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Augmented reality to promote collaborative and autonomous learning in higher education

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ABSTRACT

The learning scenarios described in this work reach further than any previous approach. The connections between augmented reality (AR) and traditional learning based on textbooks through the well-known augmented books also known as "magic books," are already there. However, they are restricted to just a few isolated uses that commonly take place on a PC showing 3D information with few actions in higher education. In a collaborative and autonomous way, this work combines every learning process from the electrical machines course in the electrical engineering degree. It allows interactive and autonomous studying as well as collaborative performance of laboratory practices with other students and without a teacher's assistance. Tools presented in this work achieve a connection between the theoretical explanations and the laboratory practices using augmented reality as a nexus. Students feel comfortable about it and consider that tools are nice, easy, and useful, according to the goal of learning contents, training on performance, and design of installations and machines.

1. Introduction

This past decade has been the time when all information and communication technologies (ICTs) have been extended to every field of our society, and of course in the learning field where there have been abrupt changes in teaching methodologies, as well as in teaching resources used in the learning process. ICTs are presented as a tool associated with the actual social context where the need of access to information anytime and everywhere, the quick technological changes, deeper social knowledge, and demands of a high level education, which is constantly up to date, becomes a permanent demand.

Right now, education and teaching institutions try to avoid traditional teaching methods despite their validity and successful results, as the interest now focuses on more productive methods that may improve the learning experience and the students' intellectual level. Computer technologies have provided a strong improvement according to educational tools, allowing development of new teaching methodologies. During the last few years, the educational institutions from all levels have tried to evolve by integrating and using ICTs in teaching methodologies for improving the teaching–learning processes. Many universities have adopted virtual learning environments (VLEs) for helping in the teaching process. Following this trend, Pan, Cheok, Yang, Zhu, and Shi (2006) have already demonstrated that virtual learning applications may provide the adequate tools that allow users to learn in a quick and efficient way, interacting with virtual environments. Both learning environments and computer tools have enjoyed good feedback from students and teaching staff. Those students may be considered as digital natives, because in their ordinary life they are constantly interacting with a lot of graphic information provided by videogames, the Internet, or 3D movies. This fact causes many researchers, teachers, and pedagogues to focus eagerly on new visualization methods for improving the current teaching models. One of the most promising technologies that currently exist is augmented reality (AR), which allows a combination of real world elements captured through a camera with multimedia elements such as text, images, video, or 3D models and animations. Computer Supported Collaborative Learning is a pedagogical approach that can be used for deploying educational apps based on augmented reality in higher education. Collaborative learning is a method applied to learners for performing common tasks in small groups in order to reach shared goals or learning results (Heejeon, 2011), which is introduced as a learning strategy

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that supplements issues found in the traditional learning environment since it presents an opportunity for students to experience enriching interactions and to participate in active learning. Researchers have pointed out that collaborative learning is where the greatest potential of the AR (Billinghurst & Kato, 2002; Kaufmann, 2003). Collaboration occurs when learners are involved with social interactions, which would result in improved learning capabilities. In the AR where the virtual and physical worlds coexist, users learn while communicating with others in the same space. This naturally leads to collaborative interactions (Park, Jung, & You, 2015). Mobile devices, particularly smartphones, are an ideal platform for the collaborative AR. Billinghurst and Kato (2002) describe the main characteristics of collaborative AR.

Azuma (1997) defines AR as a variation of virtual environments (VR). VR technology completely immerses the user in a synthetic environment, which can interact with obtaining answers, while not seeing the outer real world. However, an augmented reality environment allows the user to see the real world with virtual computer-generated objects superimposed or merged with real surroundings. In terms of used technology, AR can be said to require the following three characteristics: it combines the real and virtual, it is interactive in real time, and registered in 3D. Among the most innovative tools for virtual education used in higher education have been the development tools from virtual worlds on education (Lucke & Zender, 2011). The virtual environments allow students to create an avatar and train, learn or manipulate virtual objects. The virtual world experience emulates the experiences and items from real life, but AR technology allows the coexistence of virtual elements in real environments, so interaction between objects is completely real (Saleeb & Dafoulas, 2011; Schiller, Mennecke, Nah, & Luse, 2014).

According to The New Media Consortium's 2011 Horizon Report (Johnson, Smith, Willis, Levine, & Haywood, 2011) augmented reality is becoming a technical trend in higher education for making technology blend virtual and real worlds, and is expected to reach mainstream use in education through augmented reality textbooks (augmented book).

Today, one of most relevant changes in our society is augmented reality, which is a technology that is being developed in several fields and applied to medicine, architecture, marketing, advertising, military, archeology, leisure, etc. (Craig, 2013). The versatility offered by AR technology has allowed the development of applications for several knowledge areas of education like mathematics, mechanic, physics, and town planning, among many others. The work of Ibáñez, Serio, Villarán, and Delgado (2014) is an experience based on AR learning about the basic principles of electromagnetism. Although it was a close approach to our contribution, our work context goes even further, promoting real learning in both collaborative and autonomous learning. *Physics Playground* is an interesting tool developed by Kaufmann and Meyer (2008) for explaining physical experiments and concepts through animations, where the student has the chance to interact with virtual objects and practice with them to learn in a fun and entertaining way. Over time there have been more teaching tools with augmented reality technology, such as training of spatial abilities by Martín-Gutiérrez et al. (2010), and the training for future anesthetists using operating theater material through an AR simulation (Quarles, Lampotang, Fischler, & Fishwich, 2009).

According to Bujak et al. (2013) this technology creates possibilities for collaborative learning around virtual content in non-traditional environments. Besides, the authors of this work provide guidelines for future AR learning experiences from the analysis of existing AR applications, considering its pragmatic and technological concerns facing the widespread implementation of augmented reality inside and outside the classroom. Cuendet, Bonnard, Do-Lenh, and Dillenbourg (2013) starting from the premise that classroom usability increases if the learning environment satisfies all classroom constraints, proposes a design of material and resources adapted to classroom based on AR for performing teaching duties following collaborative learning guidelines. Authors such as Kerawalla, Luckin, Seljeflot, and Woolard (2006) made reference to the 'AR for learning' term proposing several design requirements which may be considered: (1) AR systems should be flexible enough for the teacher to adapt to the needs of their students; (2) the content should be taken from the curriculum and delivered in periods as short as other lessons; and (3) the system should take into account any constraints of the context. Goals of our contribution include considering these three requirements, applying it to three different teaching contexts: use of electrical machines at the laboratory, professional use (reading and interpreting diagrams for inspecting installations) and autonomous study of contents.

In higher education, some AR experiences have been performed already but they have not generated any didactic material for continued use. We can just mention a few collaborative learning studies about land and town planning fields (Chen & Wang, 2008; Fonseca, Martí, Redondo, Navarro, & Sánchez, 2014). These experiences concluded that AR technology may improve the design of tasks performed by students and their academic performance.

In the context of collaborative AR learning is worth mentioning the experiences from the chemistry and molecular biology teaching field (Gillet, Sanner, Stoffler, Goodsell, & Olson, 2004; Cai, Wang, & Chiang, 2014).

Luckily, university classrooms have been updated, giving them the infrastructure needed for using the most suitable teaching technologies such as internet networks, computers, electronic blackboards, projectors, and videoconference systems. Every one of these technologies could allow the integration of augmented reality inside the classrooms; in fact, research has shown that learning does occur in virtual environments (Harrington, 2006). One of the earliest works in this area, applying AR to an educational context, is the "Classroom of the Future" (Cooperstock, 2001), which conceptualizes how it could be possible to enhance interaction between instructor and students to interact through various interactive scenarios in a collaborative environment.

Augmented reality can also be used to enhance collaborative tasks. A good example is this work, as it allows several users to perform tasks together. In this paper, actions described have been performed with 50 engineering students from the electrical machines course. Through augmented reality technology, the students were able to perform training of the use of dangerous machines in a safe way, checking the virtual information associated with the symbols on the diagrams and electrical installations, and study with notes upgraded by virtual information provided by the teacher. Besides, it should be noted, that the use of new technologies increases student motivation, although that is not the goal of this work. Any methodology that captures the interest and enthusiasm of the students improves their performance.

In the following section, we present recent didactic materials and experiences about the application of augmented reality in higher education contexts. After that, the observed results and feedback surveys are analyzed. Finally, conclusions are presented as well.

2. Augmented reality applied for training and education in electrical engineering

Since the creation of the European Higher Education Area in 2010, university education across Europe, especially in Spain, has undergone a deep transformation within the new European framework, regarding the structure, methodology, and the philosophy of technical education. In this context of renewal and convergence, there is a new concept of the European Credit Transfer System, which measures not only classroom teaching hours, but also the total amount of work needed to meet the goals of the program of study (EHEA, 2010). The changes clearly show a new philosophy aimed at customized teaching and encouraging autonomous work of the students. It implies a deep change in the Spanish educational system and requires a new teaching methodology based on new strategies and objectives. The reform promotes "tutored" work rather than "master" teaching. At the same time, there has been a large increase of students in Spanish universities due to the existing economic crisis in the country and the high unemployment rate. This situation is particularly severe in technological careers where the teacher/student ratio has not been increased (as would be expected from the reform), but reduced due to the growing demand for these sorts of degrees.

This fact has a negative influence over the attention paid to students and the quality of teaching. The problem is especially noticeable in the practical teaching of these subjects, where student mentoring and supervision is much more necessary, and learning must be completely personal and manipulative. Therefore, we are aware of the need to seek new ways of teaching in electrical engineering practice, and are looking for more efficient alternatives to minimize the problems we face in the current context.

Given this new challenge, teachers have to take advantage of the tools that new technologies may provide, such as Virtual Teaching and augmented reality (AR). The teaching of engineering is particularly suitable for the use of these technologies. We have experienced some Virtual training in the area of engineering teaching. We have used Virtual Simulators for the study of electrical machines. Virtual reality is a good way to increase the knowledge acquired by students; but for a future engineer, real practical learning is essential when dealing with their future professional challenges. In that sense, the AR teaching opens new possibilities because it allows us to combine the real and virtual worlds, increasing the autonomy of students while maximizing the time and resources available.

Focusing on the electrical engineering branch, we have implemented different applications of AR in order to improve several aspects and needs of the students in this field. We understand that engineering education should include both theoretical and practical aspects, and in the following sections, three applications that have been developed and used to achieve this goal are described.

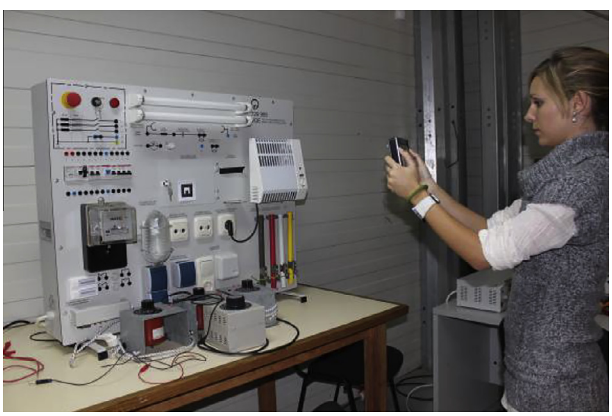

Fig. 1. User visualizing the training she is about to perform on AR.

3. Material

3.1. ElectARmanual: AR training for installations and electrical machines practice

The authors have developed an educational augmented reality application called *ElectARmanual* (Martín-Gutiérrez, Fabiani, Meneses-Fernández, & Pérez-López, 2012), which is supposed to support students in a practice laboratory and then in training for use of electrical machines (Fig. 1).

The application is an assistant, which guides the student step by step through the tasks that he may perform in order to understand instructions and explanations of the practice's manual provided by the teacher in the laboratory. An animation of 3D models is superimposed over the main panels at the workplace indicating how to connect the wires, and place several components (coils, magnets, rotor, wide pole pieces, etc.) for creating installations of several sorts, creating configurations of electrical machines with different purposes. For visualizing each sequence, the user will press a key from the laptop or press the "next" button on tablet or smartphone's screen.

The Electrical Machine Laboratory has four independent workplace ranging from protection systems, analysis, construction and operation of different types of electrical machines, to industrial

Fig. 2. Workplaces in the electrical laboratory.

electrical equipment—training in electrical machines' automatic control (Fig. 2).

- Electrical protection (Masterlab-5000, by 3E Electronic didactic material).
- Construction and study of electrical machines (TPS 2.5, by Leybold Didactic GmbH).
- Performance and operating characteristics of electrical machines (Lucas-Nülle GmbH).
- Coach of industrial electrical installations – training in electrical machines automatic control (Masterlab-3000, by 3E-Equipos Electrónicos Educativos, S.L.).

ElectARmanual has been implemented for performing practice or training over the mentioned equipment. These practices are devoted to students in the university degree's first courses, and who are without any previous experience in this subject. Due to the laboratory's structure, it is hard for the supervisor to perform all teaching and control duties because different groups should develop quite different practices at the same time. The traditional practices model is not efficient, since a single teacher has to guide and teach 25 students, conducting very different practices simultaneously. As a result, direct mentor time spent by the teacher for each student is greatly reduced. There is also the danger of this type of practice, where students must manipulate actual pieces of an engine with high working voltages. Use of *ElectARmanual* provides the students with a positive attitude and autonomy while training, and it also reduces the teachefs dedication to every student, thus improving safety in the laboratory.

3.1.1. ElectARmanual description

To develop this app, we have worked with researchers from Labhuman institute (www.labhuman.com) to create a software library called HUMANAR (Martín-Gutiérrez et al., 2010). It uses computer vision techniques for calculating the real camera viewpoint relative to a real world marker, which calculates integration of three-dimensional objects codified by the camera and captured by itself in real time. When the marker enters the scene picked up by the camera, the fusion of the real world with the virtual object is shown on the screen. This requires the application to relate the two worlds (real and virtual) in a single system of coordinates. The key technical issues for the development of the AR practical guide have been marker detection, camera calibration, calculation of marker position and orientation, augmentation of virtual object.

Our AR software identifies fiducial marks. Each mark is a black frame image containing a white surface divided into 4 rows and 4. We have 16 squares where black and white colors will define the individual mark. Using the binary base of each cell, the mark can be converted into a hexadecimal base digit that will be read by the software. Our augmented reality software identifies the marker through a decimal association, and that is why this hexadecimal code of 4 digits should be transferred to decimal notation. Finally, we associate the decimal code belonging to a mark with a sequential description of a practice, including some 3D model files in any of these formats: FBX, MDL, VRML, and OBJ.

The application is programmed so a different 3D model's sequence is superimposed over the real machine to show the instructions and explanations in the practice's manual. For visualizing each sequence the user will just press a key from the laptop. While executing the application, a menu is shown where student may choose between eight different training sessions (two trainings per workplace). Each panel front of workplace has a different mark, so each mark defines two different trainings. The fiducial mark is the activator of the virtual elements from the chosen training in the menu (Fig. 2).

The trainings of electrical machines performed on *ElectARmanual* are based on alternating current (AC) and direct current (DC) generators with permanent magnets and separate exits as well as single-phase motors (synchronous and asynchronous). The main panel allows assembly of different kinds of electrical machines.

3.1.2. Virtual information

The 3D Studio software has been used to create the models and 3D animations that we want to incorporate into the real scene (Fig. 3). The information has been saved in MDL format, as this format is compatible with the graphic engine of the GAME STUDIO A8 software, which is the one over that our augmented reality graphic viewer will work.

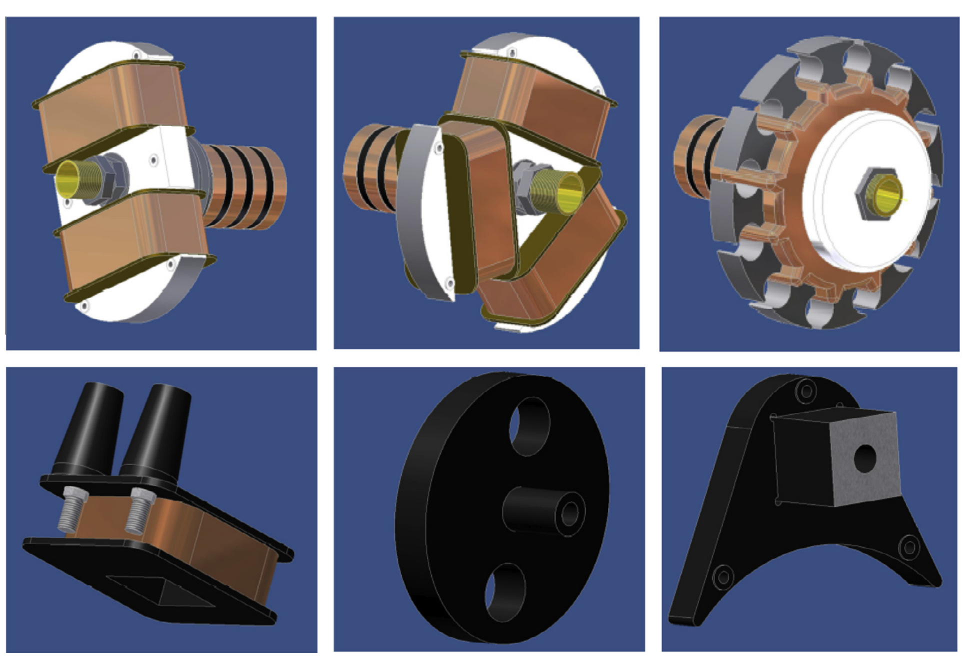

Fig. 3. Some 3D models of pieces for training with electrical machines.

3.1.3. Interface devices

The code uses Windows platforms. The students can use PC devices or a tablet for visualizing the virtual objects in the practice. The application has also been tested by using a head mounted display (HMD) (Martín-Gutiérrez et al., 2012). The use of this HMD device is optimum for this kind of work, where the students need to manipulate objects. However, it is not the best choice for great numbers of students given that is quite expensive equipment (Fig. 4).

3.2. ELECT3D: App for electrical plans reading

This AR application allows the students a more realistic and useful learning of electrical engineering and its symbols. Future engineers must be able to elaborate and understand engineering projects, which implies the comprehension and understanding of electrical symbols. To achieve this goal, the application must interpret both complex and realistic symbols and images, then show the corresponding virtual information.

The application we have developed is both realistic and useful; it can be used on any electrical diagram, professional or academic, because of the normalized standard symbols used. On the other hand, it uses an extended library of symbols and objects, so this application can be used not only in the electrical engineering field, but also in any other field that uses electrical normalized symbols, thus allowing its proper understanding and comprehension via AR.

3.2.1. Marker-less system

Unlike the previously described applications, *ELECT3D* does not need fiducial markers to connect the real and the virtual worlds. The system can understand any symbol or image predefined with a cloud of points, e.g., normalized symbols, which are widely used in the industry. Our application can use standard electrical plan drawings or complex electrical circuit diagrams.

Fig. 4. User undertaking training with HMD.

Fiducial markers-based AR applications are limited to previously defined and controlled environments (where defined marks have been introduced). However, a marker-less system can be used in any environment as well as in real situations where normalized symbols are used (which is usually the case). Students can use not only the former academic material, but also real work developments (Fig. 5).

3.2.2. ELECT3D Software description

Free and open source software (Metaio's SDK -software development kit) has been used for developing this AR app. The main advantages of this software are the following:

- Any (∗.png) reference images can be used, not only predefined ones.
- Detection method is performed through a cloud of points (not looking for symmetries), allowing customized tracking configuration. Therefore, the level of sensitivity can be adjusted to our application's needs.
- The speed and stability are quite good, depending on the size and characteristic of the library.
- Software is easy-to-learn, and good tutorials are provided, making it a suitable choice for students with no previous AR experience. Students can even develop the application by themselves.

3.2.3. Virtual information

With this project, we have tried to make the included virtual information as realistic as possible. To this end:

- We have selected elements commonly used in electrical applications, with preference for those that are used in the labs and those most widely used in low voltage electrical installations.
- We have made realistic models of the most usual electrical elements.
- We have associated the above with the electrical symbols available to the students in the workplace. As already mentioned, only elements with standard symbols were selected.

For the simplest elements we use 2D images (∗.obj), whereas for more complex elements we perform and incorporate 3D images, whose rotation allows more detailed information about the object. This reduces the memory requirements, because we only use "volume elements" when it is necessary.

The elements selected for their complexity are video recorded. From these videos we create the 3D models library with "VideoTrace software" (Van den Hengel, Dick, Thormählen, Ward, & Torr, 2014). The video recording and modeling was performed by students who participate in a "Teaching Innovation" project at the University of La Laguna (Fig. 6).

Fig. 5. Users making use of ELECT3D. Reading of plan drawings.

Fig. 6. Recording real objects for obtaining the 3D models using VideoTrace software.

We have complemented the 3D images by a text file, which includes the object name and a short description of its operation and usual application. Finally, this "image + text/symbol" library is integrated onto the AR software so the user can choose between just watching the image and increasing information; by observing a particular symbol you get an image, a text, or both by just touching the devicés screen.

3.2.4. Interface devices

The philosophy for *ELECT3D* is easily accessible through portable devices, such as smartphones and tablets. We have selected Android as the most widespread operative system in these devices. The Elect3D users can download the application to their own devices, where it is accessible at all times.

3.3. ElectAR_notes: Theoretical electricity notes enriched with AR contents

For complementing actions developed through previous sections, we have included AR in the notes of several electrical engineering topics (app *ElectAR_notes*). With the inclusion of 3D players, videos, explanations and animations, our main goal was to improve the spatial perception and theoretical comprehension of difficult-to-understand concepts, such as the generation and behavior of electrical and magnetic fields inside the electrical engines. AR also contributes by dismissing one of the weaknesses detected during the validation study of the practical app previously described. We get a better connection between theoretical and practical teaching. It allows the students to relate the laboratory learning with the theoretical knowledge (Fig. 7).

3.3.1. Notes book description

The name of the developed notes book is *Basic Electrical Machines*, and includes basic theoretical contents on electromagnetism, ferromagnetism, and operating principles of electrical machines. We have added AR contents on both text and images. This "classical/AR" combination is aimed, on one hand, at improving the understanding of the contents with more realistic and detailed explanations, and on the other, at increasing the interest level of the students with the use of more interactive notes.

We have chosen topics that are usually not clearly reflected in written text or 2D images included on notes. First, when working with vector quantities, concepts such as the rotation's direction, the movement, or the machine components, requires special 3D vision that cannot be introduced into traditional notes, but, however, is easily explained by three-dimensional contents and animations (Fig. 8). Hence it is difficult for students to find the connection between the theoretical contents described in the books and the reality of the practice they are carrying out in the lab. With the introduction of AR elements we can combine theory and practice, and students will find it easier to relate abstract contents with real situations.

3.3.2. Virtual information

As just mentioned, we have included virtual files with three different formats in the library: 3D images, video files, and audio contents. The 3D modeling is something completely new for students accustomed to traditional 2D photo books, and allows the student to visualize the elements from different angles and perspectives, broadening their particular vision of the problem. They can provide more information about objects and processes, and they can also be manipulated (rotate, zoom, etc.). To make 3D models we have used two softwares: Autodesk Inventor and Cheetah3D. The explanatory videos have been performed through collaboration with the audio-visual service from La Laguna University (ULLmedia, 2014), composed by professionals from the audio-visual field. The teacher himself through Camtasia Studio software performed some simple videos.

We have created and included two kinds of videos for this application: recorded videos and 3D virtual animations. The first kind was recorded with small laboratory experiments and practices that relate theory to reality, showing the explained processes from a practical point of view. The material used for these videos is the same one the students will use later on in the laboratory practical teaching, so they can become used to it.

Furthermore, we have performed small virtual animations for viewing invisible abstract concepts in the real world (this is precisely one of the main strengths of the AR technology). The role of the magnetic field in the electrical power generation, the interaction of ferromagnetic materials with electrical power generation, the interaction of ferromagnetic materials with electrical currents, or the electromagnetic forces that explain the operation of electrical engines are some examples of abstract contents. The animations have been made using Autodesk inventor and Cheetah3D.

Besides being able to visualize virtual contents, it is also possible to listen to audio explanation files that the teacher added to the text. This range of actions complemented by augmented reality intends to increase the interaction between teacher and students, giving a more direct and dynamic explanation to some complex concepts.

3.3.3. Software, marks, and interface devices

The *ElectAR_notes* app was aimed to develop versatile and useful study notes for use in engineering education. The application has been developed for Android, iOS and Windows OS, aiming to ease access to augmented contents for students while they study the theoretical contents.

The pages of study notes are accompanied by a "double AR Mark," so it can be used with all kinds of devices, regardless of their operating system. This way, students can use the didactic material either on a PC/tablet or with their own mobile device. The Windows app identifies fiducial marks, and it has been developed with the HUMANAR software library. The mobile app was created with the Metaio Creator software, and it can identify any symbol or image. The software and marks in this app are similar to those used in the previous section.

4. Method

The prototypical solution of the presented system was developed in the Basic Electrical Engineering course, the first course of

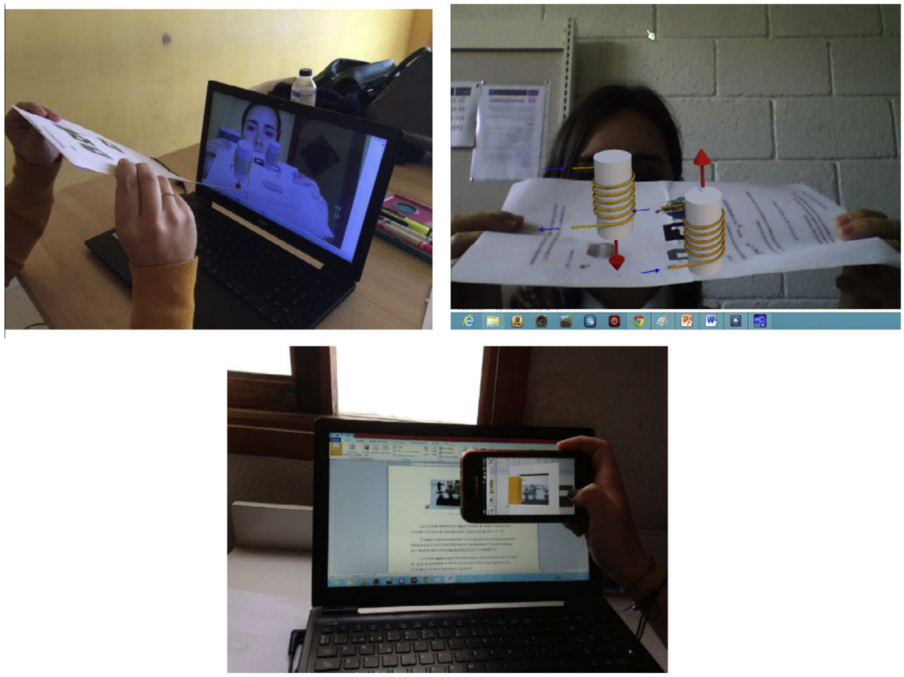

Fig. 7. User studying notes through ElectAR_notes.

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AR

Fig. 3: Producción de un campo magnético

En la figura se muestra un núcleo rectangular con un devanado de N vueltas de alambre enrollado sobre una de las ramas del núcleo. Si el núcleo es de hierro o algún otro material ferromagnético, casi todo el campo magnético producido por la corriente permanecerá dentro del núcleo, de modo que el camino de integración de la ley de Ampère es la longitud media del núcleo, l_c. La corriente que pasa por el camino de integración I_{net} es entonces Ni, puesto que la bobina de alambre corta dicho camino N veces mientras porta la corriente i. La ley de Ampère se expresa entonces:

$$H\ell_c = Ni$$

donde H es la magnitud del vector de intensidad de campo magnético $\vec{H}$. De esta manera, la magnitud de intensidad de campo magnético en el núcleo debido a la corriente aplicada es:

$$H = \frac{Ni}{\ell_c}$$

La intensidad de campo magnético $\vec{H}$ es una **medida del "esfuerzo" de una corriente por establecer un campo magnético**. La potencia del campo magnético producido en el núcleo depende también del material de éste. La relación entre la intensidad de campo magnético $\vec{H}$ y la densidad de flujo magnético resultante $\vec{B}$ producida dentro del material está dada por

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Es lo mismo que ocurre en el núcleo de un transformador de corriente alterna: La variación de flujo en el primario produce unas fem inducidas en el núcleo de hierro. Pero éste núcleo es también un conductor y cualquier sección puede considerarse formada por varios circuitos conductores cerrados, uno dentro del otro. El flujo a través de cada uno de estos circuitos cambia continuamente, de modo que hay una circulación de corrientes parásitas en todo el volumen del núcleo, eltando las líneas de flujo en planos perpendiculares al mismo.

Estas corrientes parásitas tienen dos problemas:

- ✓ disipan energía y
- ✓ ellas mismas crean un flujo magnético

AR

Fig. 12: Corrientes de Foucault Fig. 13: Núcleo laminado

En los transformadores reales estas corrientes parásitas se reducen utilizando un núcleo laminado, es decir, formado por láminas o capas delgadas. La resistencia eléctrica entre las superficies de las láminas (oxidación natural o barniz aislante) confna las corrientes en torbellino a cada lámina individual. La longitud de la trayectoria resultante aumenta mucho, con el consiguiente aumento de la resistencia ┐ la fem inducida es la misma pero I disminuye (V=IR) con lo cual se reduce la potencia disipada y sus efectos caloríficos ($P=R\,I^2$).

Memoria 69

Fig. 8. Notes with fiducial marks (for PC use) and marker-less (for smartphone use).

the electrical engineering degree. The students were able to study the provided notes from the teacher, visualizing virtual contents associated with notes through their mobile devices. The virtual contents associated with notes are related to work developed in the practice laboratory. Furthermore, two other applications are used for reading the electrical plan drawings and training in building and manipulation of electrical machines. The assessment of the three applications took place with 50 students of electrical engineering.

4.1. Technical aspects

The course has six groups of 25 students each. A group was chosen at random for using the three learning support applications during the semester between February and May. The goal is to explore the usability of the applications as well as feedback from students about their use. The System Usability Scale (SUS) questionnaire was used for measuring usability (see questions in Table 1), as well as a feedback survey that took place ad-hoc by the authors (Table 2), applied to 25 students for assessing the degree of stability and satisfaction achieved by every application. This group is considered as group 1. Once the course was over (in May), there was a demonstration of the three applications to other group of 25 students belonging to the same course (group 2). After the practical demonstration, these students have also completed the usability and feedback surveys.

The SUS usability questionnaire, originally created by John Brooke in 1986, allows evaluation of a wide variety of products and services, including hardware, software, mobile devices, websites, and applications. It enjoyed great feedback as a usability measure tool. It comprises 10 questions covering the different aspects of a system's usability, such as the need of support, training, and complexity so it is highly valuable as a tool for measuring the usability of a certain system. The answers cover a Likert scale ranging from 1 (completely disagree) to 5 (completely agree). The questionnaire was applied after the survey subjects had the chance to use the system under assessment. The instant answers for each item are compiled without allowing time to think about it, aiming to capture the user's first impression. This questionnaire's particularity is that if the participant does not feel able to answer a certain item, he may choose the center value on the scale (3).

The SUS questionnaire is integrated by two subscales: odd and even questions with different weighting systems. The final result of the questionnaire is a unique percentage value that denotes a measure composed by the ease of use from the studied system, given that scores for individual items are not significant by themselves.

Table 2
Feedback survey.

This survey reflects my feedback about the following application: ☐ ElectARmanual ☐ ELECT3D ☐ ElectAR_notes	
A1	Rate quality from 3D models and animations
A2	Rate quality from 2D models and videos
A3	Application easy to use
A4	Application helps my learning, improving my understanding of contents
A5	I regard this application as useful in the teaching field for this subject as well as for others
A6	Rate your experience of use about this application
A7	I believe that the application helps mental visualization of abstract contents
A8	The application can be used anywhere and anytime due to its portability

For calculating the SUS score, first we must add each item's scores. The contribution from each item to the final score is calculated as follows:

- For items 1, 3, 5, 7 and 9 the score is that which is provided by the user minus one.
- For items 2, 4, 6, 8 and 10, the score is that which is provided by the user minus five.
- The average score obtained by each item is also added.
- The final score is obtained multiplying previous addition by 2.5.
- The final result will be between 0 and 100.

The students were provided with the download link for installing the applications on their smartphones or laptops. They were free to use them at the laboratory and for further practice with electrical plan drawings and installations.

5. Results

The results from the usability survey are compiled in Table 1 for all three applications performed by both groups of students, the ones who enjoyed the four-month experience, and the ones who only received a demonstration.

The usability results offered very high scores according to ease of use. The survey was performed on both groups (those using it frequently and those using it just once) for knowing both perceptions. The result is analogue in both cases so the score obtained for the three applications is around 80%. A product's usability is considered acceptable for values higher than 55%. Regarding the feedback survey, it was only completed by students who used the AR applications during the study (group 1). The survey has eight answers (items A1–A8). The students evaluate each application using the same survey.

Table 1
Usability questionnaire. Weighted Value (WV).

	Questions	ElectARmanual (WV)		ELEC3D (WV)		ElectARnotes (WV)	
		Group 1 n = 25	Group 2 n = 25	Group 1 n = 25	Group 2 n = 25	Group 1 n = 25	Group 2 n = 25
1	I believe I will use this system frequently	4.76 (3.76)	4.68 (3.68)	4.8 (3.8)	4.72 (3.72)	4.68 (3.68)	4.38 (3.48)
2	I regard the system as unnecessarily complex	1.16 (3.84)	1.28 (3.72)	1.129 (3.88)	1.2 (3.8)	1.24 (3.76)	1.44 (3.56)
3	I thought the system was easy to use	(2.12) 1.12	(2.2) 1.2	2.08 (1.08)	2.16 (1.16)	2 (1)	2.08 (1.08)
4	I believed I would need technical support for using this system	3.93 (1.08)	3.84 (1.16)	3.88 (1.12)	3.84 (1.16)	3.72 (1.28)	3.64 (1.36)
5	It seemed to me that several features in this system are well integrated	4.88 (3.88)	4.8 (3.8)	4.8 (3.8)	4.68 (3.68)	4.76 (3.76)	4.6 (3.6)
6	I believe there are many inconsistencies in this system	1.16 (3.84)	1.2 (3.8)	1.16 (3.84)	1.32 (3.68)	1.28 (3.72)	1.4 (3.6)
7	I think most people will learn to use the system quickly	(4.92) 3.92	4.96 (3.96)	4.76 (3.76)	4.64 (3.64)	4.72 (3.72)	4.64 (3.64)
8	I regard the use of the system as bothersome	1.2 (3.8)	1.28 (3.72)	1.28 (3.72)	1.36 (3.64)	1.32 (3.68)	1.56 (3.44)
9	I felt quite safe using the system	4.76 (3.76)	4.8 (3.8)	4.96 (3.96)	4.84 (3.84)	4.72 (3.72)	4.6 (3.6)
10	I had to learn many things before being able to use the system	1.08 (3.92)	1.04 (3.96)	1.24 (3.76)	1.36 (3.64)	1.4 (3.6)	1.56 (3.44)
	Total	32.92	32.8	32.72	31.96	31.92	30.8
	Addition * 2.5 (%)	82.3%	82%	81.8%	79.9%	79.8%	77%

Table 3
Satisfaction survey results.

	ElectARmanual	ELECT3D	ElectAR_notes
A1	4.1	4	4.25
A2	4.2	4.125	4.25
A3	4.6	4.75	4.9
A4	4.8	4	5
A5	5	4.375	4.8
A6	4.5	3.75	4.75
A7	4.7	4.125	4.65
A8	1	5	4.7

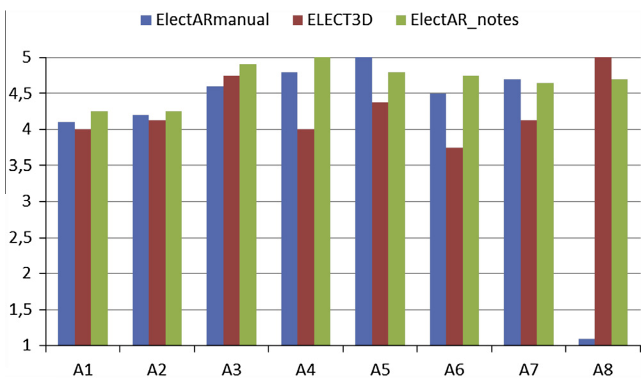

Fig. 9. Satisfaction results.

Table 2 shows the formulated questions for finding out the satisfaction of the students using each application. The evaluation takes place through a 5-point Likert scale.

The results from the three applications are quite similar in terms of the feedback from students, indicating high scores. The multimedia content is regarded as a high quality one (A1–A2), and the application does not show any unforeseen difficulty about its use, which is quite easy (A3).

The students consider without any doubt that these three applications are a great help for learning, and they could be used in other similar subjects (A4–A5). The personal experience while using it is quite satisfactory as well, showing high values above average (A6).

The perception of the participants is that tools help to understand the abstract concepts from electrical engineering (A7). They consider that both ELECT3D and ElectAR_notes tools are portable, while the ElectAR_manual is not regarded as such, due to its availability at the practice laboratory only (A8) (see Table 3 and Fig. 9).

6. Conclusions

The increasing number of students that opt for studying engineering degrees makes the practice laboratories overcrowded, worsening the teaching quality and reducing the teacher's dedication to every student. Besides, learning and teaching procedures need to evolve and take into account the high technological profile that most students show. In some cases, outdated teaching creates barriers for some students that are used to interacting with modern technological gadgets and computers.

AR applications allow that in certain teaching/learning contexts, they can be performed by the student on his own, thus saving teacher's time spent on repeating explanations. The students gladly welcome this technology, so a well-planned AR application will allow them to successfully perform any learning processes.

The tools developed in this work have achieved a dual effect as they allow the teacher to improve guidance at the training sessions within the practice laboratory, and to offer attractive and motivational tools to the student during the learning process of contents.

AR applied to different learning contexts in the framework of this work provides proper methods for developing professional competences from the contents used in this subject, but besides transversal competences are also developed such as: instrumental competences (analysis and synthesis skills, planning and organization skills, solving problems, managing information as well as taking decisions), personal competences (teamwork, workplace interpersonal relations skills, critical reasoning), systemic skills (autonomous learning, leadership, initiative, entrepreneur, motivation for quality) and others such as the skills to apply theoretical knowledge and put it into practice. From the point of view of effective human resource management for business, the contribution of training qualified and motivated professionals for good performance allows employing the right people for higher profitability, less rotation, higher product quality, lower costs in manufacturing as well as faster acceptation and implementation of the organizational strategy (Lytras & Ordóñez de Pablos, 2008).

The usability study, which the three augmented reality applications underwent, indicates that they are free of errors in terms of effectiveness and efficacy. Also, the students left high feedback scores for the three of them indicating that they feel comfortable while using them, and consider them to be quite adequate for learning both practical and theoretical content.

This paper comprises the validation experience of the three applications that have been integrated in the electrical machines course in the electrical engineering program. As a consequence of the good results from the usability and feedback surveys, we recommend extending the use of these tools to other degrees where the same subject is being taught (chemical, electronic, mechanical, and civil engineering degrees.)

The results from the feedback survey and the student's attitude observed by the teacher indicate that student motivation is a key factor, which has improved respecting other academic courses. We believe that this motivation and attitude toward work has been reflected over the academic performance. This fact can be conveniently studied upon the extension of these tools to every student of the other subjects mentioned.

Through this empirical study, we have witnessed the great potential and acceptance of the inquiry-based AR tools. The research shows that different AR learning scenarios presented in this work are adequate for promoting collaborative and autonomous learning. In future actions, we will consider analyzing if students' academic performance will be enhanced by the AR learning tool and if learning is retained any longer on the memory of students using AR learning tools.

Finally, it should be underlined that augmented reality is a cost-effective technology for providing students more attractive contents than paper, so we regard as interesting the extension of this experience to other laboratories such as mechanical and hydraulic engineering which may help solving any faults on equipment and physical machines for virtual equipment in order to perform practical training. The work taking place in this kind of laboratory should allow that students have their hands free of any item or device in order to perform them properly interacting with virtual objects, so we considered using visualization devices at vision level such as glasses. Augmented reality glasses from META business start-up will be available on the second semester of 2015, showcasing great potential (www.spaceglasses.com). Meanwhile, the Moverio BT200 augmented reality sunglasses manufactured by the EPSON brand (www.epson.com/moverio) are already available to us so we will use them in the short term at the mechanical engineering laboratories.

References

Azuma, R. T. (1997). A survey of augmented reality. *Presence, 6*(4), 355–385.

Billinghurst, M., & Kato, H. (2002). Collaborative augmented reality. *Proceedings of Communications of the ACM, 45*(7), 64–70.

Brooke, J. (1986). *System usability scale (SUS): A quick-and-dirty method of system evaluation user information*. Reading, UK: Digital Equipment Co Ltd..

Bujak, K. R., Radu, I., Catrambone, R., MacIntyre, B., Zheng, R., & Golubski, G. (2013). A psychological perspective on augmented reality in the mathematics classroom. *Computers and Education, 68*, 536–544.

Cai, S., Wang, X., & Chiang, F.-K. (2014). A case study of augmented reality simulation system application in a chemistry course. *Computers in Human Behavior, 37*, 31–40.

Chen, R., & Wang, X. (2008). An empirical study on tangible augmented reality learning space for design skill transfer. *Tsinghua Science and Technology, 13*(S1), 13–18.

Cooperstock, J. R. (2001). The classroom of the future: Enhancing education through augmented reality. In *Proceedings of the international conference on human–computer interaction* (pp. 688–692). <http://srl.mcgill.ca/publications/2001-HCI.pdf> [Retrieved 27.01.14].

Craig, A. B. (2013). Augmented reality applications. In A. B. Craig & M. Kaufmann (Eds.), *Understanding augmented reality* (pp. 221–254). USA: Boston.

Cuendet, S., Bonnard, Q., Do-Lenh, S., & Dillenbourg, P. (2013). Designing augmented reality for the classroom. *Computer and Education, 65*, 557–569.

European Higher Education Area, EHEA (2010). <http://www.ehea.info> [Retrieved 28.06.14].

Fonseca, D., Martí, N., Redondo, E., Navarro, I., & Sánchez, A. (2014). Relationship between student profile, tool use, participation, and academic performance with the use of augmented reality technology for visualized architecture models. *Computers in Human Behavior, 31*, 434–445.

Gillet, A., Sanner, M., Stoffler, D., Goodsell, D., & Olson, A. (2004). Augmented reality with tangible auto-fabricated models for molecular biology applications. In *Proccedings of the 15th IEEE visualization conference* (pp. 235–241). http://dx.doi.org/10.1109/VISUAL.2004.7.

Harrington, M. C. R. (2006). Situational learning in real and virtual space: Lessons learned and future directions. In *Proceeding of SIGGRAPH '06: ACM SIGGRAPH 2006 Educators program* (pp. 48). ACM.

Heejeon, S. (2011). Collaborative learning models and support technologies in the future classroom. *International Journal for Educational Media and Technology, 5*(1), 50–61.

Ibáñez, M. B., Serio, A. D., Villarán, D., & Delgado, C. (2014). Experimenting with electromagnetism using augmented reality: Impact on flow student experience and educational effectiveness. *Computer and Education, 71*, 1–13.

Johnson, L., Smith, R., Willis, H., Levine, A., & Haywood, K., (2011). The 2011 horizon report. Austin, Texas: The New Media Consortium. <http://www.nmc.org/publications/horizon-report-2011-higher-ed-edition>.

Kaufmann, H. (2003). Collaborative augmented reality in education. *Position paper for keynote speech at imagina 2003 conference*, 2003.

Kaufmann, H., & Meyer, B. (2008). Simulating educational physical experiments in augmented reality. *Proceeding of the international conference on computer graphics and interactive techniques*. *ACM SIGGRAPH ASIA 2008 educators programme*. New York, NY, USA: ACM. http://dx.doi.org/10.1145/1507713.1507717.

Kerawalla, L., Luckin, R., Seljeflot, S., & Woolard, A. (2006). "Making it real": Exploring the potential of augmented reality for teaching primary school science. *Virtual Reality, 10*(3–4), 163–174.

Lucke, U., & Zender, R. (2011). 3D interactions between virtual worlds and real life in an E-learning community. *Advances in Human–Computer Interaction*. http://dx.doi.org/10.1155/2011/684202 [Article ID 684202].

Lytras, M. D., & Ordóñez de Pablos, P. (2008). Competencies and human resource management: Implications for organizational competitive advantage. *Journal of Knowledge Management, 12*(6), 48–55.

Martín-Gutiérrez, J., Fabiani, P., Meneses-Fernández, M. D., & Pérez-López, D. C. (2012). Adaptation of electrical laboratory systems through augmented reality for optimization of engineering Teaching University. *Eurographics 2012-Education Papers* (pp. 3–8).

Martín-Gutiérrez, J., Saorín, J. L., Contero, M., Alcañiz, M., Pérez-López, D. C., & Ortega, M. (2010). Design and validation of an augmented book for spatial abilities development in engineering students. *Computers and Graphics, 34*(1), 77–91.

Pan, Z., Cheok, A. D., Yang, H., Zhu, J., & Shi, J. (2006). Virtual reality and mixed reality for virtual learning environments. *Computers and Graphics, 30*(1), 20–28.

Park, S. B., Jung, J. J., & You, E. (2015). Storytelling of collaborative learning system on augmented reality. In Camacho, D., Kin, S.-W., & Trawinki, B. (Eds.), *New trends in computational collective intelligence, series studies in computational intelligence* (Vol. 572, pp. 139–147).

Quarles, J., Lampotang, S., Fischler, I., & Fishwich, P. (2009). Scaffolded learning with mixed reality. *Computers and Graphics, 33*(1), 34–46.

Saleeb, N., & Dafoulas, G. A. (2011). Effects of virtual world environments in student satisfaction: An examination of the role of architecture in 3D education. *International Journal of Knowledge Society Research, 2*(1), 29–48. http://dx.doi.org/10.4018/jksr.201101010.

Schiller, S. Z., Mennecke, B. E., Nah, F. F.-H., & Luse, A. (2014). Institutional boundaries and trust of virtual teams in collaborative design: An experimental study in a virtual world environment. *Computers in Human Behavior, 35*, 565–577.

Ullmedia – Unidad para la Docencia Virtual, Universidad de La Laguna (2014). <http://udv.ull.es/portal/ullmedia/> [last access 25.09.14].

Van den Hengel, A., Dick, A., Thormählen, T., Ward, B., & Torr, P. H. S. (2014). Image-based modelling for all. Software Punchcard: VideoTrace. <http://punchcard.com.au>.