A Mobile Augmented Reality System for the Learning of Dental Morphology

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Abstract

Three-dimensional models are important when the learning content is difficult to acquire from 2D images or other traditional methods. This is the case for learning dental morphology. In this paper, we present a mobile augmented reality (AR) system for learning dental morphology. A study with students was carried out to determine whether learning outcomes were greater using the AR system or following a video session that was recorded in a real class. Other aspects were also considered. Thirty-eight undergraduate students, 6 Master's students and 11 employees of the center (most of them lecturers) participated in the study. The analysis about the acquired knowledge indicates that the students increased their knowledge using the two methods. When the post-knowledge scores for the two methods were compared, no statistically significant differences were found. Therefore, the AR system could be used as an effective transmitter of knowledge. The rest of the questions, which all of the participants answered, indicated that they were highly satisfied with the AR system, they considered the AR system to be very easy to use, and they would like to use it for dental learning. Moreover, as a mobile AR system, it could facilitate versatility in the learning process.

Keywords

Augmented Reality; Mobile Augmented Reality; dental education; dental morphology

I. Introduction

Three-dimensional models can help greatly when the learning content is very difficult to acquire from 2D images, such as learning about dental morphology. Dental morphology is a branch of dentistry that deals with the study of anatomical factors of the teeth in order to know their function, exterior shape, position, size, structure, development and movement of eruption. In all dental specialties, it is considered essential to fully know dental morphology. The traditional learning methods include 2D images (print or blackboard and chalk) in which the teacher explains the structures, elements, etc. Figure 1 shows an example of a 2D print image. Figure 2 shows a professor drawing a dental piece with its morphological elements on the backboard. With these techniques it is very difficult to observe the details in a general explanation. Real 3D models that are obtained using different materials such as polystyrene or calcium sulfate can also be used. For example, Figure 3 shows a dental piece made of polystyrene. Figure 4 shows the pieces of the lower dental arch. The pieces were made of calcium sulfate and later painted. In these cases, the details are more easily observable. However, the students cannot take the models home. In an attempt to reduce these difficulties, we have developed a mobile Augmented Reality (AR) system for learning dental morphology. Our mobile AR system runs on mobile devices. It is based on target recognition, that is, the system recognizes a specific image. The camera of the device captures the real world in which the target appears. The mobile screen shows the augmented scene in which a virtual object is superimposed on the target.

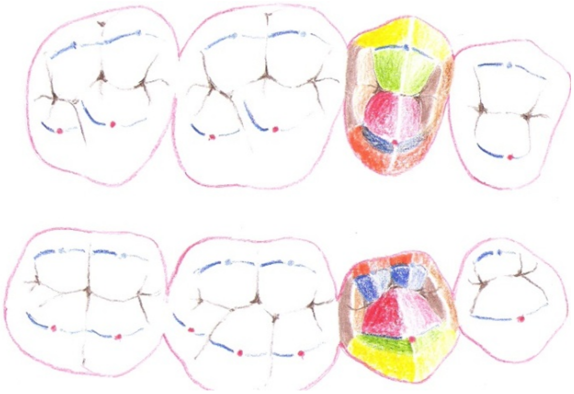

Figure 1. 2D print image for dental learning.
Source: Compiled by the author

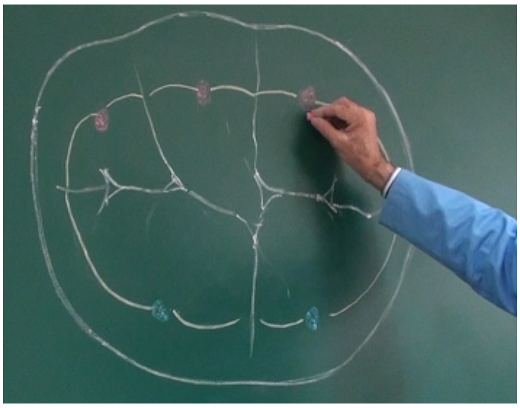

Figure 2. A professor using the blackboard for dental learning
Source: Compiled by the author

Figure 3. A real dental piece made of polystyrene.
Source: Compiled by the author

Figure 4. The pieces of the lower dental arch made of calcium sulfate.
Source: Compiled by the author

II. Background

To our knowledge, no one has reported on a system that is similar to our proposal for learning dental morphology. However, several previous works that are related to new technologies and the dental field can be cited. Most of the systems for learning dentistry are pretty basic; some of them use web technologies (Meckfessel et al., 2011) or multimedia material. One of the first works that studied the possibility of learning dentistry using computers was carried out by Grigg & Stephens (1998). They evaluated the knowledge of their time in an objective manner in order to make predictions; for example, that Computer-Assisted Learning would have an impact not only on how dentists would be trained, but also on the skills they would need to acquire in the future in order to keep up with these new technologies. Walmsley (2003) explained that computer-aided, dental-learning programs are either more effective than or equally as effective as other methods of education. Welk et al. (2006) showed that the benefits of computer-assisted learning can be seen, for example, in self-paced and self-directed learning and increased motivation. Rosenberg et al. (2003) analyzed the effectiveness of Computer-aided programs in dental education. They concluded that computer-assisted learning can provide innovative and interactive ways of presenting material, and, therefore, should be used with conventional teaching or as a means of self-instruction that can elicit a positive response from students and can motivate them.

Some early applications focus on improving the skills of dentists. Other applications focus on increasing their knowledge. To improve the skills of dentists, Urbankova & Engebretson (2011) developed a simulator that allowed the students to practice with a dummy patient and to learn through this practice. The simulator includes a monitor that shows the inside of the mouth and the dental instruments that interact with a dummy patient. Yoshida et al. (2001) developed a virtual reality haptic dental training system. With this system, the students can interact with a virtual model on a monitor screen on a PC. The students can use the system at their convenience without having a trainer. Rhienmora et al. (2010) developed a Haptic AR Dental Trainer. The system allowed students to practice surgery in a real environment combining a 3D model of the tooth and a specific tool for dental surgery. For the visualization, they used Head-Mounted Displays (HMD). They carried out a study with five novices (fourth-year dental students) and five experts in prosthodontics. The participants' opinion was that the training feedback generated was acceptable. For dental implant surgery, it is very important for the surgeon to see the position of the implants in the real context or in a context similar to the real one. Katić et al. (2010) developed and evaluated a context-aware AR system for dental implant surgery. For the visualization, they used HMDs. The system provided an appropriate visualization about 85% of the time. The surgeons' feedback was also favorable regarding usability.

To increase dentists' knowledge, Meckfessel et al. (2011) developed online courseware, including an interactive learning module so that the students had access to the e-program from any networked computer at any time. It contains animated videos, dental information, and some questions about the lessons. The results showed that after two years of using the e-course, the failure rate in the final examination dropped significantly (from 40% to less than 2%). De Boer et al. (2013) provided examples of realistic virtual teeth with and without pathology that could be used for dental education. Salajan & Mount (2012) developed a web system for dental education that provided a lot of media and interactive examples. This web system was similar to the Meckfessel et al. (2011) courseware. Woelber et al. (2012) tested two programs of Computer-Assisted Learning: one of them is a high-interactive e-learning program and the other is a low-interactive learning environment (Easy-to-use). They obtained statistically significant differences in the level of knowledge acquired; the students that used the easy-to-use program obtained better results on the post-test.

With regard to mobile AR, it has already been used for educational purposes in other fields. For example, Dunleavy et al. (2009) presented Alien Contact!, a mobile AR game for teaching math, language arts, and scientific literacy skills to middle and high school students. Ardito et al. (2009) presented a mobile AR game called Explore! for supporting visits and explorations of middle school students to archaeological sites in Italy. Juan et al. (2011) used a mobile phone (Nokia N95) for learning how to recycle. Tang & Ou (2012) used a mobile AR application for learning butterfly ecology. Furió et al. (2013b) used an iPhone and a Tablet PC for reinforcing children's knowledge about the water cycle.

III. Materials and methods

To develop the AR system, we used Unity (also called Unity3D) and Vuforia SDK. Unity is a cross-platform game engine. We used the 3.5 version. The Vuforia SDK has an extension for Unity 3D, which facilitates the inclusion of animations and very complex virtual objects. These inclusions are not as easy if only Vuforia SDK is used. Vuforia uses Computer Vision techniques to recognize and track the following types of fiducial elements in real time: Image Targets, Frame Markers, Multi-Image Targets, Cylinder Targets, Virtual Buttons, or Word Targets. In our case, we used the image that appears in Figures 5 & 6 as the Image Target. Unity and Vuforia make it possible to develop applications for Android and iOS devices. Since spring 2016, early access to upcoming Vuforia features for Windows 10 has been available upon request. In our case, we developed our own AR system for Android devices. To do this, we were required to obtain the Unity Android mobile plugins from Unity Technologies. The Unity iOS mobile plugins from Unity Technologies is also required to build applications for iOS devices. Both plugins can be installed at the same time. Once the system has been developed, the platform for which the application has been built can be selected and the same code can be used for building applications for Android or iOS devices. Unity's slogan indicates, "Build Once, Deploy anywhere", so our system could be built for iOS devices as well.

The development and testing of the AR system were achieved using a mobile device with Android OS. Specifically, we used a Motorola Xoom 2 tablet. The main features of this device are the following: A display with 800×1280 pixels, 10.1 inches (149 ppi pixel density), and a 5 MP camera. The OS was Android, v3.2 (Honeycomb). However, the system can run on nearly any Android device with similar features. The system will still work with a device with inferior features, but with some limitations. With an inferior processor, the system could not have real time. With a camera with less resolution, the system could have more problems recognizing the target. We chose this tablet because it had a processor that was good enough, good camera resolution, and low weight.

To protect the tablet from damage and also to provide more stability when holding the device, we designed and printed an external case (Figure 5) on a 3D printer. For the external case to weigh as little as possible, the design only took into account the edges of the tablet. An outline that matches the edge of the tablet was generated based on the actual measurements of the tablet. This outline was spread along the perimeter, leaving room for the handles. The 3D printer that we used was a Rapman 3.1. 3D printing is achieved using an additive process, where successive layers of material are laid down according to the design pattern. The material used was ABS white, which was then painted blue. Since the Rapman 3D printer cannot print elements of the size of the external case in one piece, the printing was divided into smaller pieces, which were subsequently joined by means of adhesive. The external case can be assembled and disassembled through the upper and lower central joints that are not glued and that are joined by two pieces that are bolted.

For the 3D models, we started from 3D meshes in the STL (STereoLithography) format, with a very large number of polygons. This large number of polygons was reduced using Autodesk 3ds Max with ProOptimize. To obtain a surface with no edges, we used a predefined Smooth function. Figure 7 shows tooth number 47 during the graphic treatment process.

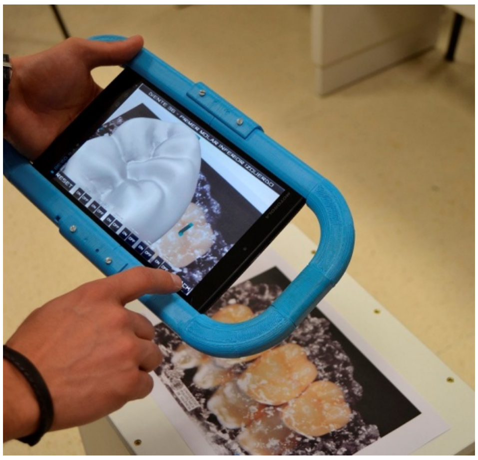

Figure 5. Image Target and the augmented scene with the model of the lower jaw.
Source: Compiled by the author

Figure 6. Image Target and the augmented scene with tooth number 36.
Source: Compiled by the author

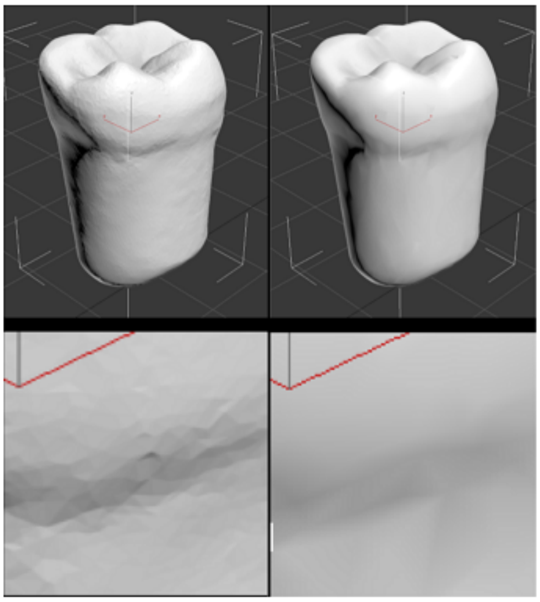

Figure 7. Left to right: Original model (.stl); Final model.
Source: Compiled by the author

For the AR experience, the camera of the mobile device must focus on an image target. The AR system recognizes the image and obtains the position and orientation of the camera relative to the center of the image target. After this process, the system superimposes the virtual elements on the center of the image target. For example, Figure 5 & Figure 7 show the augmented scene in which the model of the lower jaw appears. The user can zoom in/out, rotate, raise, lower and move the device at any time in order to observe the virtual model from any point of view. Another possibility is to touch the screen (a simple drag and drop gesture) to rotate the model around its own z-axis. At first, the lower jaw appears. The upper jaw can be selected at this point. Once, the lower or the upper jaw is shown, the user can select a specific tooth to see its morphology. The user only has to touch the tooth on the screen in order to select it. To facilitate this process, the areas to be selected appear in blue over each tooth (Figure 8). After selecting a tooth, its 3D model appears over the image target. Figure 9 shows the augmented scene with tooth number 46. In the lower area of the screen, several buttons that correspond to the tooth morphology appear. The user can activate/deactivate a 3D wire that defines the selected structure by simply touching these buttons. The possibilities that have been included in the AR system are: triangular ridge, marginal ridge, buccal cusps, lingual cusps, fosse and grooves, and supplemental grooves. When you press a button such as "marginal ridge", it appears immediately over the tooth. Figure 10 shows tooth number 46 with all of the morphological details that are included in our AR system.

Figure 8. Augmented scene showing the model of the lower jaw.

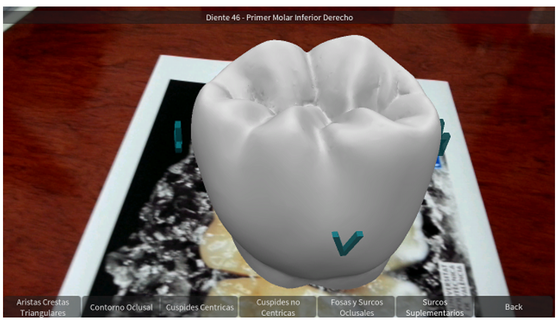

Figure 9. Augmented scene showing tooth number 46.

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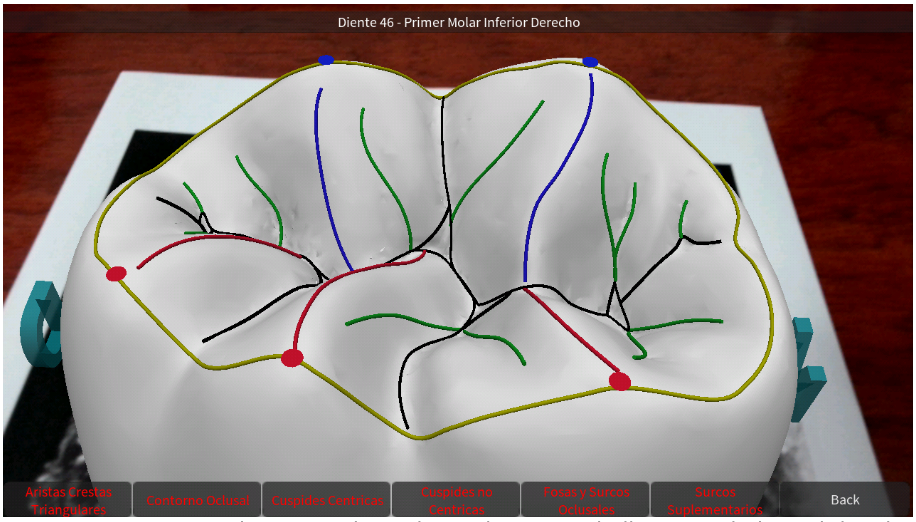

Figure 10. Augmented scene with tooth number 46 and all its morphological details. Source: Compiled by the author

IV. Study

We carried out a study with 38 undergraduate students, 6 Master's students and 11 employees of the center (8 lecturers, 3 technical staff). The study was conducted at a School of Dentistry (C.F. Folguera-Vicent, Alboraya, Spain). The mean age for the undergraduate students was 23.37±4.37, and 51% were men and 49% were women. The mean age for the Master's students was 23.8± 3.9, and 50% were men and 50% were women. The mean age for the employees of the center was 41.0±14.2, and 9% were men and 90.9% were women. We divided all the participants into two groups:

- Undergraduate students, group without knowledge of dental morphology. They are learning it.
- Master's students and employees of the center, group with knowledge of dental morphology that have mastered the knowledge taught in the AR system. Therefore, this group only uses the AR system to know their opinion about it.

In our study with the students, we compared the AR system with a video session. For the video session, we recorded a Dental Prosthesis professor explaining the morphology of the tooth number 36 to a class. This video was used to simulate a traditional lesson. The video lasts about two minutes and the participants can watch it as many times as desired. The participants watch the video on a laptop, and they can watch it repeatedly. The total time spent by each participant was about 15 minutes for the entire process.

A total of 38 students participated in our study. They were specializing in two areas: Hygiene and Prosthesis. They were divided into two groups, Group A (α) and Group B (β). Each group had participants from both specialties who were assigned to one of the following two groups:

- Group A: Participants that learn by watching a video and afterwards used the AR system. Figure 11 presents this protocol graphically.
- Group B: Participants that used the AR system and afterwards learn by watching a video. Figure 12 presents this protocol graphically.

A person was in charge of supervising how the study was conducted. In the AR session, the students use the same AR system individually one after another. At first, the person in charge of the study provides a quick overview of how to use the AR system. Basically, the information is the following: "Initially the lower jaw appears, and the participant only has to touch the desired tooth. The selected tooth appears on the target. The participants can rotate the tooth by touching the screen (left or right). In the lower area, there are several buttons that correspond to the tooth morphology. The user can activate/deactivate a 3D wire that defines the selected structure by simply touching these buttons. When the back button is touched, the application returns to the lower jaw and the user can choose another tooth."

The following five questionnaires were used in the study (Q1, Q2, Q3, Q4).

- ✓ Q1 is a pre-test. This test was used to evaluate the students' knowledge before the study. In this test, the students had to draw the morphological structures on the surface of a tooth. The tooth used was number 36 (Figure 13). The score that can be obtained ranges from zero to ten. The tests were corrected by an expert professor. The *knowledge* variable was created to condense the correct identification of the morphological structures of the tooth based on this scoring.
- ✓ Q2 was the same as Q1. The acquired knowledge can be determined by comparing the results of Q2 with the results of Q1.
- ✓ Q3 is a usability and satisfaction questionnaire. This questionnaire includes 14 questions.
- ✓ Q4 includes a comparative question between the two methods. It also has free answer questions where the participants can add open comments.

Figure 11. Group A protocol
Source: Compiled by the author

Figure 12. Group B Protocol.
Source: Compiled by the author

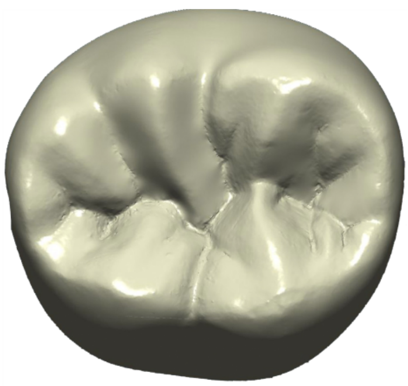

Figure 13. Tooth number 36 used in the study.
Source: Compiled by the author

V. Results

a. Results for the undergraduate students

For the students' acquired knowledge, several t-tests were performed to determine if there were statistically significant differences. Table 1 shows these tests. The "**" characters indicate the statistical significance at level α= 0.05. First, we checked whether there were statistically significant differences regarding the initial knowledge of the students in the two groups (Table 1. First row). No statistically significant differences were found. Therefore, the previous knowledge was considered to be similar for the two groups. A paired t-test revealed that there were statistically significant differences for the acquired knowledge for the two groups (Table 1. Second and third rows). We checked if there were statistically significant differences between the post-tests about the acquired knowledge of the two groups, and no statistically significant differences were found, (Table 1. Fourth row). Figure 14 shows the box plot for the knowledge variable of Group A (Real) and Group B (AR) in the Q1 (Pre) and the Q2 (Pos) questionnaires.

Knowledge	G1	G2	Mean G1	Mean G2	df	t	p-value	Cohen's d
Initial. α and β	Pre- α	Pre- β	8.23±1.43	7.54±2.00	33	1.11	0.274	0.378
Acquired. α	Pre- α	Post- α	8.23±1.43	9.60±0.72	15	-5.05	<0.001**	1.262
Acquired. β	Pre- β	Post- β	7.54±2.00	9.00±1.56	18	-6.08	<0.001**	1.395
Acquired. β and α	Post- β	Post- α	9.00±1.56	9.60±0.72	33	-1.39	0.174	0.471

Table 1. T-tests for the knowledge variable.
Source: Compiled by the author

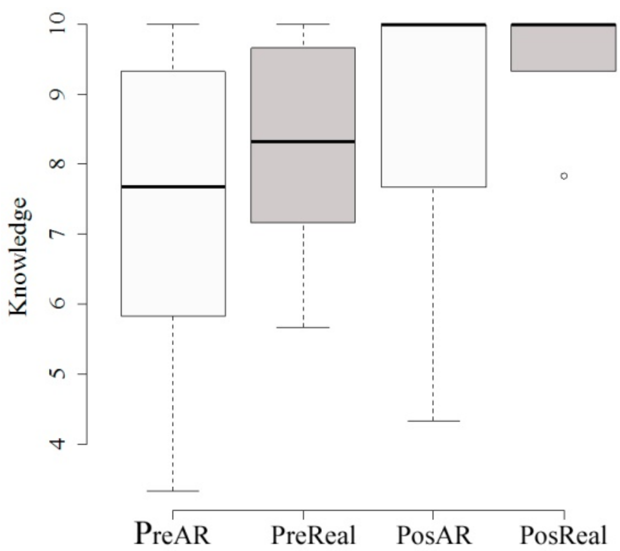

Figure 14. Knowledge variable results
Source: Compiled by the author

With regard to the preferences of the students, a Fisher's exact test was performed for the preference question ("Which system do you prefer? [1. AR system / 2. Video session]"). The test revealed that there were no any statistically significant differences (p= 0.670). However, if the percentages are considered, 69% of the participants that had played with the AR system first preferred the AR system, and 80% of the participants that had followed the classic class first also preferred the AR system. Taking into account all of the participants, 75% of them preferred the AR system.

For the usability, satisfaction, and immersion questions, several non-parametric tests were performed for the Likert questions (the Mann-Whitney U test) to determine if there were statistically significant differences in the students' opinions. Table 2 shows the questions and the results. The results indicate that there was only a difference in question Q313 (Did you have the sensation that you can touch the teeth?). In this question, the users thought that they had the feeling of having a real front tooth in the Tablet.

Generally, the students had a lot of fun playing (Q301). Most of them would highly recommend the application for their partners (Q302). They liked very much the idea of their professors using the AR system in class (Q303). In relation to the difficulty, they thought that the AR system was very easy to use (Q304). They understood the AR system rules perfectly (Q305). Selecting the elements was very easy (Q306). They liked very much the models that the AR system shows on the screen (Q307). They also liked the AR experience very much (Q308). They thought that seeing the models from different positions was very useful (Q309) and very easy (Q310). They thought that they had learned a lot using the AR system (Q311). The participants perceived the teeth to be almost real models of plaster (Q312). The global score was very high (Q313).

Question	Mean α	Mean β	*U*	*Z*	*p*-value	*t*
Q301: How much fun did you have? [1-5]	4.56±0.50	4.53±0.50	157.5	0.21	1.000	0.036
Q302: Would you recommend the AR system to your partners? [1.Nobody / 2.Almost no one / 3.I do not know / 4.Somebody / 5.Everybody]	4.75±0.43	4.89±0.31	130.0	-1.12	0.379	0.189
Q303: Would you like your professor use the AR system in your classes? [1-5]	4.25±0.56	4.47±0.60	120.5	-1.18	0.272	0.199
Q304: What was the level of difficulty of the game? [1.Very difficult / 2.Difficult / 3.Normal / 4.Easy / 5.Very easy]	4.50±0.61	4.53±0.50	153.0	0.04	1.000	0.006
Q305: Did you understand the rules? [1.No / 2.Not always / 3.Yes]	2.94±0.24	3.00±0.00	142.5	-1.09	0.457	0.184
Q306: Was it easy to select the options? [1.Very difficult / 2.Difficult / 3.Normal / 4.Easy / 5.Very easy]	4.50±0.50	4.37±0.58	168.0	0.60	0.639	0.102
Q307: How did you like the image? [1 - 5]	4.25±0.66	4.21±0.52	160.0	0.31	0.842	0.052
Q308: Did you like seeing the dental pieces on the table? [1-5]	4.44±0.61	4.42±0.49	158.5	0.25	0.863	0.041
Q309: Do you think seeing the dental pieces from different positions and zooming it in / out is useful? [1-5]	4.62±0.48	4.63±0.58	146.0	-0.24	0.890	0.041
Q310: Did you find easy to see the dental pieces from different positions and zoom in / out? [1-5]	4.31±0.58	4.53±0.50	124.5	-1.04	0.361	0.176
Q311: Do you think that you have learned with the AR system? [1-5]	4.00±0.71	4.11±0.64	140.0	-0.44	0.787	0.074
Q312: Did you think that the teeth were real models of plaster and that they were on the table. [1 - 7]	5.06±1.43	5.42±1.31	124.5	-0.94	0.357	0.159
Q313: Did you have the sensation that you can touch the teeth? [1 - 7]	4.94±1.09	5.74±1.12	82.0	-2.40	0.016**	0.406
Q314: Score the AR system from 1 to 10. [1 - 10]	8.50±1.00	9.05±0.83	104.5	-1.65	0.113	0.279

Table 2. Usability, satisfaction, and immersion questions.
Source: Compiled by the author

b. Results for the Master's students and employees of the center

The questionnaire used for this group is presented in Table 4. The knowledge questions were not asked. In order to have a global score for the questions included in this questionnaire, we used a new variable called *satisfaction*. This variable consists of the sum of the values of all of the questions. To analyze the satisfaction variable, a multifactorial ANOVA test was performed. The factors of gender, specialization, and age were between subjects. The specialization factor refers to the different groups of participants (e.g., dental professors). The effect size used was the partial Eta-squared (η^2). Table 3 shows the results. No statistically significant differences were found among the different factors. In Table 3, Specialization classifies the participants into four different groups: Master's students, lecturers who teach dental morphology, lecturers who do not teach dental morphology, and technical staff; Interactions refers to the interactions among Gender, Specialization, and Age.

Factor	d.f.	*F*	*p*	*partial* η^2
Gender	1	0.011	0.922	0.003
Specialization	3	5.401	0.096	0.935
Age	1	1.874	0.264	0.384
Interactions	1	<1.61	>0.714	<0.051

Table 3. Multifactorial ANOVA for the satisfaction variable. N=17.
Source: Compiled by the author

The analysis of the different questions about satisfaction is shown in Table 4. As Q601 shows, the users thought that the AR system was very easy to use and that the different choices of the application were very easy to select (Q603). They answered that they liked the images very much (Q604), and their opinion was that the students could learn a lot using the AR system (Q605). The score was very high when asked if they would like to use the AR system in their classes (Q606). They liked the AR experience very much (Q607) and they thought that it was very useful to see the teeth from different positions and zoom in/out (Q608), which was very easy to perform (Q609). No statistically significant differences were found for the specialization factor in Q610 (F[8]=2.332, p-value=0.159) or in Q611 (F[8]=1.514, p-value=.315). Finally, they gave the AR system a mean score of 8.76±1.26 over 10, which indicates a high degree of satisfaction.

When the participants were asked whether or not they understood the rules of the AR system (Q602), 100% of them answered affirmatively. Another dichotomy question was about whether or not the participants thought that the AR system is a useful tool for dental learning (Q613). All of the participants (100%) answered affirmatively.

#	Bounds	Mean
Q601 What was the difficulty of the system? [1.Very difficult / 2.Difficult / 3.Normal / 4.Easy / 5.Very easy]	[1-5]	4.65±0.48
Q602 Did you understand the working rules? [1.No / 2.Not always / 3.Yes]	[1-3]	3.00±0.00
Q603 Was it easy to select the options? [1.Very difficult / 2.Difficult / 3.Regular / 4.Easy / 5.Very easy]	[1-5]	4.47±0.61
Q604 How did you like the image? [1-5]	[1-5]	4.24±0.64
Q605 Do you think that students can learn with the AR system? [1-5]	[1-5]	4.47±0.50
Q606 Would you like to use the AR system in your classes? [1-5]	[1-5]	4.59±0.49
Q607 Did you like seeing the dental pieces on the table? [1-5]	[1-5]	4.35±0.48
Q608 Do you think seeing the dental pieces from different positions and zooming in / out is useful?	[1-5]	4.47±0.50
Q609 Did you find it easy to see the dental pieces from different positions and zoom in / out?	[1-5]	4.24±0.55
Q610 Did you think that the teeth were models of real plaster and that they were on the table. [1 - 7]	[1-7]	4.94±1.70
Q611 Did you have the sensation that you can touch the teeth? [1 - 7]	[1-7]	5.37±1.28

Q612 Score the AR system from 1 to 10. [1 - 10]	[1-10]	8.76±1.26
Q613 Do you think the AR system is a useful tool for dental learning? [1. Yes, 2. No]	[1-2]	1.00±0.00

Table 4. Master's students and employees of the center. Satisfaction results.
Source: Compiled by the author

VI. Discussion

To our knowledge, this is the first time that a mobile AR system has been presented for learning dental morphology. Most of the systems presented to date for learning dentistry are pretty basic; some of them use web technologies or multimedia material. However, mobile AR systems have already proven to be an effective tool for other learning purposes when they are compared with traditional methods, for example, for learning multiculturalism, solidarity, and tolerance (Furió et al., 2013a). With this work, we demonstrate the potential of AR for education in fields in which it has not yet been extensively exploited. We would like to highlight that most of the previous AR systems are based on so-called markers (generally, black squares with symbols in the center). The Vuforia SDK can use image targets, and the performance of AR systems is superior to markers of that type. The most outstanding difference is that the image can be partially occluded. Even when you place your open hand over the image, Vuforia still recognizes the image. According to our tests, the image target can be reduced up to 25% and Vuforia still recognizes the image. The angle between the camera and the image target does not need to be 90 degrees; Vuforia is still able to recognize the image target at only 20º. These features make the augmented experience much more complete than when other types of markers are used.

We carried out a study to determine whether or not the students acquired new knowledge after using the AR system and a video session. The results showed significant differences for the two methods indicating that the students had acquired significant knowledge after using both methods. There were no statistically significant differences regarding the amount of knowledge acquired by each method. This indicates that the students remembered a lot of the knowledge transmitted in the AR system as well as in the video session. We can also say that our AR system has been effective when it comes to transmitting knowledge in the short-term. This result is in line with other previous comparisons that identified that computer-aided dental learning programs are either more effective than or equally as effective as other methods of education (Walmsley, 2003). From our point of view, having significant differences regarding the acquired knowledge before and after using the AR system is a very good result. This implies that the students had indeed learned new concepts after using the AR system. This could imply that these kinds of AR systems could be used as a way to reinforce the knowledge learned in class with the advantage that these AR systems can be used anywhere and at any time (Jones & Jo, 2004). Welk et al. (2006) argued that the benefits of computer-assisted learning can be seen in self-paced and self-directed learning and increased motivation. We believe that these benefits are also applicable to AR and that AR systems can be powerful tools for helping the teaching-learning process. The students can reinforce their knowledge with the help of the mobile device and without requiring the supervision of the professor.

We also studied whether or not there were differences in the acquired knowledge regarding gender, specialization, and age. No significant differences were found. This is an excellent result because it means that the AR system is well suited for these factors and that the AR system can be used in more situations without many restrictions. It is especially important to highlight that there were no differences for gender. Therefore, our AR system can be used equally and effectively by both men and women.

Usability can also be considered to be an important factor that affects educational effectiveness (Mayes & Fowler, 1999; Squires, 1999). Other authors have argued that systems that are easy to use help students to focus their attention on the content (Sun et al., 2008). In our case, the AR system was very easy to manipulate (with means above 4.5 on a scale of 1 to 5 for the two groups involved). Moreover, the person in charge that was observing the participants during the activity stated that most of the users did not have any problems interacting with the device. Therefore, based on these considerations, our AR system does help students to focus their attention on the dental morphology content.

Our study could also be carried out replacing the video session with a traditional classroom session with an explanation by the lecturer. In our case, for organizational purposes, we chose to record the class of the lecturer and the students could participate individually. However, we would like to mention, that the flipped classroom is a pedagogical model in which the student has to work at home and use the classroom only for more practical aspects such as answering questions or doing exercises. Furthermore, now it is also possible to attend distance-learning courses (e.g., Massive Open Online Courses (MOOC)) in which video lessons or tutorials are major tools. From our point of view, our AR system could be used with methods involving more individual learning or with more traditional learning models.

With regard to the opinion of the Master’s students and the employees of the center, their acceptance of the AR system was the highest possible. All the participants (100%) thought that the AR system is a useful tool for dental learning. To conclude this section, we include several comments made by them.

- The AR system encourages observation, perception, and understanding of dental morphology. It stimulates learning and self-assessment in the progression of the acquired knowledge.
- The AR system is completely intuitive and facilitates the study of the teeth at home without the need for a model.
- The dental anatomy is very well reproduced by the 3D models.

The Master’s students and the employees of the center also indicated several possible extensions, which include the following:

- The AR system could be a valuable tool for commercial use in clinics and laboratories.
- The various parts of the dental pieces could be distinguished using colors
- An intraoral camera could be used to view a real image. This would not only help learning but also help diagnosis.
- AR could be applied to occlusion.

VII. Conclusions

We have developed the first mobile AR system for learning dental morphology. We compared the AR system with a video session to measure learning outcomes. We also measured the usability and satisfaction of the participants for the AR system. The analysis of the acquired knowledge demonstrated that there was similitude between the two methods. For the rest of the questions, all of the participants considered the AR system to be very easy to use and they stated that they would like to use it for learning purposes. Therefore, the AR system could be used as an effective transmitter of knowledge. The AR system could facilitate versatility in the learning process since the learning activity could be performed anywhere and at any time without requiring supervision. In our opinion, the AR system could be autonomously used by a student at home to complement or reinforce the knowledge acquired in the classroom.

For future work, we are currently using the AR system as a helping tool for dental learning, combining traditional learning and the AR system. For the moment, the students have fully accepted this combination. We would like to determine whether or not the students' grades are influenced by this combination. We would also like to determine the level of acceptance of our AR system at other centers.

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