Received: 14 October 2020 | Revised: 22 February 2021 | Accepted: 24 March 2021

DOI: 10.1002/cae.22415

RESEARCH ARTICLE

WILEY

Improving the learning of engineering students with interactive teaching applications

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Abstract

Over decades, Mechanical Engineering students often find some difficulties to grasp some contents and/or struggle with some parts of the course. With the increasing development of new technologies, promising innovations can be implemented enhancing learning and improving success rates. In this study, a new learning interactive method is proposed and evaluated using the experience of over 600 students of Mechanical Engineering. This study describes a 4-year experiment based on new interactive applications for education. The experiment has been implemented using E-learning techniques and new technologies (a combination of remote and virtual examples, videos, quizzes, and theory). Specifically, several applications have been programmed to be executed on different devices, such as mobile phones and PC/laptops (Android and Windows). The experiment is applied using small applications that help the students identify the most challenging contents and guide them throughout step-by-step. The main objective of this interactive method is to help students find their lack of knowledge and offer them contents to cover it. These didactic applications are portable and intuitive. Thanks to these interactive applications, it is possible to accomplish better practices of "E-learning" and "Computer Simulation and Animation" together. Since they are portable applications, they allow the student to interact and check conceptual understandings at any place. Students really appreciate this aspect. The results of the course titled Mechanism and Machine Theory have been analyzed during these four last years in which these interactive applications have been offered to the students.

KEYWORDS

computer simulation and animation, educational game, E-learning, interactive application, mobile learning

1 | INTRODUCTION

To pass a course, students are required to understand the theoretical concepts [28] (also called conceptual knowledge in the literature [18]) and procedural skills [18].

In the last years, different types of methods that use electronic resources have been developed to improve students' conceptual understanding. These methods are known as E-learning. For example, Radinschi et al. [27] and Botelho et al. [3] have applied computer simulations in engineering education. Kresta employed full-scale lab experiments [16] using Computer Simulation and Animation (CSA) to learn mechanisms [3]. In general, CSA has been widely adopted in engineering education [9,10] as powerful tools for teaching and learning. The problems of these methods are that they do not help find the lack of conceptual knowledge. Students do not know where their lack of knowledge is.

The high penetration rate of devices at the global level sets new challenges, and universities can continue with this trend. Nowadays, students are always using their laptops, smartphones, and tablets Thus, there is increasing use of devices in E-learning and despite the fact these technologies could be seen as a dysfunction in the past [14], they are now seen as a relevant teaching ally. As an example, virtual networks are currently used to share materials that can be accessible every time and everywhere [30].

With the widespread use of mobile devices in learning activities, the development of mobile learning content for these devices has become a great need, and research on mobile applications and game development is increasing considerably in the last few years.

Several types of applications have been applied in high education, mostly in universities where education is being continuously updated with new tools. The number of applications used at universities is increasing, as demonstrated by De-Casas-Moreno [8], and they have proven to be very useful, as seen by Matsuo [20]. Due to the good results, other authors have generated guidelines for programming applications. Jang generates a guide to facilitate the work of programming teaching applications [13]. Kudumovic also generates a guide to generate applications for the specific case of Electronic students [17]. Hernandez-Del-Olmo creates software to help teachers without previous experience generate test applications [12]. Darabkh conducted an interesting study on how to teach drawing through Virtual Reality apps [7]. Vieira proposes a very original application for chemical engineering students to perform laboratory simulations [29].

Other types of electronic tools have been developed, as in the case of Ojeda-Castelo that uses a combination of Kinect and an app for teaching and rehabilitation of students with special needs [25]. Al-Othman presents a web of education, which the students can access from the Smart mobiles to facilitate learning [2]. Ozdemir examined the effect of an educational mobile android game on the attitude of engineering students with good results [26].

For these reasons, these proposed interactive applications have been implemented in the course of Mechanism and Machine Theory (MMT) at the Universidad Carlos III de Madrid. The course of MMT, bachelor's degree in mechanical engineering, has many theoretical concepts. It is not enough for the students to memorize that knowledge; they must understand it. Hence, the course is divided into theoretical lessons, exercises lessons, and laboratories. This teaching structure is observed in other courses in the engineering program. This method works correctly as long as the student understands the theoretical concepts. That forces universities to find new didactic methods to help and motivate students to reach the desired level of theoretical knowledge. This is possible, thanks to new technologies [4]. Nowadays, the course MMT at Universidad Carlos III of Madrid has already been updated with E-learning, but the problem with E-learning is that it does not solve the lack of time of the students [15]. Moreover, students at the Universidad Carlos III de Madrid were given some interactive test applications that have been very much appreciated and the learning results of the courses have improved [6]. These tests were presented as multiple choices covering all the theoretical contents of the course. Even so, students have demanded more because these tests were useful for them to find their lack of knowledge. For that reason, they have also required different applications that include explanations, both theoretical concepts and for problems solved progressively, and they have also demanded applications compatible with the PC and the laptop. The demands of the students have been fulfilled and constitute the aim of the present work.

The most used E-learning methods are the knowledge pills. These pills are very useful for theoretical concepts [19]. The next step is to find a method to discover what specific pill the student needs. Thanks to interactive didactic methods, this is possible. The applications created for this study help the students to find the knowledge pill they need.

This paper describes how interactive and portable applications have been implemented, following the philosophy of promoting the interest of the student. The effects of the use of these applications have been analyzed in terms of learning results and satisfaction of the students for a period of 4 years.

The manuscript has been divided into the following sections: in Section 2, the objective of the applied teaching method is described in depth; in Section 3, the technologies where it has been applied are detailed; in Section 4, it is described how the applications have been developed; in Section 5, the interactive scheme of the applications is provided; in Section 6, it is explained how the experiment and the data collection have been performed, and the last section shows the main conclusions of this paper.

2 | OBJECTIVE OF THE INTERACTIVE METHOD

The main objective of this interactive and didactic material is to give students the possibility to find their weaknesses so they can solve them. To achieve this, the application must give the student the option to go through theoretical concepts, which the student already knows, and be able to explore in detail the concepts the student does not know. Moreover, the applications introduce some gamification elements to make them more attractive.

It is desired to solve the knowledge gap of theoretical concepts of mathematics and physics for the MMT course in the Universidad Carlos III de Madrid. Thanks to these new methods, it is possible to teach in a more "practical way" using computer technologies (Applications, virtual laboratories, and E-learning).

It is understood as a more "practical way" not only to memorize the theory but also to understand it. Many studies verify that students learn more with a more "practical" method, such as Mayer and Chandler [21], which found that interactive multimedia learning allows the students to acquire knowledge faster. It is needed for the students to think, understand, and also memorize as Clark et al. [5] shows in the based guidelines to manage cognitive load. The desired application not only provides theoretical concepts, but also must check if they understand them, and it explains the "practical" concepts.

The applications are designed to include:

(a) Interactive tests (able to identify students' mistakes and explain why they have failed). These can be questions with text, or with images or gifs. The questions are multiple-choice. So, students can easily solve them and autoevaluate. Some of these questions require calculation.
(b) Problems solved "step by step" (with the possibility of clarifying/explaining concepts). The students have the ability to skip the explanations they already know and understand, to focus just on the ones they do not know. This helps students to maintain their concentration.
(c) Theoretical concepts explained with the help of videos and gifs (with the possibility of clarifying/explaining concepts). These concepts must be concrete and not too extended. This facilitates their searching and learning in the form of small pills.

It is very important to highlight that students have the possibility to see the explanations simply about the concepts they want. Thus, they can quickly go through all the contents they know and mainly focus on the parts they are struggling with.

The last objective, but not least, is portability. This is managed, thanks to the development of different versions so that the application is compatible with different operating systems: Windows and Android, and it can be executed on different devices, such as laptops, smart phones, and tablets. The possibility of working fast and without the necessity of Internet connection is a must for the students to use the application. All these strategies mentioned making these applications a perfect tool for getting good results and get the students motivated, helping them to build a passion for their work, which will play an important role in their future professional life.

3 | DEVELOPMENT OF THE APPLICATIONS

To support students throughout their learning of Mechanical Engineering, several applications have been developed and provided to students. This section aims to describe the main features and the development of the applications.

The aim of these tools is that students can use them to review some concepts and to go deeper and practice relevant exercises related to the skills they need to obtain. This yields to different kind of applications: some of them are focused on presenting concepts or reviewing them through multiple-choice questions, while others include step-by-step guides to solve more complex cases studies. Even though the specific objective may be different, all the applications focus on a single topic of the course, and they allow students to focus on the weaknesses they identify in the face-to-face classes.

One key aspect of these tools is portability. As many of these tools provide questions that can be reviewed everywhere, one important aspect is to ensure that a learner can use the applications on different devices everywhere. For example, it would be advisable to allow learners to use these tools while commuting as mobile learning has become relevant in the past few years [24]. To address this issue, some tools have been created in different versions so that they can be opened on a mobile device (using a mobile app) and a PC/laptop through an executable version.

Most of these applications have been developed using Android Studio so that Android users can download an.apk file and run the app on their mobile phones [1,23]. Figure 1 depicts the structure of an Android Studio interactive application.

Alternatively, other applications have been developed using HyperText Markup Language (HTML) as web pages. Particularly, applications with step-by-step solutions use this format [22]. The advantage of using HTML for these applications is that it is easy to create an interface and embed different elements, such as images, equations, videos, and so on. In this case, since little processing is required, it is not necessary to use other programming languages for software development, such as Java, Python, and so on, which would make the development more difficult and time-consuming (particularly if graphic interfaces are integrated into them).

One advantage of these pages is that they can be uploaded to a server and they can be accessible everywhere (provided students have an Internet connection) and they are not linked to any specific device. They are easy to use as they contain steps of the problems in different pages and students can move forward and backwards through the problems as they complete the different steps.

However, a downside of this approach is that pages would need maintenance in case there is any change in the server, and they could not be accessible without Internet (unless students know how to download them all). Because of that, executable versions (.exe files) were also generated from the webpages so that students can use their own offline version, which they can store and execute. These .exe versions were generated using HTML Compiler, which is a small and easy to use software that converts HTML pages into executables that contain the same interactivity as the online version.

4 | INTERACTIVE APPLICATION SCHEME

The developed applications aim to be interactive and they contain several multimedia items to make concepts easier to understand and to encourage students to use them. One main feature of these applications is that they

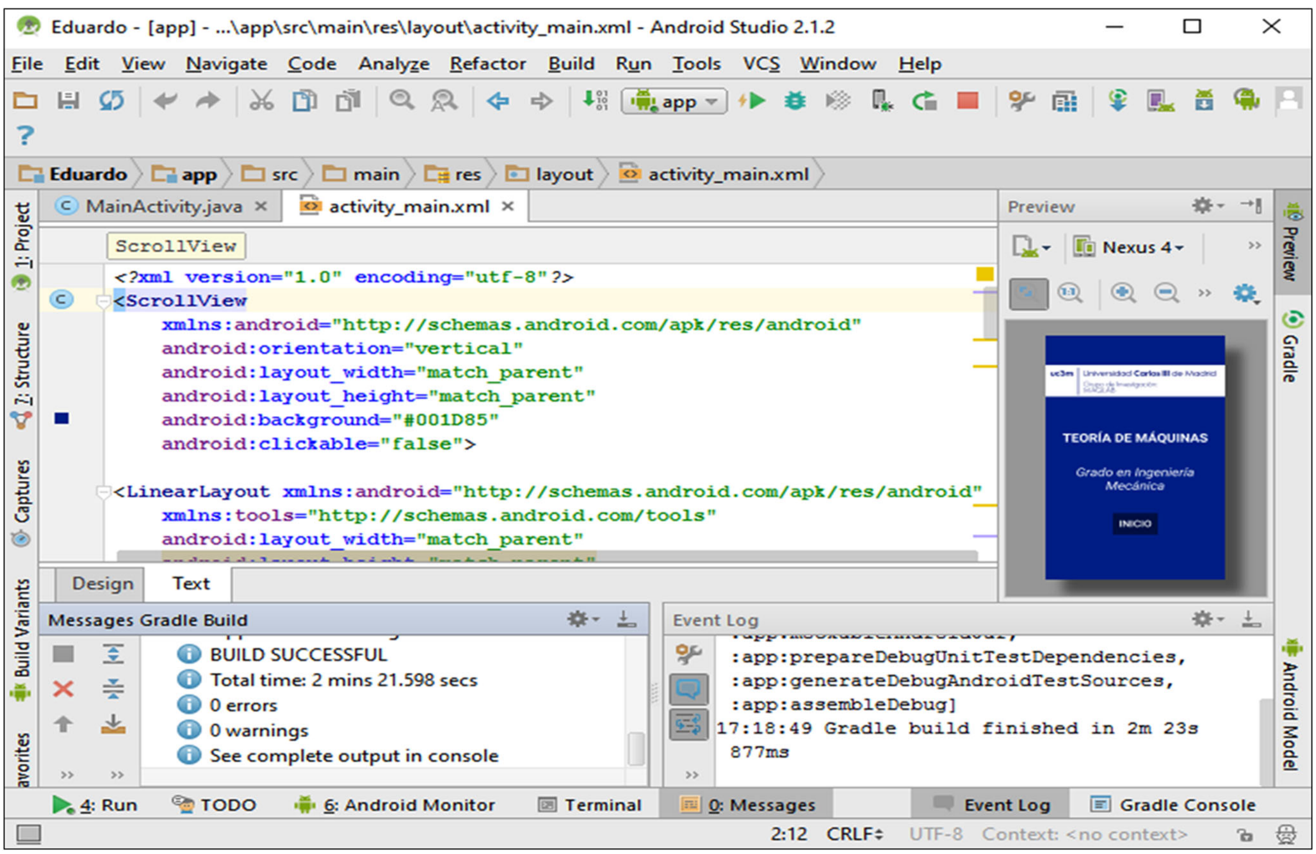

FIGURE 1 structure of an Android interactive application

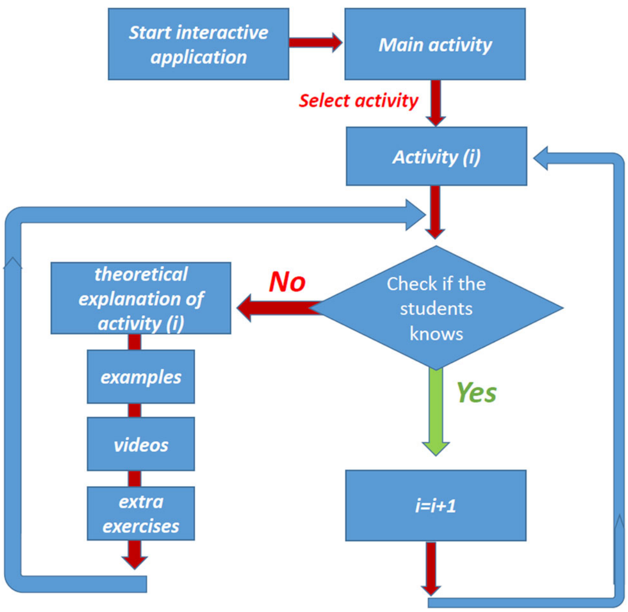

FIGURE 2 Scheme of an interactive application

allow learners to take their own path through the application so they can focus just on the parts that they want to. This is beneficial because learners may use these apps to better understand the parts they struggle with, and this allows them to skip the parts they master and focus on those that present more difficulties to them. To delve into the design of the applications, this section provides a scheme about how the applications work and the degree of interactivity that can be achieved.

For all the applications, the general scheme is presented in Figure 2. This scheme shows that when apps are opened, the Main Activity (application start screen) is displayed. Next, students can select the interactive activity they want to do. Afterward, the activity is displayed, and they can check whether they master the contents related to that activity. If students know the contents, they may skip to the following activity. Otherwise, they can engage with the activity and use different materials to get the right answer and see the explanation. After finishing an activity, they can continue to the next or come back to the Main Activity menu. The activities provided in these applications are understood as pills of knowledge. Each interactive application has its own format to make it more motivating.

Figure 3 shows the scheme and three captures of one application related to the MMT course. As abovementioned, there is one index with the start of the app (Start interactive application in the scheme) followed by a menu to select the activities (Main Activity). Students check their conceptual knowledge and check their progress at the end to get feedback. However, the format of the activities and the interactivity varies depending on the application.

The level of interaction can also change depending on the application. Some applications require the student to provide an answer to a question and feedback is provided based on the answers. However, there are other applications where the input is some information, and the student needs to reflect on their understanding. This is the case of the step-by-step problems provided in HTML (and executable). Figure 4 shows an example of this kind of application and how it also fits with the general scheme. This figure shows the Activity page where its description is presented together with the tasks the students need to perform. Afterward, the student can move forward to the different tasks and see the explained solutions combined with different resources, including images, formulas, and videos.

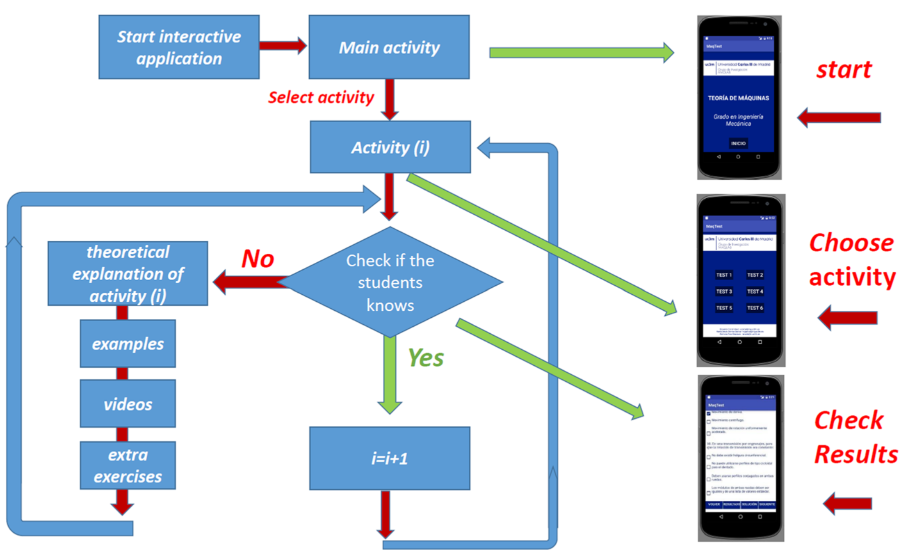

FIGURE 3 Scheme of the main activity

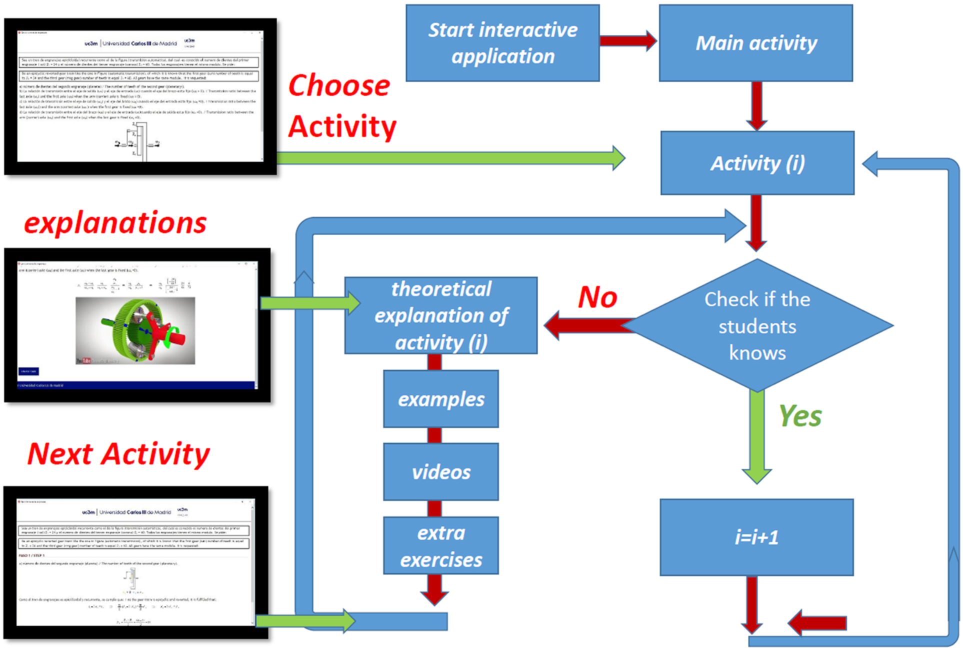

FIGURE 4 Scheme of the theoretical explanation of the activity

Finally, it is noteworthy that despite the fact the tools share a similar style and follow a common scheme, the contents and format vary for each tool. This is to ensure that each application sticks better to student demands. For example, problems that students struggle with more often in the course are designed with the step-by-step approach, while more conceptual exercises that may be easier to grasp are designed with questions.

5 | EXPERIMENT, DATA COLLECTION, AND EVALUATION

The interactive method of this study has been implemented in MMT, a mechanical engineering course taught at a public university of Madrid, Spain, for 4 years (2016–2020). This is a compulsory subject for the mechanical engineering degree, taught at the third year. The average age of the students is between 21 and 23 years old. The number of female students is around 20%.

During these years, the teachers and coordinators of the subject have been the same: Eduardo Corral, Cristina Castejón, and Maria Jesus Gomez. All of them have more than 10 years of experience in teaching this subject. These teachers have been tutors of MMT students who have competed in the Students International Olympiad on Mechanism and Machine Science organized by the International Federation for the Promotion of Mechanism and Machine Science (IFToMM).

This study pursues to estimate the improvement in student's learning, thanks to these applications. To obtain this information, students' grades have been analyzed during these 4 years in comparison to the year right before including this method (2016). During all the compared years, professors were the same (the authors of this paper) and they gave the same lectures at the university in the same level classes.

Results of MMT in 2016, 2017, 2018, 2019, and 2020 are studied. The first group (2016) studied the course material only in the form of lectures without any interactive method. The new interactive applications were offered in 2017. Students that took the course between 2017 and 2020 were provided with extra interactive applications, apart from the material that was offered for students in the 2016 cohort. In all courses analyzed, the number of students is about 200, all of them belonging to the Mechanical Engineering degree. Result improvements were calculated using the "Learning Gain" and the "Approving Gain" ("LG" and "AG"). Student gains were calculated using the following equations [11]:

$$\mathrm{LG} = \text{Learning Gain} = \frac{\text{postscore} - \text{prescore}}{100 - \text{prescore}},$$

$$\mathrm{AG} = \text{Approving Gain} = \frac{\text{postapproved} - \text{preapproved}}{100 - \text{preapproved}}.$$

The "prescore" is the result of the students (over 100) in those years that the new interactive application method had not been offered. The "postscore" is the result of the students in the years which the new interactive application method (over 100). The "preapproved" is the number of passed students in the years without the knowledge of interactive applications (in percentage) and the "postapproved" is the number of passed students in years with the knowledge of interactive applications (in percentage).

"LG" and "AG" are reliable evaluation of the improvement these applications provide in students learning. "LG" evaluates the grade variation and "AG" evaluates the increase in the number of students who had passed the course.

In addition, the students had completed a survey on their experiences with these interactive applications and gave their opinions. All surveys had participation greater than 95%.

6 | RESULTS

The student learning outcomes have been obtained by comparing students' degrees during 4 years in an engineering course (MMT) at the public university of the capital of Spain (UC3M).

The interactive applications have been implemented in 2017. In Figure 5, the percentage of approved students of MMT from 2014 to 2019 can be observed. The percentage of approved students has increased from 14.84% in 2016 to 37.76% in 2017, and it continues around 38% and 39% in 2018 and 2019. This improvement has been achieved due to the use of thisinteractive method.

In 2016, the number of approved students was 19 out of 128. The number of approved students in 2017 was 54 out of 143 (AG equals 23.6% and LG is equal to 10.2%). This great improvement is due to the use of these applications.

Additionally, several opinion surveys were carried out. In all surveys, there has been a participation rate greater than 95%. Surveys show that around 95% of the students used the interactive applications and 90% of the students said that the reason why they used the interactive applications is the portability/accessibility: through the smart-phone (Android) or PC/laptop (Windows).

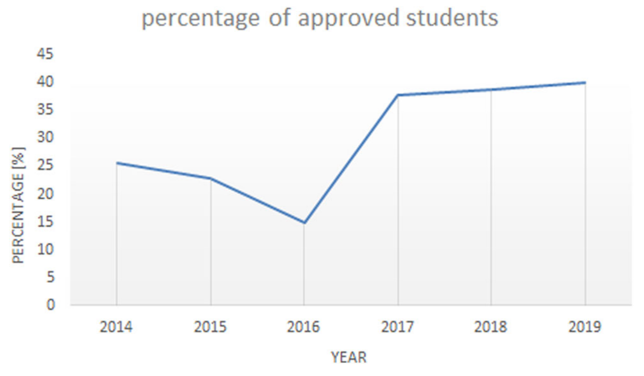

FIGURE 5 History of approved students

Figure 6 shows the results of the survey covering student satisfaction with the interactive method. It can be seen 72.1% are very satisfied, 22.3% are satisfied, and 5.6% are not satisfied. Most of the students commented that they preferred this system of interactive applications to video methods (MOOCs and SPOCs).

Figure 7 shows the average opinion of the students about the transfer of lecture content, the interest in the lecture, the understanding of the lecture, the concentration of the lecture, and the accessibility and portability. It has been carried out in groups with the conventional method and in groups with interactive applications. The results are calculated as a percentage showing the improvement with the iterative application method. It is easy to see a great improvement in accessibility, interest, and understanding. It is important to notice that students have highly valued applications and they want more interactive applications for other subjects. Students really value these new didactic methods. It is appreciated how they clearly value accessibility and portability as it improves their concentration, understanding, and interest, thanks to these interactive applications. The majority of students (89%) consider that the interactive application has helped them improve their grades.

7 | CONCLUSIONS

This study describes a new interactive learning method based on portable and accessible applications.

Given the large number of students involved in this study and the fixed methodology across the extensive study period, the results are very stable.

Applications help students find where their lack of knowledge is. This was one of the main objectives and has been achieved, thanks to the interactivity of the application. The applications are showing topics, giving the student the possibility to skip the topics that they already know. Another great advantage is that it does not require any special equipment or disbursement of money since all students have a smart phone or PC/Laptop/tablet. Android is free and open software and Windows is very widespread.

The method has been evaluated on the MMT course of the Mechanical Engineering Degree of Universidad Carlos III de Madrid during four courses. The results represent a significant and repeatable pattern since there

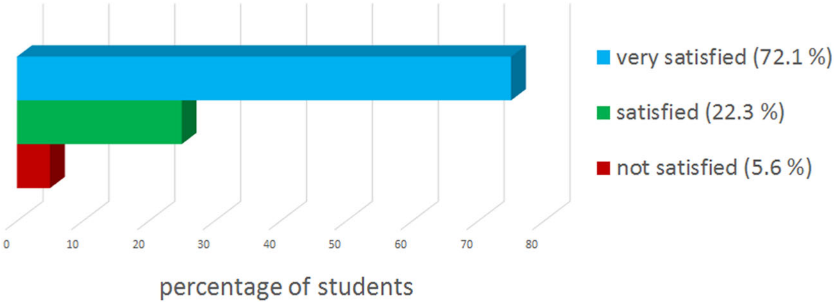

FIGURE 6 Opinion of the students

		Bad (%)	Normal (%)	Good (%)	Summary
Transfer of lecture content	Conventional method	10	60	30	
	With interactive application	15	35	50	
Interest in the lecture	Conventional method	40	30	30	
	With interactive application	20	40	40	
Understanding of the lecture	Conventional method	40	35	25	
	With interactive application	20	35	45	
Concentration of lecture	Conventional method	30	40	30	
	With interactive application	10	50	40	
Accessibility, portability	Conventional method	40	40	20	
	With interactive application	20	30	50	

FIGURE 7 Table of the opinion of the students (2019)

are many students involved, and there has been a fixed methodology across the extensive study period. The results are analyzed both in terms of students' results (based on the "AG" and "LG" results, which estimate the improvement between pre- and post-interactive applications) and students' opinions.

The results of students show a successful implementation and a demonstration of how this interactive method can significantly support students, besides the results are very stable. There has been a notorious improvement of the approved students (from 15% to 38%). On the other hand, the high satisfaction of the students with the method (89%) is reflected in the opinion surveys. Also, 96% of the students consider that there should be more interactive applications. It can be concluded that providing students with these interactive applications enhances the effectiveness of students' learning and satisfaction throughout the course contents.

We would also like to comment that during the period of confinement by COVID-19, these methods have been highly appreciated by the students. They have helped a lot to enhance telematics teaching quality. It is valuable for students to have an interactive portable method to study and auto evaluate their knowledge.

Future work should focus on the development of more applications that could support students in a wider range of subjects.

ACKNOWLEDGMENTS

The authors wish to thank the "COnvocatoria De Innovación Docente 2017–2018" of the UC3M.

PEER REVIEW

The peer review history for this article is available at https://publons.com/publon/10.1002/cae.22415

DATA AVAILABILITY STATEMENT

Data available on request from the authors.

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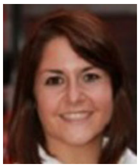

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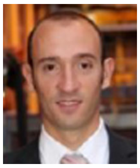

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How to cite this article: E. Corral Abad, M. J. Gómez García, E. Diez-Jimenez, P. M. Moreno-Marcos, and C. Castejón Sisamon, *Improving the learning of engineering students with interactive teaching applications*. Comput Appl Eng Educ. 2021; 29:1665–1674. https://doi.org/10.1002/cae.22415