, the learning of the different aspects that govern the creation of machine components.
- The student perceives as favourable the use of these resources as a new and current way to facilitate the learning of engineering.
- This educational innovation contributes to the improvement in the quality of the learning of design by promoting the development of higher order cognition, both disciplinary and transversal.

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BIOGRAPHIES

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