Active Learning Program Supported by Online Simulation Applet in Engineering Education

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Abstract: Nowadays education programs in engineering degrees have evolved towards advanced learning models and methodologies, which are either partially or entirely sustained by ICT (Information, Communication, and Technology) resources, and blended approaches. In this sense, electronics courses have become of paramount importance in most education plans within engineering degrees at university. Therefore the adaption to such novel methodologies is increasingly demanded. According to this, we propose an improved teaching program concentrated on the use of an online simulation tool, amongst other digital resources. The program is addressed to students in first levels of engineering degrees, within the framework of the Spanish public university system. In particular, the methodology has been devised through the use of an online circuit simulation applet in Java, which does not require any software installation. The main purpose is to enhance the general achievement of the students, particularizing on their practical competences, digital skills, engagement and motivation towards the learning of electronics, sustained by digital resources such as simulation. A population of 258 students enrolled during the academic year 2017/2018 has been established as a sample for presenting achievement results, surveys data and comparison statistics with other digital resources. Additionally, test groups of roughly 50% out of the total population of students have been established in order to confirm the success of the approach, in contrast to the former teaching methodology. As a result, the approach proves to be an active model which allows the students to develop long-term and autonomous skills in electronics and simulation.

1 INTRODUCTION

Over the last decades, simulation resources have been extensively integrated within teaching programs, especially in engineering. Initially, many approaches have relied on the use of software tools for simulating a wide field of engineering problems (Huanyin et al., 2009; Campbell et al., 2002; Dickerson and Clark, 2018). This tendency has been extrapolated to the use of other digital resources. Virtual labs (Menendez et al., 2006; Diwakar et al., 2012; Valiente et al., 2018), web-based courses (Yalcin and Vatansever, 2016), mobile apps (Musing et al., 2011; Rakhmawati and Firdha, 2018), are some up-to-date examples. Besides the sort of tool, the instructional design represents another important aspect in this context. Traditional methodologies are constantly renewed with blended-based (Aguilar-Peña et al., 2016), project-based (Amiel et al., 2014) and problem-based approaches (Perales et al., 2015), amongst others. Nonetheless, the actual success of such programs is always dependent on the sort of activities designed by the instructors. The final success is closely tied to the validity of the designed activities to stimulate active learning through the taught concepts, and their relation with the engagement and motivation (Arrosagaray et al., 2019; Zylka et al., 2015) awaken in the students. Hence the purpose of this work is defined from that starting point, from where related objectives are then established in order to overcome the most typical difficulties reported by students of electronics subjects.

Regarding such difficulties, research on engineering and technical education fields has evidenced serious misconceived ideas amongst students of electronics courses (Trotskovsky and Sabag, 2018; Sangam and Jesiek, 2012). Most of these issues arise from the instinctive reasoning and understanding they generally apply to the basis of electronics principles and electronic circuits (Pitterson et al., 2016). Several studies (Martínez et al., 2018) confirm that the key aspect for these misconceptions are commonly asso-

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Table 1: Group of students participating in the study.

Engineering Degree	Mechanics (ME)	Energy (EE)	Electronis & Automation (EAE)
Test group (no. students)	65 (46%)	24 (53%)	36 (49%)
Enrolled (no. students)	140	45	73

ciated to macro physics models erroneously assumed, such as the typical assumption by which many students think that electric current flows inside a pipe.

Overall, taking into account all these aspects, we have proposed a blended learning program sustained by an online circuit simulation applet in Java (Falstad P., 2019), for simulating a wide variety of problems and exercises with a straightforward implication to real electronic circuits, during both the theory lectures, practical tutorials and hands-on sessions in the electronics laboratory. This tool was selected due to its simplicity of use through its website, without the need of any software installation. Our experience reveals that its use turns to be easier and attractive for students, in contrast to more complete and professional softwares such as $Orcad-Pspice$ or $Matlab/Simulink$ (Peng and Bao, 2012; Iyoda and Belanger, 2017). Apart from its simplicity and intuitive use, it does not require any software installation. In addition to this, it provides a very simple menu with almost all the components the students usually study in the course.

The intervention was performed in several Bachelor's degrees in engineering, fact that permitted comparing achievement results in the active learning of students, engagement, motivation and attitude towards the program. The validity of the use of an online simulation tool is also compared with the use of other digital resources during the course. Moreover, test groups were voluntarily established by students, in order to extract further insights and comparisons with the outcomes of the rest of enrolled students. It is evident that certain bias is likely to appear when members of the test groups are conformed voluntarily (Chapman et al., 2006; Frederiksen, 1984). Nonetheless our institution only considers voluntary participation during the first pilot experiment of a program. After the main outcomes and benefits are demonstrated for this academic year, the program will be further studied with formal test groups selection, in next courses.

The rest of the paper is structured as follows: section 2 presents an overview about the designed methodology; section 3 focuses on the results extracted after the implementation was carried out; section 4 provides a discussion on the main conclusions and insights derived from the results.

2 MATERIALS AND METHODS

This learning program was devised and conducted during the academic year 2017/2018 with several undergraduate engineering students within the Spanish official university system. The program was divided into theory lectures, practical tutorials and hands-on sessions in the electronics laboratory.

2.1 Implementation

The set of executed actions were chronologically planned along two semesters, according to the following development steps:

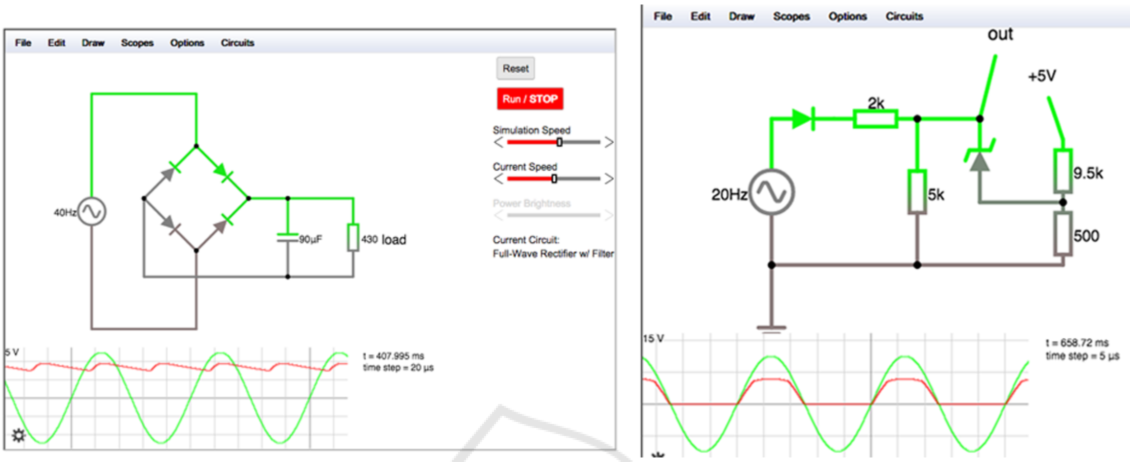
1. Studying and selecting an efficient online simulation software alternative.
2. Elaborating a survey to assess student's conceptions, engagement and satisfaction with the program.
3. Teaching an introductory seminar to the simulation applet tool (Falstad P., 2019).
4. Preparing a set of activities with simulation support for all the theory lectures, practical and hands-on sessions. Designing an extra assignment dossier with activities to be solved by simulation.
5. Analysing the survey results and the corrections of the assignment dossier with activities.
6. Assessing the achievement of the students at the end of the course (test groups and the rest of the enrolled students).

2.2 Target Groups

The entire set of students participating in this study are presented in Table 1. They were students enrolled in three different engineering degrees (Mechanics; Energy; Electronics and Automation) who all took the electronics course presented in this work. Despite formal approaches for test groups selection (Chapman et al., 2006; Frederiksen, 1984), we were limited by institutional policies to allow students to voluntarily join the test groups. They accepted to hand in a final assignment dossier of activities to be solved with the online simulation applet, during the entire course.

Table 2: Classified questions of the survey.

Question no.	**Content**
1-10	Electronics' essentials
11-12	Availability and use of support resources
13-16	Motivation, satisfaction and attitude to the program



(a) (b)

Figure 1: Main menu window of the simulation applet in Java (Falstad P., 2019).(**a**): typical full-wave rectifier circuit with filter, for AC-DC conversion. (**b**) custom limiter circuit studied in the course.

In terms of percentage, the test groups represented almost the 50% out of the total number of enrolled students in each degree. This permits obtaining consistent and significative results when defining comparative results and statistics.

2.3 Assessment

As described above, the learning program was conceived to be supported by circuit simulation during all the stages of the course: theory lectures, practical tutorials and hands-on sessions. All the activities and exercises presented by the instructors during the sessions were afterwards validated with the simulation applet, regardless they comprised theory aspects or analytical resolutions of electronic circuits. Abstract physics concepts and the main difficulties detected in the students, were tackled with the aid of simulation examples and activities. Using graphical representation of variables, together with the simultaneous evolution of the current and voltage signals on the circuit, revealed significative benefits on the active learning of the students, who demonstrated to rectify their previous misconceptions by their own, with the slight guidance and supervision of the instructors.

In order to assess the actual benefits of this program more specifically, we elaborated a survey to be answered by students. This survey was validated by a group of five full professors from other universities, with broad experience in the field. It contained questions related to basic electronics concepts, motivation and attitude to the program. The questions were classified, as denoted in Table 2, into three main blocks: questions 1-10 dealt with physic magnitudes, general circuit lows, simple circuit resolution, graphical representation and interpretation; questions 11-12 were intended to evaluate the use of support resources made by students. Finally, questions 13-16 were aimed at assessing the general engagement and motivation towards the learning of electronics, as particularly experienced during this program, and the attitude of students to the use of the online circuit simulation applet.

Moreover, the test groups received a specific assignment dossier with activities to be solved with simulation. Figure 1 presents two examples of activity with the simulation applet. Figure 1(a) represents a typical application of a full-wave rectifier circuit for AC-DC conversion, whereas Figure 1(b) presents a custom design for a limiter circuit. In this manner, we aimed at a more explicit evaluation of the outputs of this approach, which permitted comparing results amongst the entire group of students enrolled in the course (who did not work on the assignment with simulation), versus the specific test groups in each degree.

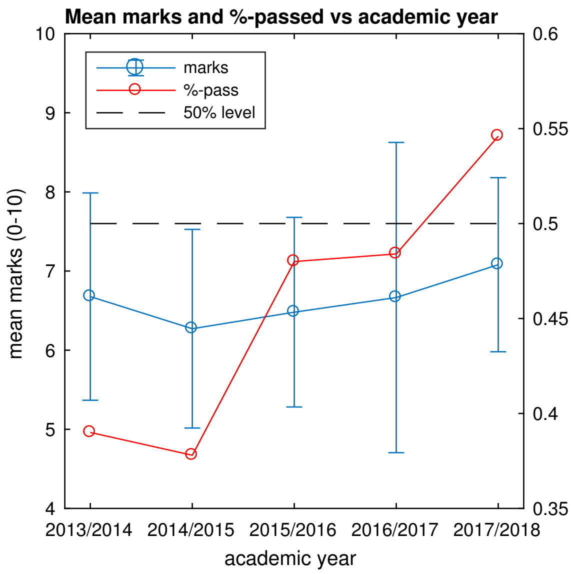


Figure 2: Mean marks & percentage of students who passed the course during the five last academic years.

3 RESULTS

The main results extracted from this study are focused on: *i*) the achievement of the students and *ii*) the perceived motivation and satisfaction for the active and autonomous learning through this program, and its actual validity for the long-term learning and self construction of knowledge of the students.

3.1 Achievement Results

Firstly, the current academic year, 2017/2018, in which the simulation tool has been first included, is compared in terms of mean marks. A record corresponding to the five last academic years is presented for comparison in Figure 2. The left-side axis encodes the mean marks of the entire set of enrolled students within the three degrees (Table 1). It can be observed that the current academic year presents better marks. It is also worth highlighting the substantial increase in the percentage of students who succeed in passing the course (marks$\geq$5), in the right-side axis, up to the 55% in the current academic year (highest value over the five past years). As a preliminar output, we can state that the inclusion of simulation resources within the program in 2017/2018, has significantly improved the final achievement of the entire set of students, in contrast to the previous years.

Nonetheless, more specific comparison data are required. Hence we compare in Figure 3 the marks obtained by the test groups and the rest of the students, in the academic year 2017/2018. Firstly, Figure 3(a) depicts an illustrative insight, since it evidences that the marks distribution is significantly improved for the test groups, where a 50% of the students reached the highest marks ([8-10]). The percentage of students who did not pass the course is also lower for the test group. Finally, but not less important, all the students within the test groups took the exam, in contrast to a 37% out of the rest of the students, who dropout the course during the current academic year. Secondly, Figure 3(b) presents a comparison for both groups in terms of mean marks. Then it also reveals better performance for the test groups in mean terms.

Another aspect to consider is the influence of the use of the simulation applet and its benefits, in contrast to other methodologies and digital resources. Despite the fact that the course is eminently oriented towards the use of simulation during the theory, practical and hands-on sessions, the students also have other additional resources. The students have access to a (*Moodle*) site where diverse digital resources are available: a collection of solved exercises, videos with theory lessons and resolution of exercises, a forum to ask questions, some multiple choice test for self-assessment, etc. In this sense, we have also analysed the relation of the students achievement and the dependency on the sort of resources.

Table 3 comprises the correlation results for such framework, in which the marks of the students who participated in the test groups (who took the assignment based on simulation activities) are compared with students who made use of other digital resources in the *Moodle* site of this course, and also with students who did not use any of the previous. It is worth emphasizing that students in the test groups worked on the assignment dossier with the simulation tool during the entire course (two semesters). In this context, the test groups present the only significative correlation (>0.7) between the use of simulation and the positive marks. Moreover, a statistical contrast test has been carried out by means of a χ^2-test. The marks have been considered qualitatively as *fail* or *pass*, for each type of digital resource. Assuming a confidence value of 95% for the test (α=0.05), the only resource which proves a clear dependency between its use and the marks obtained by the students is simulation, since $\chi^2 > \chi^2_{test}$ (23.74>3.84) and p-value$<alpha$ (5.74E-7<0.05). Besides this, it is clear that students who do not use any kind of digital resource have less chances to obtain high marks, as per the negative correlation value, r_p=-0.12.

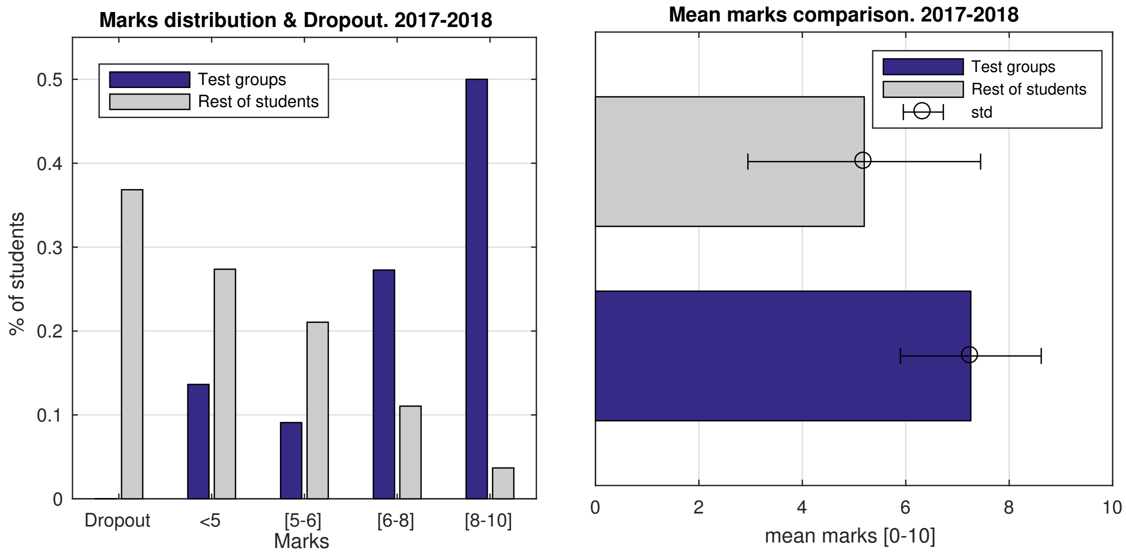


Figure 3: (**a**): marks distribution for the test groups and the rest of the students during the academic year 2017/2018. (**b**) mean marks comparison between test group and the rest of the students, in the academic year 2017/2018.

Table 3: Correlation results and contrasts tests between the use of specific digital resources and the marks obtained by students.

Digital resource	r_p	χ^2	p**-value**	χ^2_{test}
Moodle	0.31	2.11	0.096	3.84
Simulation assignment	0.77	23.74	5.74E-7	3.84
None	-0.12	1.03	0.24	3.84

3.2 Survey Analysis

The results processed from the responses of the survey are presented in Figure 4. As described in Section 2.3 (Table 2), the set of questions were classified into concepts regarding electronics essentials (questions 1-10), availability and use of resources to support their learning (questions 11-12) and general engagement, motivation and satisfaction towards the learning of electronics sustained by the online simulation applet (questions 13-16). On the one hand, Figure 4(a) and Figure 4(c) represent the mean results for responses of the rest of students enrolled in the course, who did not participate in the test groups. For further detail, the different degrees have been represented separately by with colored bars. It can be observed that students in the degrees of Energy and Electronic & Automation prove slightly higher levels in all the sort of questions. Nevertheless, the general trend in the responses is quite similar for the three degrees.

On the other hand, Figure 4(b) and Figure 4(d) represent the mean results for responses of the students in the test groups (who took the assignment dossier with the online simulation tool during the entire course). Again, significant outcomes are demonstrated by the test groups, which present a substantial increase all over the three blocks of questions, in contrast to the rest of the students. All in all, the survey confirms the beneficial outcomes of the use of simulation resources, not only in the learning of concepts, but also on the self-confidence and motivation for the long-term and active learning of the students in the near future within their current engineering education.

4 CONCLUSIONS

This work has dealt with a case study in which a learning program for a course of electronics in engineering degrees has been redefined through the support of an online simulation applet implemented in Java, without the need of local software installation. Three set of students enrolled in different undergraduate engineering degrees within the Spanish official university system, have taken part in the study. The basis of the program consisted of a blended learning model with an incipient support of activities carried out with simulation, in order to aid during the theory lessons, the practical and the hands-on sessions. The main goal was to enhance the global achievement of the students

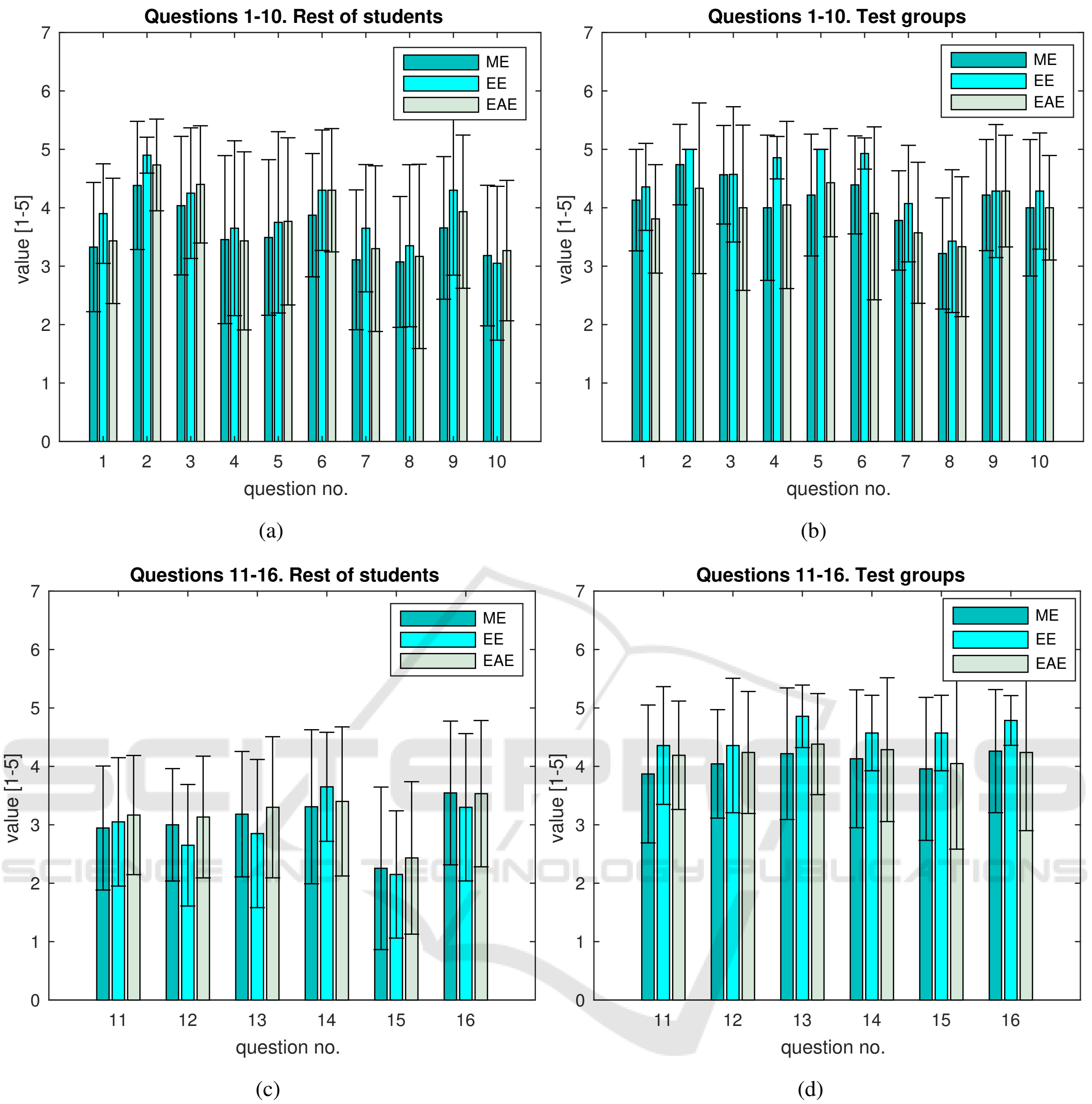


Figure 4: Left axes (**a**), (**c**): survey results associated to the responses of the rest of the students enrolled in the course. Right axes (**b**), (**d**): survey results associated to the responses of the test groups. ■ Mechanichs Eng.; ■ Energy Eng.; ■ Electronics & Automation Eng.

in terms of self-autonomy and comprehension, for their further active learning. Long-term knowledge and understanding of concepts are reinforced, and robust and consistent development of competences are promoted through digital skill acquisition.

According to the statistical results processed in this work, in comparison to previous academic years, the current course (2017/2018) in which the simulation tool was first included as a pilot experiment, reveals improved mean marks, and specially, encouraging rates of *pass* marks. Nevertheless, further insights can be extracted from the analysis. Students within test groups (who worked on an assignment dossier of activities to be done with the simulation tool during the entire course) demonstrated enhanced achievement results than the rest of the students. The distribution of their marks is another evident outcome of the program, but most importantly, the fact that none of the students in the test group did dropout the course, contrarily to the high rate of dropout registered for the rest of the students in the course. Future works will consider more proper studies which avoid possible bias on the voluntary enrollment of the members in the test groups. So far, our institution only considers voluntary participation during the first pilot experiment of a program. Other possible bias such as those associated to the academic record of the students in previous courses will be also consider in more detail.

Additionally, a survey was designed in order to assess more precisely the success in the understanding of fundamental electronics concepts, but also to evaluate the use of resources made by students, and their motivation, satisfaction and attitude to the learning program conducted in the course. Again, the results presented demonstrate a clear increase in terms of comprehension and general satisfaction by the students who participated in the test groups, in contrast to the rest of the students. Finally, the use of other available digital resources has been compared with the use of the simulation tool, as a final prove of the validity of the approach. The only resource which proves a linear correlation between its use and the achievement of the students is simulation. To that aim, statistical contrasts tests have been performed. Again, our future work is considering inferences from the survey and internal consistency between different responses.

Overall, we can conclude that the main objetives have been covered by the presented learning program. According to the results, the validity and suitability of this approach for its future application is confirmed by the positive improvements measured on the self-autonomy of the students and the active and long-term learning, sustained by the inclusion of an easy simulation applet within the main teaching methodology.

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