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M-learning and E-learning Interactive Applications to Enhance the Teaching–Learning Process in Optical Communications Courses

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In this paper, we propose to enhance and speed-up the teaching–learning process in optical communication subjects by designing and implementing new e-learning and m-learning strategies and applications. The new educational scenario demands a methodological renewal focused on the learning process and the acquisition of skills. In this way, telematic and interactive tools can promote this change due to their flexibility and great development. As a consequence, students can be provided with a set of powerful software tools that help them to increase their autonomy and their capacity to acquire skills. The range of tools that is nowadays available is enormous, but we have chosen strategies based on e-learning and m-learning applications in order to take advantage of the different strengths of the two approaches. First of all, we propose to provide subjects with high flexibility by designing voice-guided tutorial videos of complex concepts and software simulators used in lectures and laboratories. In particular, in this paper we focus on subjects from the optical communications area, since this area is highly complex and it is a good scenario for the practical use of our proposal. The main objective is to promote a virtual access to optical communication experiments and simulations related to laboratory subjects. However, these video-tutorials also look to be a powerful tool in lectures to explain fundamental principles and physical phenomena better. On the other hand, we have designed a set of Android applications, since mobile learning is an effective technique to transform and strengthen the traditional training and learning strategies. The involvement of mobile devices in the learning process aims to improve the interaction of teachers with students and to be used as a complementary support to increase their capacity for work and their motivation out of class. In summary, the development and integration of these software techniques exhibit great advantages since they may speed-up some learning tasks and they can be used to enhance the quality of the teaching methodologies.

Keywords: Bologna; e-learning; video-tutorials; m-learning; Android

1. Introduction

The current educational system is requiring a renewal in the traditional teaching and learning strategies that are more focused on the learning process and the acquisition of skills. Furthermore, in this new educational system students, as well as their learning achievement and their autonomy to acquire specific skills play a central role. Therefore, it is essential to establish new methodologies that promote their independence by acquiring learning skills and enhancing their motivation and abilities. In this way, virtual teaching methodologies and the interaction with suitable online telematic tools would lead to a smooth transition towards the new educational scenario defined in the European Higher Education Area (EHEA) [1–2]. Indeed, e-learning and m-learning tools have experienced a real development and provide high flexibility for their use in Higher Education Degrees.

On the one hand, e-learning methodologies can make subjects more attractive for students and the teaching process much easier for teachers through the interaction with powerful software tools. The presence of these technologies become more critical in engineering subjects, since the complexity of some concepts and physical phenomena are quite difficult to explain and understand. At the moment, the development and integration of e-learning strategies based on video-tutorials is a very popular technique widely applied in Higher Education Degrees. For example, in [3–5] teachers designed a mobile opencast application to watch and comment on video-recorded lectures by means of an active blog. In [3], teachers developed videocasts regarding electronic power supplies to be accessible from mobile devices. Another seamless approach was presented in [4], in which authors made an experimental prototype for the Information and Communications Technology Higher Education Degree. The conclusions achieved in every educational prototype shown that this e-learning methodology was perceived to be more efficient than traditional strategies. On the other hand, mobile devices have

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become very popular in our society and they have contributed to changing our daily life. Mobile learning exhibits many advantages for educational purposes and it is gaining popularity in every educational situation. As well as e-learning techniques, mobile learning allows the teaching process to be more dynamic and attractive than traditional methodologies. It also promotes the individualization of the learning process of students, as they can use and adapt these tools according to their abilities, objectives and skills [6–7]. However, mobile learning provides new real advantages that complement and enhance e-learning techniques, such as a higher portability, mobility and flexibility. As a consequence, there are many educational experiences that integrate mobile devices to develop novel teaching–learning techniques in Higher Education [8–11]. In particular, authors in [8] proposed an experiment in electrical engineering that enhances the motivation and results of students by delivering training exercises to them during the class. In [9], authors developed an interactive mobile application that allows students to electronically document a patient's wounds. In addition, the Mobile System Analysis and Design (MOSAD) prototype was designed to help students to do revision as preparation for the assessments [10]. Another interesting project was presented in [11] in which mobile learning quiz applications were developed for examination and revision purposes. In summary, e-learning and m-learning strategies accord with the new educational system since they help students to support and enforce their knowledge better both in and out of class. Furthermore, these interactive and dynamic online techniques would help teachers to enhance and speed-up tasks regarding the educational process and consequently they help to improve the quality of the teaching process.

On the basis of these previous experiences, we have designed and developed a set of e-learning and m-learning software tools to improve the existing teaching–learning methodologies in optical communication subjects. As was mentioned before, these strategies have initially been adopted in optical communication subjects due to their strong presence in the Bologna adapted degrees of our faculty. However, their applicability and integration in other engineering degrees can easily provide the same benefits for the teaching–learning process. In addition to previous experiences reflected in the literature, our proposal relies on the well-known constructivism theory. This educational theory considers learning as an active and adaptive process in which students construct their own knowledge based on their personal experience [12–13]. In this educational context teachers play a fundamental role, since they should encourage the students' autonomy and initiative and provide a wide range of materials such as interactive or multimedia resources and applications. Therefore, computers and technology may move learning from an outside-guided process to a self-guided process and promote an instruction as the guidance of socially-based exploration [14]. Moreover, there are many experiences that seek for an integration of the constructivist learning theory and mobile technology. Constructivist theory permits mobile technology to focus on the students' autonomy to acquire knowledge and draw their own conclusions. Students learn more when they can personally experiment or explore rather than being told why things works [15]. In line with this educational approach, our proposal encourages individual and personal knowledge acquisition based on experimental and visual interactive tools. First, we have designed a platform of voice-guided video-tutorials that may act as a support for teachers and promote the acquisitions of the students' skills. These videos have been designed to show important and interesting concepts regarding optical communications subjects due to the high complexity of some principles and fundamentals. Secondly, we have developed a set of Android interactive applications that allow teachers to reduce their invested time to explain difficult concepts on a blackboard and provide an additional learning support for students. These software tools are quite easy to maintain and they are accessible for everyone, anytime. Moreover, they help to enhance and speed-up different tasks regarding the educational process, such as the acquisition of specific skills and knowledge.

This paper is organized as follows. In Section 2 we describe novel methodological techniques based on the design of voice-guided tutorial videos. In Section 3 we explain the mobile learning applications implemented for Android mobile devices. Finally, in Section 4, we summarize the most significant conclusions.

2. Design and implementation of e-learning guided-voice tutorial videos

2.1 Video-tutorials for optical communications subjects

Before students access a new laboratory, teachers should prepare some lectures in order to explain the components, devices and software simulators that they are going to find inside, as well as how these devices work, the dangers and safety measurements inside the laboratory and the experiments that students are going to conduct. Then, the teachers should decide how best to convey all these aspects of the laboratory to the students. Lectures have been demonstrated to be a limited tool when explaining every laboratory detail, because students lack of the necessary motivation and, in general, it is difficult to explain some concepts that students are not currently seeing. As a consequence, lectures are of very limited help for students when they are facing experimental work and setups. At our university, teachers of technical degrees usually run into these problems as, for example, teachers of optical communications subjects. Thus, the aim of our proposal is to improve the students' abilities by giving them electronic access to explanations related to lab sessions in such a way that they can observe and understand experimental setups in advance as well as the disposition of the different components or devices. In this way, a set of voice-guided tutorial videos has been designed for optical communication subjects. In order to evaluate their benefits and the integration of this e-learning technique, our proposal has been applied in three optical communication laboratory subjects. One subject belongs to the fourth course of the five years Telecom engineering degree (Optical Communications). The other two subjects belong to the third course of the four years degree, one of them specializes in Telecom Technologies (Guided Communications Systems) and the other in Telecom Systems (Optical Communications). It should be emphasized that the last two subjects belong to the new Bologna degrees and the results presented in the paper are referred to the academic course in which these subjects were taught for the first time (2012–2013). The three subjects are conducted in the second semester of the academic course and they are compulsory, with a total of 75 students. On the other hand, the three subjects share some basic and important skills and objectives that students should acquire at the end of the subject. The most important can be summarized as follows:

- to know the main characteristics of basic optical components,
- to describe the most important optical fiber propagation problems,
- to design optical network systems, and
- to manage optical network simulators efficiently.

In this way, subjects consist of a mixture of lectures and laboratory classes regarding theoretical and experimental optical concepts. In laboratory classes students are divided into groups of two or three people and students must attend every weekly lab session of three hours. The laboratory subjects consist of two different blocks. In the first one, students have to face real optical instrumentation, whereas in the second block they have to deal with an optical network simulator (computer simulation). At the end of the laboratory session, students have to reason the achieved results in order to be evaluated. As these subjects belong to the last courses of the degrees their complexity is especially high and, in particular, this laboratory equipment and simulator are totally new and complex for them. Indeed, the teachers notice that the students waste a lot of time trying to familiarize themselves with the new equipment and simulators and are quite troubled by mounting the required setups. Moreover, the students have to deal with complex concepts and phenomena that are not very easy to understand. Consequently, the designed video-tutorials, which describe instrumentation, optical systems deployments and experimental setups, look to become an efficient technique to assist students and increase their success capacity inside the lab. Furthermore, video-tutorials try to promote the fact that students are more focused on the real lab objectives and can take advantage of the available time.

In our proposal, the designed videos were done using the Camtasia Studio platform [16], since it exhibits very good characteristics and functionalities to record videos and voice. The video-tutorials concern the network simulation platform Optsim, a software tool developed by RSoft [17] to design and simulate optical communication systems. This simulation platform is highly used in the optics research field, but it is also used for teaching purposes in qualified subjects. The main objectives to cover with the development of these video-tutorials are:

- to provide clarity about Optsim and its principles, since it is a new and quite complex simulation platform for students,
- to be a supportive tool for teachers to explain deeply certain complex concepts concerning optical communications,
- to permit an online access to the explanations of lab projects and experiments,
- to promote the acquisition of skills and the autonomous learning process of students,
- to be used in other courses with the same thematic and in online learning courses.

Furthermore, not only are these video-tutorials prepared for laboratory subjects, but they also can be very suitable for use in lectures in order to explain critical and complex optical communications concepts and phenomena. What is more, for the sake of clarity and to be easily handled, their duration is very short (around 3 minutes). According to the objectives, the videos intend to explain the following next optical communication concepts better:

- the design and performance of external modulation in an optical system,

- the design and performance of direct modulation in an optical system,
- the analysis of the chromatic dispersion phenomenon in an optical fiber,
- the analysis of different strategies to compensate for the chromatic dispersion in optical systems.

In Fig. 1, an example is shown of a designed video-tutorial that explains one technique step by step to compensate for the chromatic dispersion in an optical system, by means of the simulation platform Optsim.

Finally, we have integrated these video-tutorials into the learning platform Moodle (version 1.9.3+) [18], as it is free, is very popular and there is a huge user community offering support and collaborating on its development. Moodle facilitates the generation of educational web sites with appropriate tools to support distance learning and blended learning. The introduction of this e-learning platform gives an additional advantage as it facilitates the autonomous learning process required for students, since they should complete their learning objectives with complementary work out of class.

2.2 Results and discussion

In order to assess the impact of these video-tutorials concerning the acquisition of skills and knowledge, we have designed a set of weekly evaluation questionnaires in Moodle that students answer at the beginning of each lab session. These questionnaires focus on the main points explained in the video-tutorials, and they demonstrate whether students have acquired the minimum necessary knowledge in order to handle the lab equipment efficiently and solve the experimental exercises. Figure 2, represents the average mark achieved by students in the questionnaires in every subject. As it can be noticed, students obtained very good marks in these questionnaires, which shows an important degree of involvement and motivation when preparing the laboratory sessions in advanced.

Moreover, at the end of the course students had to fill in a final questionnaire to evaluate their degree of satisfaction about this e-learning proposal based on video-tutorials. The first question asked students when they visualized the video-tutorials, since one of the objectives focus on improving their motivation and autonomous learning during the class and out of class. Figure 3 shows the percent of students that used the video-tutorials after, during and before each lab session. As can be noticed, the majority of students answered that they used them at home in order to prepare the lab sessions and the evaluation questionnaires. Furthermore, around 50% of students used them during lab sessions as a support to mount and understand the simulated systems. In contrast, only a few students visualized them after the lab session. However, it should be quite appealing that students use them to prepare final exams as a complementary tool to enforce

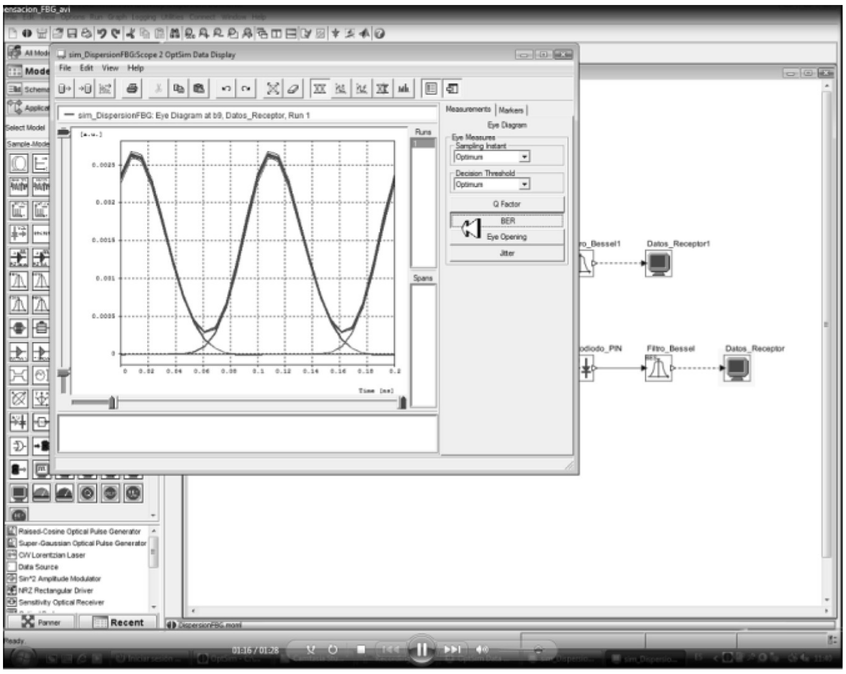

Fig. 1. Screenshot of a developed video-tutorial that shows an intermediate step for building a test to demonstrate the chromatic dispersion concept in an optical system using the commercial simulator Optsim.

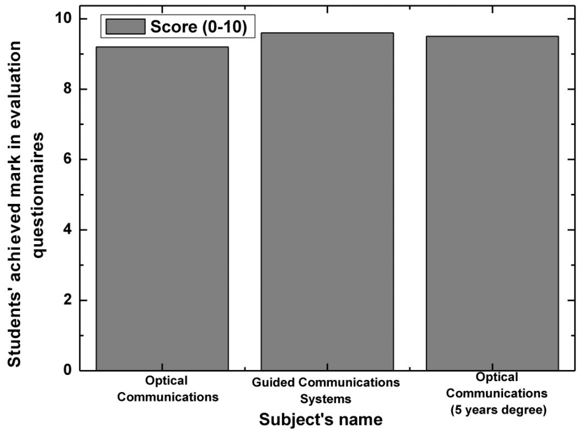

Fig. 2. Final marks of the final evaluation questionnaires regarding video-tutorials.

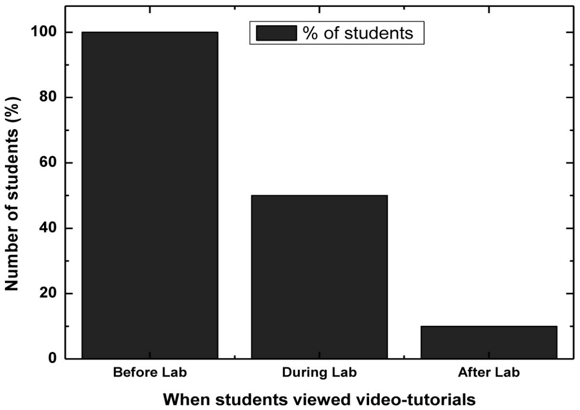

Fig. 3. Percentage of students that viewed video-tutorials before the lab, during lab or after lab sessions.

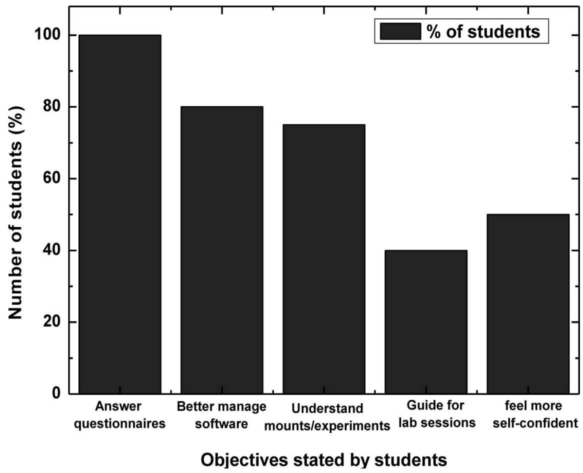

Fig. 4. Objectives perceived by students when using video-tutorials.

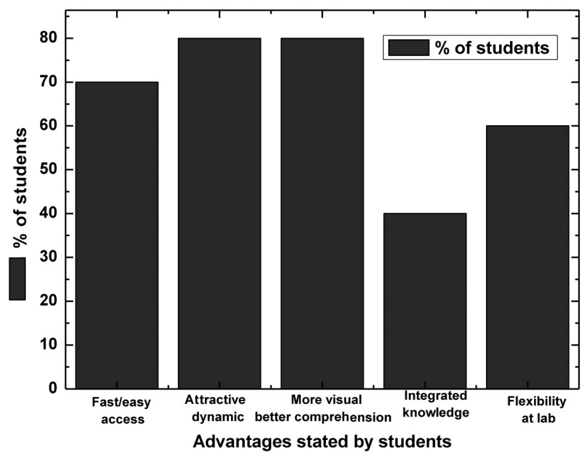

Fig. 5. Advantages perceived by students when using video-tutorials.

their knowledge. As a consequence, teachers should encourage their used for this purpose.

Students were also asked for the objectives they pursued using video-tutorials, particularly those related to acquiring knowledge and skills. Figure 4 represents the most important enumerated objectives and the percentage of students associated with each objective. As can be observed, 100% used video-tutorials with the aim of correctly answering the evaluation questionnaires. However, students stated some other objectives that accord with those we seek with our proposal. Indeed, nearly 50% of students felt more confident when facing laboratory sessions. Moreover, nearly 80% of students thought that video-tutorials helped them to manage the software simulators better and 75% found them very useful to understand the required setups and experiments better. These issues are especially important in optical communication laboratories since the software simulators and equipment used by students are totally new and quite complex to deal with. Finally, around 40% of students used video-tutorials as a guide during laboratory sessions as a support inside the lab, which in our opinion reinforces the autonomy of students, as they do not turn to teachers to solve their problems.

On the other hand, students were asked about the main advantages and disadvantages of video-tutorials. It is quite remarkable what students reflected: some related to the stated objectives, such as dynamism, flexibility, repeatability, easy access, conciseness, clearness and quite motivating. In particular, Fig. 5 collects the most significant advantages that they gave, together with the percentage of students that identified each one. As can be noticed, around 80% of students viewed this proposal to be quite appealing, giving an amusing way to learn in the lab. Furthermore, 80% thought that video-tutorials helped them to comprehend concepts and experiments better due to their graphical appearance. Moreover, around 60% of students perceived more flexibility in the lab and 70% though the fast and easy access to them, and the knowledge they provide during the lab sessions, to be very useful. Finally,

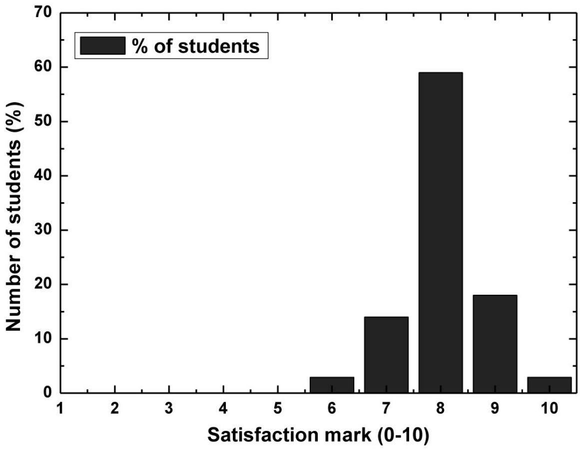

Fig. 6. Students' degree of satisfaction regarding video-tutorials at the end of the course.

near 40% of students noticed that video-tutorials integrate and compact educational knowledge in a very efficient way. With relation to the main disadvantages, the resolution and size of some video-tutorials posed a problem for students to see clearly some details as well as the format compatibility for access from different web browsers. However, these problems are very easy to overcome in the short term.

Finally, in Fig. 6, students expressed their final satisfaction level in a scale ranging from 0 to 10. It can be noticed in the graph that students show a good perception about the benefits provided by the guided-voice tutorial videos. In fact, 80% of students gave a final score above 7 and only 20% gave a final score in the range from 6 to 7.

Alternatively, not only is the student's perception critical but also the teachers' feedback permits one to draw up better final conclusions. As a consequence, we have designed a questionnaire focused on detecting the main advantages and disadvantages of video-tutorials from the teachers' point of view. They were asked about the impact of video-tutorials on students and teachers. In this way, the questionnaire consisted of four questions, as can be observed in Table 1, accompanied by a set of responses that teachers have to rate on a scale from 1 (Not agree) to 5 (Totally agree). Moreover, teachers could write any other responses or perceptions apart from those given. It should be mentioned that 30 teachers from different universities and disciplines participated in this questionnaire, so the collected data provides a very interesting and wide feedback.

The graphs shown in Fig. 7 represent the mean score (from 1 to 5) given by teachers to each response for question 1, 2, 3 and 4, respectively. For question number 1 (Fig. 7(a)), which shows the advantages that video-tutorials provide teachers with in their classes, the mean value of every response is located between 3 and 5. Thus, teachers perceive that video-tutorials improve both simpli-

Table 1. Analysis of the teachers' feedback regarding video-tutorials

Questions	Answers
Question 1: ¿What advantages do video-tutorials provide teachers for their classes?	**Response 1:** A faster way to explain concepts
	Response 2: More simplicity to explain concepts
	Response 3: Easy to repeat explanations without effort
	Response 4: Help teachers to design the subject in order to focus on the most relevant issues
Question 2: ¿What advantages do video-tutorials provide to students for their learning process and to acquire skills?	**Response 1:** Faster than traditional methods to acquire knowledge
	Response 2: Easily accessible from whatever place and whatever time
	Response 3: Repeat explanations as many times as required
	Response 4: Help to focus students in the most important issues of the lab sessions
	Response 5: Students feel more self-confident when facing complex and expensive software simulators and devices
	Response 6: Efficient support to prepare in advance lab sessions
	Response 7: Visual Guide during lab sessions
	Response 8: Better understanding of experimental mounts and techniques
	Response 9: Dynamic, attractive, amusing methodology
	Response 10: Supportiveness to prepare exams
	Response 11: More motivation
Question 3: ¿What disadvantages do video-tutorials provide for teachers?	**Response 1:** It requires much time and effort
	Response 2: Difficulties to promote their used among students to improve their learning capacities
	Response 3: Difficulties to design them so that they contain the suitable concepts
	Response 4: Lack of motivation of teachers
	Response 5: Lack of knowledge/software tools to design them
Question 4: ¿What disadvantages do video-tutorials provide to students for their learning process and to acquire skills?	**Response 1:** They do not promote autonomous learning of students
	Response 2: They do not adjust to the mean level of every student
	Response 3: Students loss skills to handle manuals for the utilization of software tools
	Response 4: Students have difficulties finding software to easily visualize video-tutorials
	Response 5: Passivity. Students identify videos with watching a television program. Lack of effort to assimilate knowledge

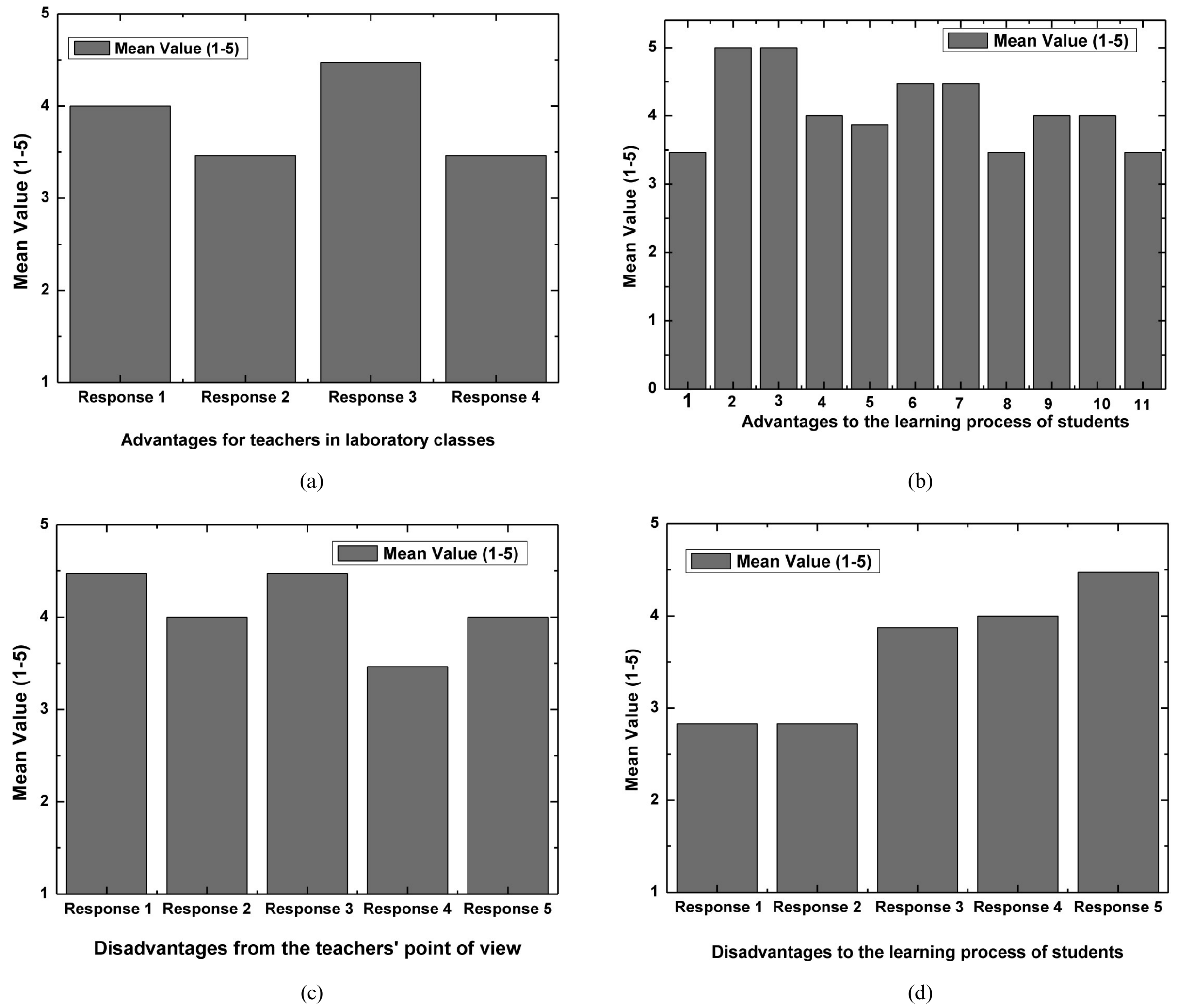

Fig. 7. (a) Advantages for the teaching process, (b) advantages for the learning process of students, (c) disadvantages perceived by teachers, (d) disadvantages for the learning process of students.

city and speed when explaining concepts or experiments and they are quite helpful in designing the subject to focus on the most relevant issues. Moreover, they find it very interesting that students can repeat the explanations without effort. However, teachers also notice other additional and interesting advantages that enhance their teaching quality. In this way, some teachers think it very appealing in its applicability to show the performance of real systems (electronic, mechanic) because in real time demonstrations failures in components or devices may appear. Furthermore, video-tutorials give the chance to design videos with multiple examples and the opposite results, so they permit one to cover a wide range of cases that can be analyzed by students. For question number 2 (Fig. 7(b)), which shows the advantages that video-tutorials provide to enhance the learning processes of students and the acquisition of skills, it can be observed that the majority of responses scored over 4. In particular, teachers highly agree with the easy access and the repetitive functionalities that video-tutorials provide. Moreover, teachers accord with the idea that video-tutorials become a suitable support for students to prepare for classes and exams.

Regarding the disadvantages of applying this e-learning strategy in class (Fig. 7(c)), it can be observed that the majority of teachers agree with the proposed responses, since the majority of teachers set a mean value above 4. Teachers highly agree with the idea that this technique can consume a great deal of time and effort for teachers and it can be quite difficult to design video-tutorials that contain the most suitable concepts. Moreover, teachers perceive that the lack of motivation and knowledge to deal with software tools to develop video-tutorials could become an important handicap for their applicability in class. However, teachers perceive other disadvantages that are quite interesting to comment upon. For example, they put special emphasis on the complexity related to the video edition. Furthermore, teachers think that video-tutorials can reduce the feedback provided in lectures and students could think that teachers do not work because the explanations have only been given once. Finally, Fig. 7(d) represents the disadvantages of video-tutorials for students from the teachers' point of view. It is quite noticeable that the troubles regarding promoting autonomous learning or making it difficult to find the mean level of the class is not the main concern of teachers. In contrast, they perceive negatively that students become passive to assimilate knowledge and they can lose skills in understanding and dealing with documentation. Teachers also think that students may have problems in visualizing them. Moreover, teachers gave other interesting disadvantages. For example, teachers find the duration of the video crucial, in the case for example of students who need to look for a specific explanation on the video. Furthermore, teachers consider that to go into complete detail in the videos could become complex in some cases. Teachers also state that if students rely on video-tutorials so much then they can loss the motivation to learn by themselves (the Google effect).

In conclusion, these results demonstrate that the implementation of guided-voice tutorial videos in optical communications subjects provides several advantages and students perceive the use of this e-learning strategy as a good chance for achieving and enforcing the required knowledge and skills. Moreover, some of these advantages can be extrapolated to other engineering subjects. In this way, video-tutorials may help students to take better advantage of the available laboratory time, especially in those laboratory subjects that involve working with complex and specific equipment or software simulators. In fact, students can be able to visually previously access instrument descriptions or techniques to build and carry out experiments and laboratory set-ups. As a consequence, students feel more confident and they are more focused and concentrated on achieving the specific objectives of each laboratory session. Furthermore, these interactive videos permit the explanations to be easily repeated, since students can interact with them everywhere and when they want. Finally, students can adapt their use according to their necessities and their available time.

3. Design and implementation of e-mobile applications for Android devices

E-learning strategies incorporate flexibility to the learning process and allow students to develop specific skills, such as autonomous learning and capacity of work. However, mobile technologies go a step further, as they greatly improve the autonomy, flexibility, portability and independence of the use of the online tools to acquire knowledge and skills. Even more, m-learning strategies allow us to develop interactive activities in class that are beyond the capacity of e-learning tools. Due to the many advantages offered by mobile technologies, we propose to incorporate m-learning strategies in optical communications courses in order to support and enhance the learning process and to adapt traditional teaching–learning techniques in engineering degrees. Consequently, at a first stage we have programmed a set of Android [19] applications regarding optical communication concepts, since in this area students have to cope with concepts and physical phenomena that are quite difficult to visualize and understand. These mobile applications try to graphically explain some important optical communication phenomena, in order to make it easier in their explanation, providing a good support for students. Even more, these graphical applications look for increasing their motivation and they try to incorporate a dynamic and an amusing way to learn and to comprehend some fundamental principles of optical communications, since students are constantly dealing with mobile devices and they view these techniques as being very attractive. Moreover, students can adapt their functionalities according to their level and their needs and they can use them in their personal mobile phones, allowing an individuation of the learning process and the acquisition of skills.

With regard to technological issues, the number of software platforms that we can use to implement our mobile applications is relatively low. Nowadays the most important are those based on iPhone OS, Android or Windows Mobile. However, we are going to use the Android environment due to its market share. Indeed, Android is one of the most spread out mobile operating systems, coping with the 75% of the worldwide smart phone market in the third quarter of 2012 [20–22]. One essential advantage of this mobile operating system is that it is free and very simple. Furthermore, Android provides the necessary tools for Android developers to design applications, making it easier to implement mobile applications and upload them onto the Android Market.

3.1 Mobile application to model optical communications concepts

The developed Android applications regard optical communication concepts used in laboratory subjects, so students are provided with complementary and graphical tools to enforce their knowledge. Furthermore, these mobile learning applications give students more independence from computers and allow them mobility inside the lab, since applications are accessible from their personal mobile devices. Consequently, the accessibility to these visual applications is immediate.

The first approach of our proposal focus on implementing two interactive applications to understand graphically and visualize two typical optical communication phenomena. On the one hand, how the light propagates through an optical fiber is one of the most important concepts in optical communications. The light propagation inside an optical fiber could be explained by the total internal reflection mechanism [23–24]. On the other hand, the concepts of phase velocity and group velocity of a wave inside an optical fiber are crucial to understanding one of the most important phenomena in an optical system, the chromatic dispersion. Indeed, the chromatic dispersion limits the maximum transmission rate of an optical system and it determines its Bit Error Rate (BER) [23–24]. However, these concepts are particularly complex to visualize and to explain on a blackboard, so a graphical and interactive explanation provides additional help so that students can comprehend them better. In addition, students can visualize them quickly and as many times as they need.

Apart from the contents of the applications, there are important technology issues that must be taken into account when a mobile application is designed. The aim of our proposal is that the mobile applications could be easily run with a clear design and objectives. Amongst these issues, the design should take into account the limitations imposed by the size and resolution of different mobile screen models. In line with these limitations, it is important to select a suitable number of menu options due to the lack of space on the screen. Moreover, it is quite appealing that the applications consist of a low number of

Fig. 8. Graphical depiction of the panel with the calculated output parameters.

panels for the sake of simplicity. Finally, it is greatly desired to have lightweight software applications because they should be installed in the students' mobile devices.

In this way, the global design of the light propagation mobile application consists of three panels, called activities, in Android. The main screen is divided into three sections: the input parameters section, the results section and a main menu section that permits users to interact with the remaining panels of the application (Fig. 8). As can be shown in the figure, the input parameters correspond to the refractive indexes, the transmission wavelength and the input angle. Once the parameters are filled, it is necessary to press the 'Accept Parameters' button to visualize the results. Then, the results section is highlighted and updated. The output parameters in the results section are the numerical aperture, the critical angle, the maximum acceptance angle and some others related to the refractive indexes. Furthermore, if the user presses the 'View' button, a panel appears that graphically represents how the light travels through the optical fiber (Fig. 9). Inside this graphical description, the most important output parameters are showed. Finally, the 'Help' button opens a tutorial guide to the application.

On the other hand, the interactive application of the phase and group velocity shows the time evolution of two transmitted waves. First, it is considered that both flat waves travel in the same direction, so that users comprehend and visualize the combination of two waves of different frequency and wavelength better. In addition, our design assumes an infinite medium, which allows a simplification of the physical model [23–24]. As a consequence, the application shows how the group and the phase velocity evolve in an optical fiber, and it permits one to notice how the chromatic dispersion takes place inside a fiber. The graphical appearance of the Android application is divided into three panels. In the two first panels, users specify the input parameters of both flat waves (Fig. 10). The first

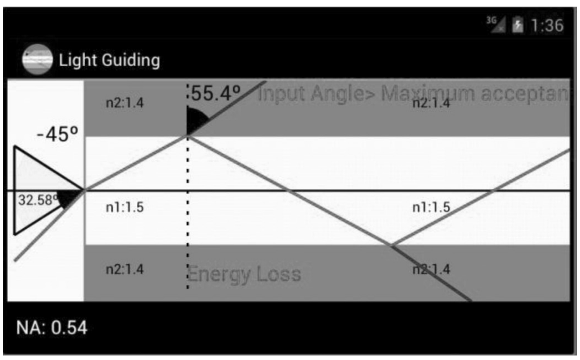

Fig. 9. This panel shows the result of the light propagation depending on the input angle.

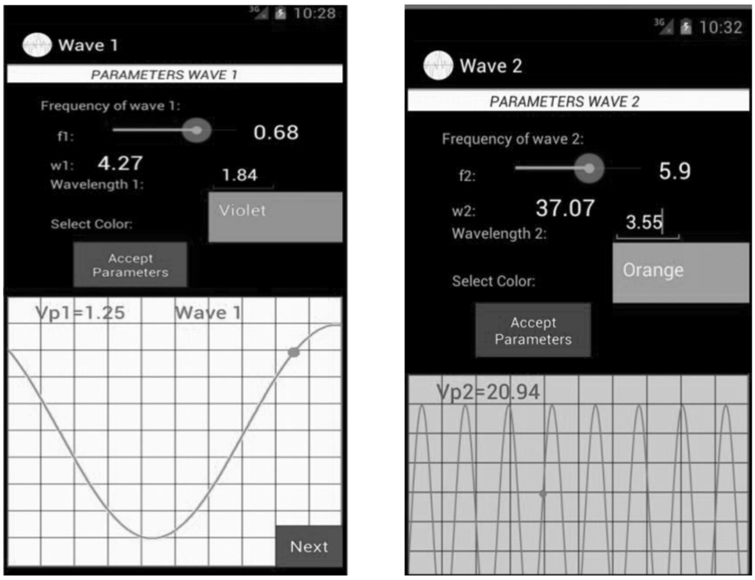

Fig. 10. Panels to introduce the configuration parameters of the two waves in order to show the group velocity concept.

panel contains the parameters of the first wave (wave 1), whereas the second one contains the parameters of the second wave (wave 2). Once these parameters are filled, the application calculates the phase velocity and also it depicts the wave form (Fig. 10).

Furthermore, there is a final panel that consists of three tabs with the parameters and graphical appearance of the time evolution of the three waves: wave 1, wave 2 and the resulting wave (Fig. 11). As was mentioned before, the resulting wave is the combination of wave 1 and wave 2.

As can be noticed in both mobile learning applications, the number of input and output parameters is suitable for their correct visualization on the mobile screen. Furthermore, the graphical depict of the light transmission and the group velocity, are quite intuitive and they easily represent the correct visualization of both phenomena. Finally, it is remarkable that both mobile applications consist of a short number of panels, two for the light transmission and three for the group velocity. Consequently, it can be stated that the design requirements accord with the previous established objectives.

Fig. 11. These three panels show screenshots of the 'Group Velocity' mobile application. Students can compare, by observing the point inserted in the three curves, that the propagation velocity is different for the original waves (the two on the right) and the composed wave (the one on the left).

3.2 Results and discussion of the mobile learning interactive applications

The mobile applications have been programmed in Android, since it is one of the most widespread mobile operating systems. In order to confirm that students mainly have this operating system, a survey of their mobile operating systems was carried out. Figure 12 shows the percentage of students with different mobile operating systems, and we can notice that more than 70% of the students have Android (versions 2 and 4) in their mobile devices. Therefore, it can be stated that the designed mobile applications can reach a good number of the students.

In order to assess the benefits of the designed applications, students had to solve a short exercise using the mobile applications. In particular, for the light propagation application, students had to calculate the numerical aperture and the maximum acceptance angle of a ray transmitted along an optical fiber. Moreover, they should understand the spatial evolution of the ray along the optical fiber depicted by the application. Then, we carried out a questionnaire divide into two parts in order to know if students were able to use these applications in order to solve some tasks inside the laboratory and also to detect their main strengths and weaknesses from the user's point of view.

Regarding the first part of the questionnaire, the analyzed results show that every student solved correctly the proposed exercise. This means that the mobile application is quite intuitive for students and clear enough to be handled. Indeed, students stated that the mobile application made it very fast and easy to understand the physical phenomenon and to calculate their related parameters. On the other hand, in the second part of the questionnaire, students were asked for the most important advantages, disadvantages and possible improvements of the developed mobile applications. Figure 13 collects the most significant advantages they perceived and the percentage of students that identified each of one. As can be noticed in the figure, 80% of students view these applications that are suitable to calculate important parameters of theoretical and experimental concepts quickly. Moreover, nearly 85% of students emphasized that the easy graphical visualization of the physical phenomenon made it easier to understand important physical phenomena. In Fig. 13 it can be observed that students gave a high score to other important functionalities such as portability/flexibility (60%), accessibility (50%) and easy management (70%) of the mobile learning applications. However, they stated other interesting advantages, as for example they perceived this kind of mobile strategy to be a good tool to complement their knowledge out of class. They also underlined that these applications can be installed in their personal smartphones and they can use them in a personal way according to their necessities and objectives.

Finally, students came up with some interesting disadvantages, improvements and suggestions to be considered in the design. Regarding the main disadvantages, some students noticed some problems with the latency and fluency of the graphical visualization of the physical phenomena. Furthermore, sometimes they found problems with the compatibility with mobile operating systems. However, these problems are very easy to deal with in the short term. Finally, they recommended some improvements regarding the design, such as changing the colours of the buttons in order to distinguish them from the background and the way they insert the value of some parameters inside the application (i.e. wavelength). They also proposed to extend the functionalities of the existing applications and even to simulate other physical phenomena.

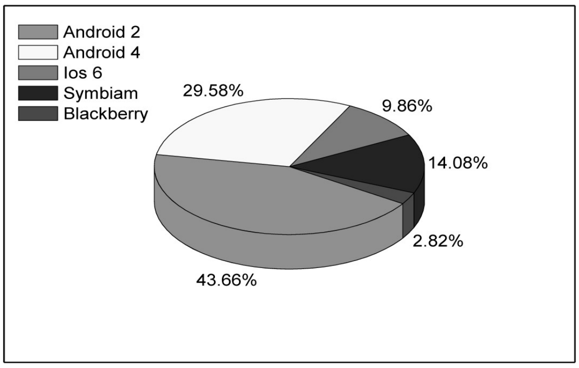

Fig. 12. Mobile operating systems used by students. Android is present in 72% of the smartphones.

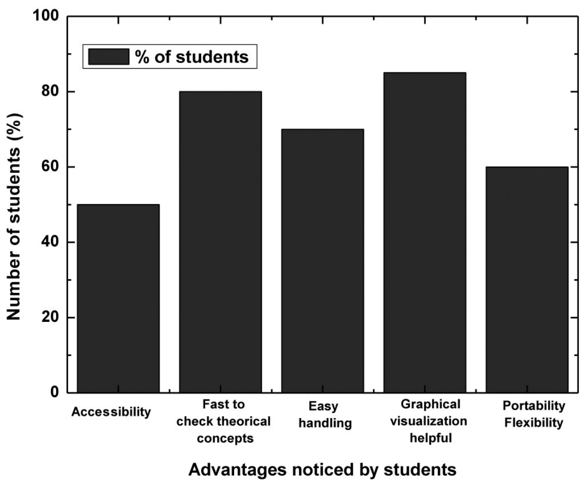

Fig. 13. Main advantages perceived by students when using the mobile learning applications.

Table 2. Questionnaire to carry out the analysis of the teachers' feedback regarding mobile learning applications

Questions	Answers
Question 1: ¿What advantages do mobile learning applications provide for the teaching process?	**Response 1:** They enrich and offer variety to traditional lectures
	Response 2: They provide students new resources to improve graphical comprehension of physical phenomena when compared to traditional strategies
	Response 3: They improve the teacher-student interaction by means of different learning strategies
	Response 4: They give additional support to fix concepts and explanations
Question 2: ¿What advantages do mobile learning applications provide to students for their learning process and to acquire skills?	**Response 1:** Knowledge portability
	Response 2: High availability and easy accessibility
	Response 3: Adaptability to the students learning rhythm
	Response 4: They promote the students' exploratory learning
	Response 5: Better understanding of experimental and theoretical phenomena
	Response 6: Dynamic, attractive, amusing methodology
	Response 7: Autonomy of the learning process
	Response 8: High flexibility and freedom in the learning process
Question 3: ¿What disadvantages do mobile applications provide for teachers?	**Response 1:** High time and effort to implement
	Response 2: Difficulties to promote their use among students to improve their learning skills
	Response 3: Difficulties to adapt teachers to mobile devices
	Response 4: Lack of knowledge/software tools to design them
Question 4: ¿What disadvantages do mobile applications provide to students for their learning process and to acquire skills?	**Response 1:** Restrictions regarding the screen size, resolution, mobile operating systems
	Response 2: Students do not adapt their use according to their learning capacity
	Response 3: Difficulties to install or use the mobile learning applications

As well as in the previous study, we have designed a questionnaire focused on detecting the main advantages and disadvantages of this proposal from the teachers' point of view. They were asked about the impact of these mobile learning techniques in students and teachers. The questionnaire consisted of four questions, as can be observed in Table 2, accompanied by a set of responses that teachers have to rate on a scale from 1 (Not agree) to 5 (Totally agree). Moreover, teachers could write any other responses or perceptions in addition to the given responses.

The graphs in Fig. 14 represent the mean score (from 1 to 5) given by teachers to each response for questions 1, 2, 3 and 4. For the question about the advantages that mobile learning applications offer teachers for their learning process (Fig. 14(a)), teachers think that they enrich traditional methodologies, providing a new way to fix concepts and graphical resources to comprehend physical phenomena. In contrast, teachers perceive that these strategies do not promote the interaction between teachers and students. Furthermore, teachers think that these mobile learning applications are highly available and accessible for students, promote autonomy, flexibility and adaptability to the learning process of students and offer a more amusing way to learn, as can be observed from Fig. 14(b). However, teachers also perceived other given advantages that are quite positive for the learning process of students. Moreover, teachers gave some other ideas that enhance their applicability in class. In this way, they think that some learning activities (pedagogical) should be associated with the mobile applications in order to motivate their use out of class. Regarding the disadvantages for the teaching process (Fig. 14(c)), teachers highly accorded with the idea that their development requires a huge amount of time and effort and teachers could find it difficult to deal with mobile technologies. In addition, the lack of knowledge regarding software tools can be a handicap for their implementation in class. Finally, in Fig. 14(d), which shows the main disadvantages for the students learning process, teachers highly agree with the restrictions regarding resolution, size screen or mobile operating systems. Moreover, teachers find it difficult that students can be able to efficiently adapt their functionalities according to their learning process and with regard to the installation of mobile applications. With relation to other responses of teachers, they think that students might feel discriminated against if they haven't got a compatible smartphone or students might be distracted away from lectures and labs if they are constantly playing with mobile applications.

The results extracted from these questionnaires permit one to state that the development of mobile interactive applications may be quite appealing and advantageous to other engineering subjects. In this way, the explanation of complex phenomena or experiments can be faster and easier using real simulations or graphical animations of processes. Indeed, it allows teachers to reduce the invested time to explain difficult concepts on a blackboard and complement their explanations. Consequently, their applicability to other engineering degrees increases the number of learning tools and resources to support the teaching–learning process better. Furthermore, students could improve and reinforce

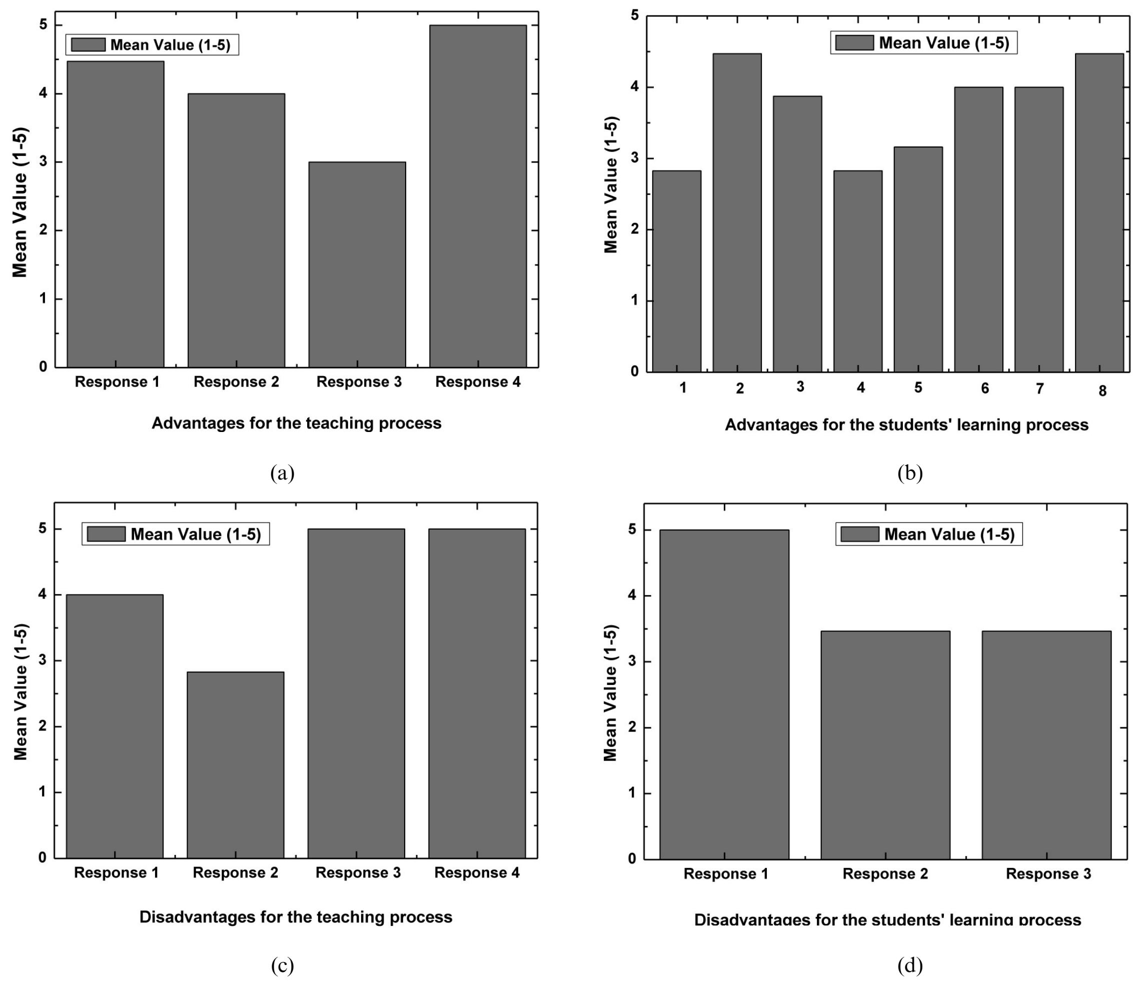

Fig. 14. (a) Advantages for the teaching process. (b) Advantages for the learning process of students. (c) Disadvantages perceived by teachers. (d) Disadvantages for the learning process of students.

their knowledge by means of their personal exploration and experimentation thanks to these mobile applications. In contrast, there are some risks that should be taken into account as, for example, the lack of awareness of the teachers in technological issues could be an obstacle to the introduction of these techniques. From the students' point of view there seems to be less obstacles, however teachers should make an effort in order to prepare some activities that promote a good use of the applications.

4. Conclusion

In this paper the design and implementation of a set of e-learning and m-learning resources focused on subjects of the optical communications area has been presented. This area is highly complex and it is a good scenario for the practical use of our proposal. These software applications aim to be a powerful tool in lectures and laboratories to explain fundamental principles and physical phenomena better. Furthermore, the developed applications aim at becoming an additional support for students when acquiring the required knowledge and skills.

On the one hand, a set of guided-voice tutorial videos has been developed with experimental mounts and projects of optical communications concepts. Questionnaires distributed among teachers and students have shown interesting advantages. In fact, students perceived this e-learning technique to be quite amusing and motivating, especially when facing difficult laboratory subjects that involve dealing with complex simulators or software. Furthermore, they stated that video-tutorials helped them to comprehend physical concepts and experiments better, due to their graphical explanation. Finally, they think that video-tutorials provide high flexibility and portability inside the lab and students can access them during the lab sessions in a very fast and easy way. From the teachers' point of view, video-tutorials speed-up and simplify explanations or experiments so that they can focus on the most relevant concepts of lab subjects. They also think that the repetitive characteristic of video-tutorials can help to enforce the learning process of students and they become a powerful technological tool to support students when preparing classes or exams. Finally, teachers think that video-tutorials are very suitable for showing the performance of real time systems and they can easily cover a wide range of cases or examples. Consequently, this e-learning strategy looks at improving the autonomous learning process of students and the acquisition of skills required for their future careers.

On the other hand, we have combined mobile learning with these e-learning teaching methodologies to improve the quality of the teaching–learning process. In particular, we have designed several interactive applications for Android devices about optical communication physical phenomena. Questionnaires distributed among teachers and students have made clear that one essential advantage of the proposed m-learning applications is that students are able to personalize their use according to their abilities and necessities when acquiring knowledge and skills. In particular, students underline that the graphical visualization of phenomena help them to understand complex concepts. Moreover, students highly emphasize other interesting advantages that mobile applications provide, such as portability, flexibility, accessibility and easy handling. In line with students, teachers highly agree with these functionalities but they also think that these mobile techniques enrich and support traditional methodologies. Moreover, teachers find it very appealing that students can use these mobile applications to fix and reinforce their knowledge by means of their personal exploration and experimentation.

Finally, we think that the adaptation of these e-learning and m-learning resources is very appealing and interesting to other engineering degrees in order to achieve the same advantages. Indeed, the proposed techniques can make teachers speed-up the explanation of theoretically complex concepts using real time graphical animations and simulations. Furthermore, they may enhance the autonomous learning of students by means of personal experimentation with the designed interactive software applications and resources.

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