

Preparing Augmented Reality Learning Content Should be Easy: UNED ARLE—an Authoring Tool for Augmented Reality Learning Environments

JOAQUÍN CUBILLO,¹ SERGIO MARTÍN,¹ MANUEL CASTRO,¹ IVICA BOTICKI²

¹*Electrical and Computer Engineering Department, National University for Distance Education of Spain (UNED), Madrid, Spain*

²*Applied Computing Department, University of Zagreb, Zagreb, Croatia*

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ABSTRACT: The purpose of this study was to investigate how an augmented reality learning environment system (UNED ARLE) can be used both by teachers and students to add virtual content into educational resources and how can it serve as a tool for acquiring knowledge, motivating and encouraging students. UNED ARLE is used to add contextualized virtual content (3D objects, animated 3D objects, videos, sound files and images) and the accompanying descriptions or narratives into printed material, thereby enriching existing content without any programming skills. This study recruited 44 students of advanced and intermediate cycles of vocational training and two teachers. It analyses UNED ARLE by examining the interaction between teachers and the system and by comparing the results of two groups of students. The study concludes that the students who used UNED ARLE show significantly better learning achievements compared to the traditional system. In regards to the teachers, the study shows that incorporating multimedia resources into augmented reality is directly influenced by their knowledge of this technology, due to the difficulty of developing new virtual objects. © 2015 Wiley Periodicals, Inc. *Comput Appl Eng Educ* 23:778–789, 2015; View this article online at wileyonlinelibrary.com/journal/cae; DOI 10.1002/cae.21650

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INTRODUCTION

Augmented reality (AR) has been one of the most promising tools for instruction and learning throughout the last years [1–4]. Although the authors have proven that AR brings benefits into education by fostering student motivation [5], AR is, at the point of writing of this paper, far from being a mainstream technology in education. It is the belief of the authors [1] that the reason for this lies in the difficulty of developing augmented learning experiences, which usually requires programming skills. The second

reason, according to Martín et al. [1], is the lack of tools specifically designed for education, rather than for general purpose, furthermore, creating virtual content is a complex task, especially when it comes to 3D objects, due to all this, the use of AR in teaching is greatly limited.

This study attempts to alleviate these issues by providing an easy-to-use authoring tool for teachers called UNED ARLE (National University for Distance Education—Augmented Reality Learning Environment), allowing for an easy creation of learning experiences containing AR objects, contextualization and questionnaires of these objects. The need for UNED ARLE emerged after analyzing of the state of the art of frameworks for creating AR educational experiences and discovering the lack of the tools specifically designed for delivery of educational content and assessment through AR. In addition to filling in that gap,

Correspondence to: J. Cubillo (jcubilloarr@educa.jcyl.es)

UNED ARLE provides the possibility of incorporating a description of virtual content, and it gives teachers the option to add multiple-choice questions (MCQ) into a virtual resource.

The paper presents the results of a study examining a batch of vocational students learning with and without the system. It also examines the use of the system by the teachers with no programming skills and with no AR knowledge. The authors were interested in examining if UNED ARLE users showed more interest and motivation compared to their classmates, who used other computer technology, and finally, if the system is simple, intuitive and useful enough to support teachers in developing their courses.

This paper is organized as follows: In Section Related work, basic concepts related to AR are introduced, as well as an overview of application of AR in education. In Section UNED ARLE—Augmented reality learning environment, an overview of the UNED ARLE system is presented. In Section Methodology, the AR as a tool to enhance the acquisition of knowledge is discussed together with the methodology of this study, including the data collection and analysis. In Section Data collection and results, the results of the system evaluation are presented, while Section Discussion and conclusions, discusses the results and concludes the paper.

RELATED WORK

A number of authors [6–8] reported their experiences on how beneficial and effective mobile devices are transmitting information and acquiring knowledge outside the classroom. The use of these tools allows for modification of the narrative content and media learning tools, also referred to as “learning to learn with technology” [9,10], which heavily challenges the current transmission models of pedagogy [11,12].

The authors see mobile devices, combined with the emerging AR technology as a micro-revolution in technology enhanced learning, each one of the students has a personal learning rhythm and therefore should have a personal learning environment, this would be possible with the personal mobile device of every student, and the accessibility of the emergent AR technology to a wider public.

The most popular definition for AR is given by Milgram and Kishino [13]: “there is a continuum of real-to-virtual environments in which AR is a specific area within the generic area of Mixed Reality”. Another commonly accepted definition was crafted by Ronald Azuma [14] explaining AR as a technology that combines real and virtual worlds, real-time interactive and recorded in 3D. AR is therefore a system of interaction that takes as input the information from the real world and generates superimposed output information (such as objects, images, text, etc.) in real time. Since learners interacting actively with the real-world contexts via AR can apply authentic knowledge and social knowledge to their everyday environments [15,16], AR can provide opportunities for science and engineering [17–20], as these disciplines place emphasis on practical training in classrooms [21,22].

Along these lines, Peng [23] affirms that mobile AR platforms may augment the learners’ interaction experience without the restrictions of fixed locations. Nevertheless, not all systems based on AR are appropriate for the educational area and it is necessary to identify the characteristics that a system should meet to achieve the goals of teaching and learning [24,25]. Liarakapis [26], lists the following requirements that an educational AR system should ideally fulfil:

- It must be a robust system
- It must provide clear and concise learning
- The educator must be able to introduce new information in a simple and effective way
- It should facilitate easy interaction between teacher and student
- The technological processes must be transparent to both the teacher and the student

Researchers indicate that the use of AR environments during lessons could provide extra motivation to students [27–30], and what is more, could create possibilities for collaborative learning around virtual content in non-traditional environments [31]. These tools are designed to teach a single concept or they are specialized in only one subject [32], which means they lack of generalization capabilities, what is more, the most of them lack of basic educational functions such as contextualization of educational resources or the evaluation of learning.

The contents are usually statically specified by the developers and there is usually no easy way for teachers to update existing content or add new content and there are no libraries of virtual resources that allow other teachers to use these resources. This is a problem since creating suitable 3D contents, or even finding such contents, is a non-trivial task for teachers and it is a fundamental part of the AR technology.

The applications which are easy to manage but fall into the category of general-purpose AR displays, they are all developer-centric, unidirectional and geared towards the student and none of them provides feedback about their use, contextualization of content, (contextualization is recognized as a valid support for learning [33–35], they help in making sense of experiences, organizing knowledge and increasing motivation [36]), functionality or quality of the resources, without clarifications explaining about, what the student is seeing or how they can interact with a resource. This has long ago been noted by researchers who report that teachers recognize the potential of AR in education, but they would like to control the resources and to adapt them to the needs of students [27]. This gap opens up a niche for AR authoring tools which can be used to personalize learning experiences for students.

The AR authoring tools can be classified in two categories, [37]: AR authoring tools for programmers and AR authoring tools for non-programmers [38]. As the name suggests, the first group consists of tools where the author of content must have knowledge of programming languages such as Java, C++, Javascript, etc. and libraries for the development of AR functions (computer vision, image recognition, pattern tracking, positioning, etc.). Examples of such tools are ARToolKit [39], NyARToolkit [40], FLARToolkit [41], ArUco [42], DroidAR [43], D’Fusion Studio [44], Wikitude SDK [45], Metaio SDK [46]. They enable the development of more powerful and adapted AR applications.

The tools for non-programmers include drag and drop interfaces for building applications without writing any code. These tools allow very fast development of AR applications; however, it is not usual that they support interaction or more complex behaviors such as modification of the displayed content, evaluation of content, contextualization of contents. To achieve that, some level of programming is necessary, for example, in Layar [47], where videos, images, and multimedia content can be inserted, however, to add new 3D objects requires some knowledge of programming languages. There are tools like Aurasma [48], Augment [49], Zooburst [50] where interaction is easy and intuitive but limited. In the case of

Aurasma, the positioning and scaling of objects cannot be modified in real time, while in the case of Augment, which allows real-time interaction, it has limited the number of models in its free version to 2, regarding to Metaio, after purchasing the Metaio Creator application, teachers can connect 3D content, videos, audio, and web pages to any form of printed medium. After careful consideration of the features of the most important tools for developing applications or experiences of AR, the decision was made to develop an authoring tool with the power of tools for programmers, which is as easy to use as tools for non-programmers. A specialized tool for learning would be included, allowing representation of virtual content and interaction with it. The evaluation of acquired contents would be made available through “augmented” questions (MCQs), they enable to increase the interest of students in what they are observing [51], and all of them are characteristics taken into account in the development of UNED ARLE.

Another feature that differentiates it from other tools is the ability to contextualize resources, with this contextualization is possible to answer questions such as what are the resources trying to teach? What can the students learn from it? What is its goal? How to get more information about the resource? Etc. This context of resource is not limited to text as is the case of Zooburst; it is possible to include images, videos, useful links, etc. [36,52]. Finally, with ARLE it is also possible to add augmented questions concerning the resource, this characteristic is not available in others tools.

As presented in the remainder of this paper, the authors aim at developing an AR authoring tool, which does not require programming skills. It should be free and simple to use in designing learning activities in any discipline. It should be able to add 3D objects and other multimedia content in an easy way, and should include a guide that contextualizes virtual resources helping students in their observation anywhere and anytime.

UNED ARLE—AUGMENTED REALITY LEARNING ENVIRONMENT

This section describes the UNED ARLE system, a learning environment based on AR, which covers each one of the characteristics defined by Liarokapis [26]. Teachers can add multimedia content such as video, images, 3D objects and even animated objects (MD2 format) to their notes, books, etc. Since the type of AR used by the system is the AR based on tracking, it is necessary to provide a mark (tag), which identifies the position and orientation in which virtual resources are represented on paper. The most important characteristics that distinguish UNED ARLE from other authoring tools are:

1. The possibility for the teacher to incorporate a description or narrative about the virtual resource, this should facilitate students understanding of the observed matter [53], while the spatial and narrative contexts offer learners “a cognitive framework for problem solving”, whereby the teacher can prepare a standalone resource which collects its own information.
2. UNED ARLE gives teachers the option to add multiple-choice questions (MCQ) into a virtual resource. The system presents this option because the students can get instant and individual feedback [54] on their understanding.
3. UNED ARLE includes a library of resources available through a web platform ready to be used by any user (teachers and students); this platform also facilitates the addition of new objects.

These main features provide a feedback to the user, this feedback from a smartphone, tablet or a PC is not the same as from a human tutor, but the students find it helpful [55], because it is flexible and they can interact with it as many times as they want. Regarding to the MCQs, these presents quantifiable results, so it is possible to analyze the level achieve by the student in each question [51]. A carefully designed MCQ can be deployed to assess learning even at the highest level of Bloom’s Taxonomy of Educational Objectives [56].

System Architecture

The system is based on a client-server architecture, in which the data and information are sent to a mobile device once the application is launched. The system has been developed using Metaio’s technology for mobile application [46] and other tools such as Android SDK, PHP, etc. The system has two distinct parts, the web platform for managing the virtual content, and a mobile application that displays the AR resource and allows interaction with it.

System Operation

UNED ARLE Web-Based Authoring Tool. The procedure of preparing an AR resource through the UNED ARLE web-based authoring tool is the following. First, the teacher must prepare the resource—video, images, 3D objects, and animated 3D objects. Figure 1 illustrates the web platform for adding virtual content, its description or context is added through the UNED ARLE editor, and Figure 2 shows the method to add test questions to the resource (number of questions that the teacher can add is unlimited).

Once the resource has been added, the teacher can preview the result directly from the mobile application. All resources are stored in UNED ARLE libraries, so any user can reuse or share them for future teaching and learning, which will increase the efficiency of the contents [57].

If a teacher or student wishes to use that resource, they will only need to download the pattern (tag) by clicking on it. After that, the teacher can use this pattern in books, notes, etc. and UNED ARLE mobile AR visualization tool will identify the pattern and play the virtual content on the pattern.

UNED ARLE Mobile AR visualization Tool. The operation mode of the UNED ARLE AR mobile visualization tool is the following:

1. Students install the application on their Android device (tablet or smartphone) complying with a minimum of hardware requirements (CPU with ARMv7 and about 800 MHz, integrated GPU with full OpenGL ES 2.x support, camera with about a 3 Megapixel resolution). Firstly, the application checks the Internet connection, if it exists, the application will check whether the user has the latest version of all the resources available in the network, if that is not the case, it will download the latest version, once done, the application starts to search possible patterns stored in its database. The visualization of digital resources, depend on both, the size of digital resources and download speed. Current processors have a high performance in

- representation of 3D objects; this offers a fluid movement and a sense of real interaction. The student starts the application, and in this time, an initial help window shows how to use and interact with the application.
- The interaction between the student and the application is made through AR buttons or through gestures. The interaction can be dragging the 3D object on the screen, moving the 3D object with buttons, scaling the size of the video, image or object, or playing a video, and optionally answer test questions. It is important to note that the object is represented with the scale and position in which it was designed, so it can be necessary to adjust its size and position with the respective buttons of UNED ARLE.
 - The student can obtain information about resource by clicking on the description button (this information was added by the teacher). At that time, a window will appear on the left side of the screen (Fig. 3), and it will display the requested information (text, images, video etc.).
 - Finally, if the teacher added MCQs to the virtual resource, an augmented buttons (A, B, C and D) will be shown to the user and they will be able to answer those questions. The results of these MCQs are reported to the web environment where they will be stored and prepared for future analytics.

It is important to highlight that UNED ARLE is applicable to any kind of environment, so each teacher will apply it to their

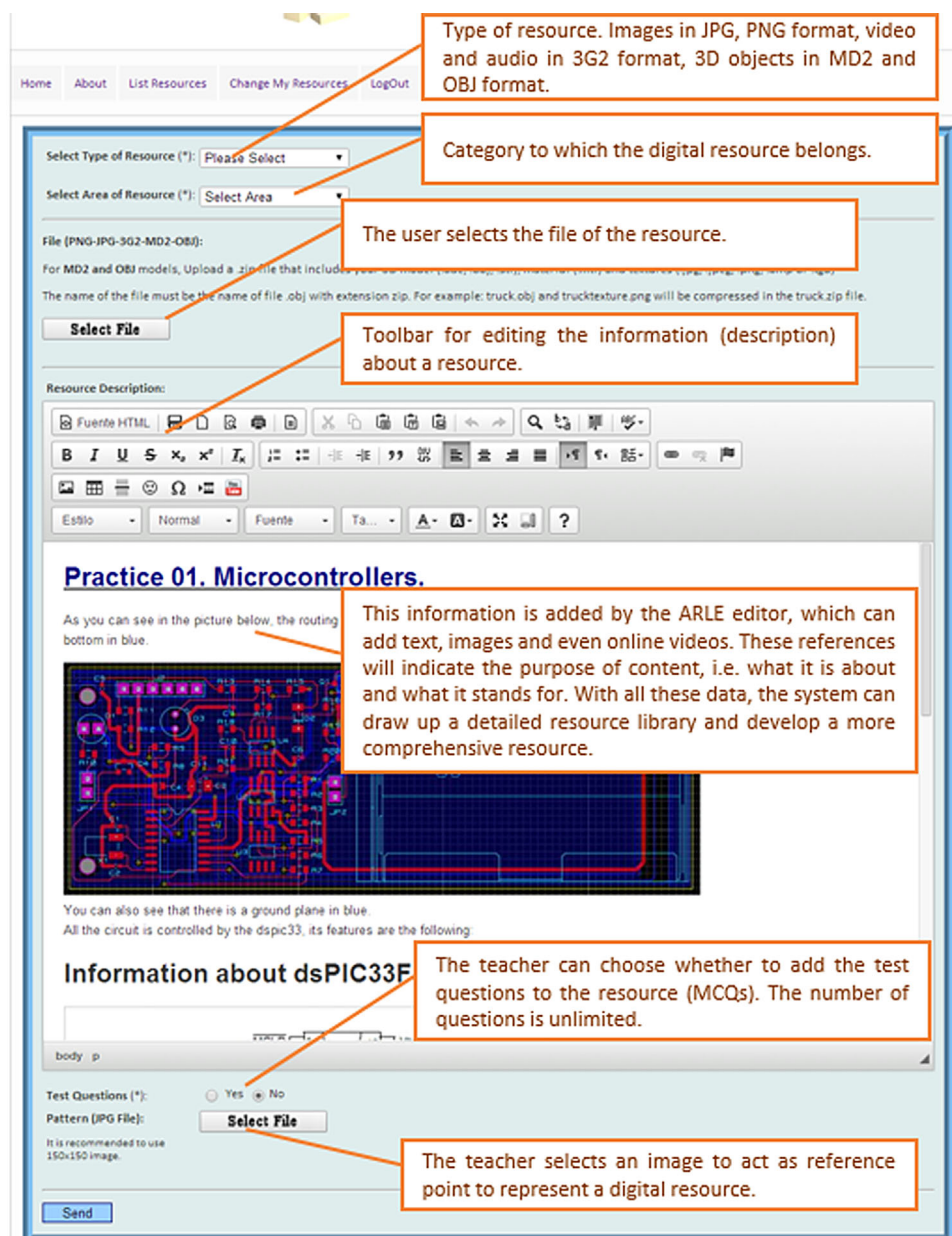


Figure 1 Steps needed to include a digital resource into the augmented reality UNED ARLE environment. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

Figure 2 UNED ARLE Web Platform. Screen for editing of MCQ. Write the question, write the possible answers and mark the correct answer. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

specific area with specific resources, either to teach mathematics, physics, electronics, etc. The examples presented in this paper are related to the fields of electricity, electronics and occupational safety and health.

To finalize this section, Table 1 shows a comparative between different tools, which could be used to carry out this experience. This presents tools designed for both programmers and non-programmers users. As it can be observed these tools show

deficiencies in relation to context and evaluation of resources, while UNED ARLE is able to do all this in a simple and easy way.

METHODOLOGY

An experiment using UNED ARLE has been conducted to check two aspects, first, if the UNED ARLE system can be used by a teacher without knowledge of AR. The teacher would use the system in their classes and include virtual content and contextualize it in a simple way. On the other hand, it will be examined whether the system motivates students and better facilitates learning compared to other computer technology. To implement the experiment, a group of teachers developed an educational resource and expanded it into two versions: an AR version using UNED ARLE and a version without UNED ARLE. The AR resource is then used by a group of students (experimental group), so that their results can be compared with the other group of students who did not use UNED ARLE (control group). The experience is based on an educational resource called Napo. Napo is an original idea conceived by a small group of OSH (Occupational Safety and Health) communications professionals as a response to the need for high quality information products aimed at breaking down national boundaries and to address diverse cultures, languages, and practical needs of people at work [58]. The digital resource is a series of short videos about Napo, at first glance, it could be considered that in this experiment

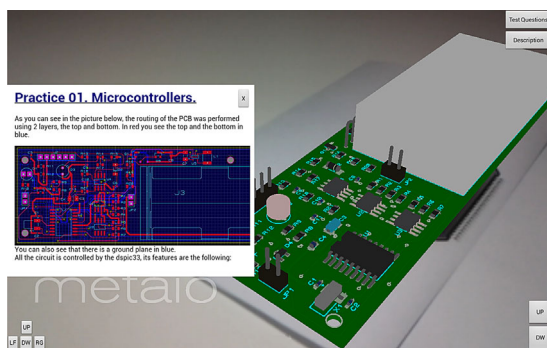


Figure 3 The student is observing a three-dimensional PCB and interacting with it. By clicking on the description button, they can get information about the object, (e.g., how it is designed). [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

Table 1 Comparative Between AR Tools Based on Pattern Tracking and Their Features

Software	Difficulty	Objects	Interaction	Reviews
ARToolKit	Very High. Programming knowledge	Images and 3D objects	A wide variety of interactions. It is necessary to program them.	Teachers must learn to program. It is not intuitive. No context, no evaluation, however, there are a wide variety of examples and manuals. Open Source and Commercial license available.
AR-media™ (Free)	Low.	3D Objects (SketchUp)	Interactions between objects limited	Interaction and models are limited to 3D objects.
Augment	Very Low. Simple and intuitive interface	3D Objects	Interactions between objects limited in free version	No context, no evaluation. Open Source. Extensive Manuals. Community of users growing. No context, no evaluation. Commercial license/ Free Use.
Aumentaty Author	Very Low. Simple and intuitive interface	3D Objects	Rotate, translate and scale objects	Manuals, tutorials. Extensive documentation. Wide community of users. No context, no evaluation. Commercial license/ Free Use.
Aurasma	Low. Although the process to create Auras is tedious	Videos, images and 3D objects and animations	Rotate, translate and scale objects, however, the interactions are not in real time	Extensive documentation and video tutorials. No context, no evaluation. Commercial license/ Free Use.
BuildAr (Free)	Very Low	3D Objects	Rotate, translate and scale objects with buttons	Limited documentation. Video tutorials. No context, no evaluation. The multimedia resources are limited to 3D Objects. Open Source and Commercial license available
LinceoVR	Medium. Simple and intuitive interface	Videos, 3D objects and animations	Gestural interaction	Extensive documentation and Development Service. No context, no evaluation. It is not free. Commercial license. (10% of the price is for company)
Metaio Creator/ Junaio Creator	Low. Simple and intuitive interface	Videos, 3D objects and animations	A wide variety of interactions. It is necessary to program them.	Wide community of users. Manuals, video tutorials (Webinars). Development Service. No context, no evaluation. Commercial license. Trial Version.
Total Immersion D'Fusion Studio	Low. Simple and intuitive interface	Videos, images and 3D objects	Multitude of interactions between objects	Extensive documentation. Video tutorials. Its own video channel. Development Service. No context, no evaluation. Commercial license.
UNED ARLE	Low. Simple and intuitive interface	Videos, images and 3D objects and animations	Gestural interaction. Rotate, translate and scale objects interaction with AR buttons.	Multimedia Context (links, video, audios...etc.), evaluation with MCQ. Resources available for reuse through a library. Free use.
VUFORIA	Programming knowledge	3D objects. Unity 3D	Multitude of interactions between objects.	Extensive documentation and video tutorials. No context, no evaluation. Commercial license. Trial Version.
ZooBurst	Low. Simple and intuitive interface	2D objects.	Very limited Interaction	It allows add context, but this context is only text (no multimedia, no links, no video). No evaluation. Commercial license/ Free Use.

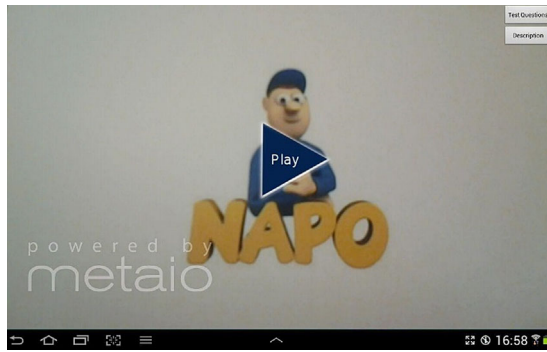


Figure 4 Pattern recognition—the pattern is recognized and the virtual resource is superimposed on it. In this case, the virtual content is a play button that allows the user to interact with 3G2 video format. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

only display a video, nevertheless, it is a video in AR, due to that the AR is not necessarily developed only with 3D. In this case teachers did not use 3D objects because they could not find any 3D resources available online about the area of occupational safety and health. These resources can be more easily used in subjects related to Art, History, Science and Technology. However, there are subjects that do not lend much to use it and, despite of the sort of resource, this experiment demonstrates that the AR remains an important tool for teaching, and the importance of the autonomous resources.

Figs. 4–5 show the operation of the mobile UNED ARLE application on an Android tablet computer. In the case depicted in the Figure 4, the digital resource is a video which appears in form of a play button. Once the play button is selected, the resource starts to play (Fig. 5). If the teacher decided to incorporate test questions into the resource, a test button is also displayed. When the test button is pressed, a MCQ is shown on the top of the resource.

The question in the example has four possible answers, and the correct one can be selected by choosing A, B, C, or D. If the answer is correct, then the next question will be shown, otherwise, the answer is shown as incorrect and waits until the user answers correctly (Fig. 6).

Participants

The experiment was conducted with vocational students of the occupational safety and health due to the following comparative



Figure 5 The user touches the AR button (play) which starts the video. It can be resized through the scale size buttons.



Figure 6 When the user responds correctly, a new AR button appears. The wrong answer is represented with a cross, and the correct answer with V. The next question to be answered is shown via blue arrow. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

advantages: (1) currently there are no documented experiences of AR in this area, (2) it is a topic in a large number of cycles of higher education and (3) it is an area of general interest as indicated by the ILO (International Labour Organization) [59]. This study recruited 44 students of advanced and intermediate cycles of Vocational Training and 2 teachers from an Integrated Vocational Training Centre located in Aranda de Duero (Spain). The criterion for choosing students was that they have not been exposed to learning health and safety topics before. The students come from different study areas: Electronic area (14 students), Computer area (14 students), and Management area (16 students). To carry out the experiment, all students was divided into two equal groups taking into account their age. In this way, the experimental group consisted of 22 students whose age ranged from 18 to 23 years old (7 electronic, 7 computer, and 8 administrative), out of which 9 students had prior experience of using AR technology. The control group included 22 students from 18 to 25 years old (7 electronic, 7 computer, and 8 administrative), who will not use AR technology. From this point onwards the experimental group is called Group A, and the control group is called Group B.

The whole experience was carried out through the collaboration of two teachers of the Department of Professional Orientation. None of them had previous experience with AR and they decided to use the UNED ARLE system to teach “the occupational risk factors in the workplace, prevention and protection measures”, a topic that would normally be taught to all students of vocational training.

Research Questions

The experiment is designed to explore the following research questions:

1. Can we develop a system that allows the incorporation of AR into notes, exercises, etc. in a simple and transparent manner? To answer this question the teachers who worked with the system and had to add the resources were surveyed. These teachers had never used AR or similar tools before. A questionnaire of 15 multiple choice questions and 2 open ended questions was developed to check the functions and usability of the system. It also queries students' view of the application.
2. Can the UNED ARLE system affect learning? To explore this question, the teachers responsible for the experiment

have developed a test querying students' knowledge of occupational health and safety.

Procedure

In the first step of the experiment, the teachers developed the virtual resource. The teachers normally use videos and presentations in their lessons, so they could choose to use one of their videos in creating the AR lesson. The teachers decided to select the Napo resource covering the occupational risk factors in the workplace, prevention and protection measures. The next step was carried out through the web platform UNED ARLE where the AR experiences were created (the steps followed were shown in Figs. 1 and 2). The editor was used for adding the description and the context of the resource consisting of an introduction to each of the videos (e.g., It indicates what kinds of environmental risks exist).

This introduction was developed using the WYSIWYG (What You See Is What You Get) editor of the platform, with text, images and links. To carry out the experiment, all 44 students received a theoretical explanation of the contents about safety and health at work. This explanation lasted for 50 min and covered environmental risks such as chemical risk, physical risks and the preventive and protective measures that should be taken into account to reduce or prevent damage due to an exposure to these contaminants. The 50 min of the class time were distributed according to the Table 2.

The teachers gave the students the notes for the topic. For group A, the notes included the pattern of resource and for group B they included the link to the web page containing the video, so that students could repeat the experience outside of the classroom.

Group A used tablets with the UNED ARLE application. This group was then instructed to use the AR system for 5 min, and left to freely interact with the system. Group B did not use AR and worked in a traditional way, this is, teachers worked as they usually do: they played the Napo video on a projector and subsequently commented the subject of the video and its most interesting points with the students. A week after the experiment finished, the students were assessed by a multiple choice question exam, covering all the concepts explained in the theoretical session and displayed on the Napo video. The students in the group A also answered an additional questionnaire comprised of 15 questions about the UNED ARLE system, previous experience with AR, ease of application management...etc.

Table 3 The Difference in Knowledge Between the Experimental Group (A) and Control Group (B)

	Group A	Group B
Average	7.59	5.82
STDEV	0.577	1.56
P value	<0.05 (significant)	
Effect size r	0.6 (large effect)	

DATA COLLECTION AND RESULTS

The Analysis of the Student Results

The results obtained from the students who have used the UNED ARLE environment were analyzed and compared with the results of the students who did not use UNED ARLE. To perform this analysis, the teachers rated the students through an exam with a maximum score of 8. The data were then aggregated and compared via the independent samples t-test as shown in Table 3.

The Analysis of the UNED ARLE Functions and Usability

This section discusses the functionality and usability of the UNED ARLE system, and presents the collected data in order to verify whether the functionality is adequate whether the ease of use relates to the system's simplicity or it is due to the user's experience in using AR tools. The data collected from the users about the system are used to decide on its possible improvements for future releases. The administered questionnaire consisted of 15 multiple choice questions (Likert scale 1–5, where 1 corresponds to the lowest score [or never] while 5 corresponds to the highest score [or always]). Table 4 shows the questionnaire analysis, including mean values and standard deviation. It is worth stressing that although the majority of respondents had not previously used the AR, they believe that the system operation is simple and intuitive. It is also important to note that users would also use the application in other areas and recommend it to other users.

Additionally, there were two open ended questions, presented in the Table 5.

DISCUSSION AND CONCLUSIONS

There are many tools that enable the development of AR and some of them can even create and generate AR experiences in which the

Table 2 Distribution of Class Time in the Experiment

Time	Group A activity	Time	Group B activity
25 min	Theoretical explanation on safety and health at work (common).		
5 min	Introduction into the UNED ARLE application.	8 min (NAPo video)	NAPo contents are displayed on a projector
15 min (NAPo video)	Students interact with UNED ARLE and NAPo. (Students use the AR, play and pause video, check description etc.)	17 min	The teacher asks the same questions that were introduced in the UNED ARLE system, but carried out as a debate.
5 min	Students read and answer the augmented questions (MCQ).		
After the session		Knowledge test	

Table 4 Results of the Questionnaire (Group A)

	Question	Average (Max 5, Min 1)	Stdev
1	Previous experience with AR	2.27	1.17
2	Ease of application management	4.18	0.89
3	Application response time	3.50	0.84
4	Functionality	3.77	1.00
5	Interaction with the user	4.09	0.73
6	Application design	3.86	0.97
7	It is a useful application for studying and preparing the course	3.64	1.02
8	It allowed me to better understand the theoretical content of the course	3.64	0.98
9	It is more entertaining and fun than studying from a book	4.45	0.58
10	Do you find it useful to have the application anytime anywhere?	3.77	0.90
11	It is useful to consolidate knowledge after face-to-face sessions	4.00	0.74
12	This type of application should be used in other subject areas	4.18	0.78
13	I recommend it to other students	4.05	0.77
14	I am satisfied with the application	4.00	0.80
15	What is your overall opinion of the application?	3.95	0.71

incorporation of 3D objects is simple. However the AR tools which are used in education are usually custom-made for a subject area, while the others are more general but limited to the reproduction of the virtual content. This paper presents an AR authoring tool for education that includes the following: (1) the ability to incorporate diverse multimedia resources in an easy manner, (2) the ability to incorporate tutored descriptions into those elements which are being displayed (thus, the student is provided with an additional information about the resource, and the content is adapted and personalized for end users), (3) the possibility of including multiple-choice questions, which may provide students with instant and individual feedback [54] on their understanding, and (4) a library of virtual content from where all resources can be fetched in a simple and transparent manner.

After the experiment, all students were asked if they had used the Napo resource in their homes to prepare for the exam. Although the two groups of students had access to the resource (one through the AR system and the other on the web), only the students in the group A used the resource outside the classroom again, while group B did not use it. The reason that the group B students did not return to view the short videos was because of “the fact that having to watch, it is boring, and it does not have not anything new that we have not seen”. The students preferred to read the notes before turning on the computer and viewing the

video. When the same question was asked in the group A, the students replied that they had used the system again, because the augmented resource was easily accessible through their mobile devices, they could use them anywhere and at any time, in addition to the augmented resource allows them to associate the real notes with virtual concepts, this union, this context and evaluation facilitates understanding of the different concepts. Furthermore, they liked the ability to show augmented objects to other students. Finally, the fact that they were able to see the descriptions provided by AR resources allowed them to remember which “things” could be more important. Therefore, time was saved while searching for content, the resources can be immediately visualized by students, the description and well formulated narrative may help clarify the contents, students can have these resources immediately available and contextualized in their tasks and notes, which all contributes to facilitating the synthesis and schematization of content and concepts.

Regarding the research questions, the independent samples t-test shown there is a significant difference between the group using UNED ARLE and the group not using UNED ARLE of $DIFF = 1.77$ ($P < 0.05$). With the analysis of the results carried out, it can be concluded that students who experimented with AR scored higher than students who did not work with it. There are differences in the results obtained; being that the students who used the application

Table 5 The Answers to the Open Ended Questions

Review of the application	Comments for improvement
The application is entertaining and useful for learning the theoretical content in an amusing way.	Add the possibility to advance or rewind the video.
It is a learning environment that can help students review the material explained in class in a more pleasant way.	Possibility of full screen.
The application is convenient because students can learn at their own pace, anywhere.	Ability to save the results of the test on the device.
The application is very intuitive.	Add new formats of 3D objects.
The multiple choice questions in the digital resource make the application more dynamic and entertaining.	Indicate why the answer to the question of the test is wrong.
It is similar to a game.	
It is interesting and very useful.	
It must be recommended in classes to consolidate knowledge.	
It should be extended to all subjects.	
Very simple.	
Helps to understand with less effort.	

could interact with the virtual content and its description. Students who did not use the application did not view the resource again because in their opinion “the video did not present anything new to what we had seen by the teacher in class, thus, the students of the Group B can only get the explication of the teacher in class, however, the students who used the application have unlimited access to the description and MCQs of the topic. Interaction, immediacy and context given by the AR help students to assimilate and to study the theoretic contents, and therefore to get a better score on the exam. If the students have specific tools to use the resources in a personalized way, the results get better and more homogenous.

The teachers and students feel that the UNED ARLE system functions and its usability are adequate, with a score of 3.95 out of 5. Students consider that the functions are correct; however, it is susceptible of improvement as is summarized in Table 5. With respect to the teachers, they also value the application, highlight its speed and the simplicity to incorporate virtual resources into books, texts, notes, in addition to having the option to use the resources added by other users (library of resources). They appreciated the facility to incorporate descriptions or information into the resource, helping them in creating resources that are more comprehensive, compared with other tools like Aurasma (which uses new concepts such as “channels” to share resources), or tools like Layar where incorporation of new 3D elements involves some knowledge of programming. Regarding to the multimedia resources, most platforms do not allow a contextualization and evaluation of concepts of the resources, in other words, these applications do not allow creation of autonomous resources.

In summary, the interaction with the application and with its information can greatly facilitate the students’ understanding of the subject, which is being taught. It can be observed that 77% of students are satisfied with the application with no negative views of the AR environment.

Finally, it is also important to highlight that as many as 95.5% of students agree it is more interesting to work with the AR. This makes UNED ARLE a tool for facilitating the ubiquitous learning in any knowledge area.

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BIOGRAPHIES



Joaquín Cubillo has a PhD from the Electrical and Computer Engineering Department of the Spanish University for Distance Education (UNED). He is Electronic Engineer by the Technician Superior Telecommunications School in Valladolid (2003) and Technician Telecommunications Engineer by the Polytechnic University in Valladolid (2001). He is professor of Electronic Systems.



Sergio Martín is assistant professor at the Electrical and Computer Engineering Department (DIEEC) of the Spanish University for Distance Education (UNED). His research interests include mobile, ubiquitous and pervasive computing, especially focusing on its applications in education, as well as improving the teaching of electronics through the use of new technologies. Martín has a PhD from UNED and is Computer Engineer.



Manuel Castro is full professor at the Electrical and Computer Engineering Department (DIEEC) of the Spanish University for Distance Education (UNED). His research interests include learning-enhanced technologies, specially focusing on engineering education. Castro has a PhD in industrial engineering from UNED.



Ivica Boticki received his PhD degree in computing from the University of Zagreb, Croatia, in 2009. He has worked at the Faculty of Electrical Engineering and Computing, University of Zagreb, since 2004 as a Developer, Research Assistant, Research Associate, Lecturer, Researcher, and, since 2012, as an Assistant Professor. He spent the postdoctoral year 2009–2010 with the National Institute of Education, Nanyang Technological University, Singapore. He works as an educational technology consultant.

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