Bringing Augmented Reality for learning in dentistry

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One look is worth a thousand words!

Frederick R. Barnard

To my parents, because every day I love them more

To my brother, I love him a lot

To my love Janou

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Abstract

In the last years we have witnessed significant technological advances on the mobile devices. They are become increasingly indispensable in our lives. The Augmented Reality (AR) concept can be considered a bridge between real and digital in our lives. The system which we propose in this master thesis intends to provide a better understanding of dental anatomy, using a friendly and intuitive interface based on AR.

This master thesis is the result of collaboration between the University Institute of Control Systems and Industrial Computing, better known as the ai2 Institute, and Folguera Vicent Dental Prosthesis School. We present in this master thesis, for the first time, a mobile and AR system which has been developed for learning dentistry and has been tested with students.

A case study helps us to demonstrate the contribution of our system to the educational environment, increasing the motivation and understanding levels of the users. The research outlined in this master thesis uses qualitative assessment methods, assembled around a series of five questionnaires. The obtained results are very promising. From the data analysis, we can see that ARDental is easy to use and the acceptance among students is high. This method opens new opportunities for learning, students can study anytime, anywhere, not just in the classroom.

Resumen

En los últimos años hemos sido testigos de avances tecnológicos significativos en los dispositivos móviles. Son cada vez más indispensables en nuestras vidas. El concepto de Realidad Aumentada (RA) puede ser considerado un puente entre lo real y lo digital en nuestras vidas. El sistema que proponemos en este trabajo de fin de máster tiene la intención de proporcionar un mejor conocimiento de la morfología dental a los estudiantes, utilizando una interfaz fácil e intuitiva basada en RA.

Este trabajo de fin de máster es el resultado de la colaboración entre el Instituto de Automática e Informática Industrial, más conocido como el Instituto ai2, y el Centro de Formación de grado superior Folguera-Vicent. En esta tesina presentamos, por primera vez, un sistema móvil de Realidad Aumentada que hemos desarrollado para el aprendizaje de la morfología dental y ha sido probado por estudiantes.

Un caso de estudio nos ayuda a demostrar la contribución de nuestro sistema en el entorno educativo, el aumento en la motivación y el aprendizaje de los usuarios. La investigación que se describe en este trabajo de fin de máster utiliza métodos de evaluación cualitativa, utilizando cinco cuestionarios. Los resultados obtenidos son muy prometedores. A partir del análisis de los datos, podemos observar que ARDental es fácil de usar y la aceptación entre los estudiantes es alta. Este método abre nuevas oportunidades para el aprendizaje, los estudiantes pueden estudiar en cualquier momento y en cualquier lugar, no sólo en el aula.

Rezumat

În ultimii ani, am fost martorii unor progrese tehnologice foarte semnificative în ceea ce privește dispozitivele mobile. Ele au devenit din ce în ce mai indispensabile în activitatea noastră de zi cu zi. Realitatea Augmentată (RA) poate fi considerată o punte între real și digital în viețile noastre. Sistemul pe care îl prezentăm în această teză de master dorește să ofere o mai bună înțelegere asupra anatomiei dentare, folosind o interfață prietenoasă și intuitivă bazată pe RA.

Această teză de master este rezultatul colaborării dintre Institutul Industrial de Automatică și Calculatoare, cunoscut ca și Institutul ai2 și Școala de proteze dentare Folguera Vicent. Vă prezentăm în această teză de master, pentru prima dată, o aplicație de RA ce a fost dezvoltată în scop didactic, pentru predarea anatomiei dentare și a fost probată de către studenți.

Acest studiu de caz ne ajută să demonstrăm contribuția aplicației noastre în mediul didactic, crescând nivelul de motivație și de înțelegere al utilizatorilor. Cercetarea prezentată în această teză de master utilizează metode avansate de analiză, realizate în baza datelor colectate prin cinci chestionare. Rezultatele obținute sunt foarte promițătoare. Din analiza datelor, putem observa faptul că ARDental este ușor de utilizat iar recepția în rândul studenților este foarte bună. Această metodă oferă noi oportunități, studenții vor putea studia oricând și oriunde, nu doar în sala de clasă.

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Chapter 1

Introduction

Why I am interested in Augmented Reality? Why the combination between real and virtual objects is useful? Certain material is easier to learn when it is visualized in three-dimensional space and if the user can interact with the 3D model in a natural way. Augmented Reality provides ways to use the 3D visualization with which the user can interact. A study made by T. Olssen and his colleges [22] show as the people are ready for new technologies. In another study [23] we can see that a lot of users also use the AR applications at home.

The penetrated environments of AR are medical [10] [36], phobia treatment [12] [13] [15], museum guidance [6], advertising [24], military [11], maintenance and repair [11], and education system [9]. In the rest of this section, we cite a few AR systems that were developed previously for learning. Here we can mention: mathematics and geometry [17] [31]; organic chemistry [7]; geography [35]; or learning difficult machine [25]. For children have been designed several AR educational games and applications: volcanoes [38]; multiculturalism, tolerance and solidarity [9], endangered animals [14] or water cycle [8].

1.1 Motivation

The research we present here is the first case study about usability of the first mobile AR system which has been developed and tested for learning dentistry. The base of our approach is the huge number of mobile devices in use and the usefulness they have in our lives.

This project is the result of collaboration between the University Institute of Control Systems and Industrial Computing, better known as the ai2, and Folguera Vicent Dental Prosthesis School. At the Folguera Vicent Dental Prosthesis School, and in general, for learning the morphology of dental pieces, the teacher uses 3D models and board. For the students is difficult to have their own 3D real models and their own boards of all the teeth so, after the class, individual study is quite difficult. Due to this difficulty and our collaboration, we identify that a mobile and AR system could help students in their learning process.

1.2 Objectives

The main objective of the thesis is to provide for the students an innovative and helpful tool into the learning process. This application does not want to replace the role of the teacher in the classroom. We want to offer him an original manner of teaching and to offer the students a new and different approach of the classical learning methods. Our mobile application wants to provide the 3D models in Augmented Reality.

To achieve this objective we set a number of goals:

- We have to design ARDental which is the first Augmented Reality mobile application with dental specific.

- We will check if there is any statistical significant difference between the knowledge acquired during a traditional class and a session with our application.

- We also analyze the satisfaction and acceptance level of the students after the use of the application.

- We want to make an exhaustive analysis of data acquired.

1.3 Augmented Reality

Two decades ago, started the research in this field, with the work of Caudell and Mizell [5]. A few years after those first steps in a virgin field, Azuma (1997) [1] and Azuma and his colleagues (2001) [2], gives one of the first definition for Augmented Reality. For the purpose of this section we follow their definition.

1.3.1 Definition

We define an AR system as one that combines real and computer generated information in a real environment, interactively and in real time, and aligns virtual objects with real ones. In the new world the augmented one, each object, real or virtual has its own purpose, but complementing each other in the same time.

According to Milgram and Kishino [18], AR is placed at a certain position on a continuum of Mixed Reality (MR) depending of the ratio between the computer generated and the real one, see Figure 1.1.

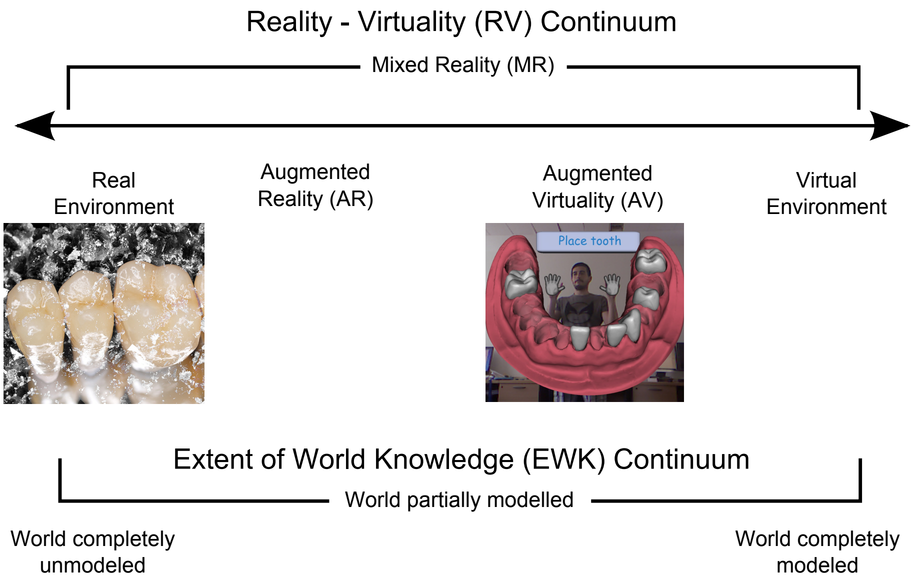

Figure 1.1: Milgram's Real Virtual Continuum

Augmented Reality is a friendly variation of a Virtual Reality

(VR). If with the VR the user is totally immerse in a digitalized world, the AR allowed the user to interact with the synthetic objects through the real object creating an augmented world.

Earlier attempts reveal the big interest of the scientific community on this field. Thanks to the significant advances in the two fields of user interface research: virtual environment and mobile computing new and innovating system are designed. We can name here The Touring Machine like the first Mobile AR system. The goal of this system is to provide user information about the surrounding areas, which in that case is the university campus. The virtual information was updating according to GPS information.

1.3.2 Types of AR displays

According to Zhou et al. [39], there are three main ways to display AR content. One includes the see-through HMD displays, which has been carried on in the earlier works. Some of the presented works are using this type of display [17] [35] [11]. As an example, iLamps by Raskar et al. [26] presented the object augmentation provided by a hand-held projector-camera system. The third type consists of hand-held displays, such as mobile phones and tablet PCs. They often act as a Magic Lens [3], where people can see digital information aligned with physical objects through them. This is the most common method and is used by the majority of the programmers [25] [6] [24].

1.3.3 AR interfaces

AR has been recognized as a promising technology. Allow users to interact with the virtual content in an intuitive way is still a challenging problem. Many NUI are designed, and one, more than another allows free and natural interaction with the system. Four types of existing AR interfaces are summarized in the following paper [4].

- **Tangible AR interfaces**, where the users are using physical objects to interact with linked digital media. As example we present SLAP [37] and TaPuMa [19] systems.

- **Collaborative AR interfaces** allow multiple users to interact with multiple AR displays in a collaborative activity. One of the intents is presented by Schmalstieg et al. [33], where they had proposed a concept to bridge multiple users, displays, applications with AR context.

- **Hybrid AR interface** combines different devices to define the interaction in a complementary way. The architecture is flexible and allow users the reconfiguration of the input and output devices. A good example can be considered the work of Sandor et al. [32].

- **Multimodal AR interfaces** use speech, mimics, gestures or other natural behavior as input commands for the interaction. The wearable gestural interface presented by Mistry et al. [20] announce a future augmented world, where digital information is controlled by natural commands.

1.4 Structure of the Thesis

- **Chapter 1** Introduction.

  On this first chapter I have made a briefly introduction about AR and which are the AR penetrated environments. We presented also the motivation and the goals of this thesis. Having a new challenge for this field, we try to see how our work can help and improve the current teaching methods.

- **Chapter 2** State of Art.

  This chapter presents other works related with my thesis subject. Tools subsection makes a short presentation of Augmented Reality platforms which are available in this moment for the developers.

- **Chapter 3** System Architecture. The third chapter describes the hardware platform used and the software framework in the first two sections. In the third section I present the implementation details for the application.

- **Chapter 4** ARDental.

  In this chapter I will present the application design, I will present the experiment design and the procedure. The experiments are designed to help us to determine if the goals are achieved.

- **Chapter 5** Analysis and Results.

  This chapter explains the analysis of data collected from the experiment. It involves the methods and procedures of performed statistical analysis, and the validation of hypotheses from the results. In the end the discussion of observations provides more insights about the techniques.

- **Chapter 6** Conclusions and Future Work.

  The last chapter summarizes the work and contributions, proposes future directions and possible extensions.

- **Appendix** Questionnaires

  In this appendix we present the all five questionnaires I used during the experiments.

Chapter 2

State of Art

2.1 Related Work

2.1.1 Human body viewer

Anatomy 4D is an interactive application which allows you to explore an AR 3D body. Tabs from the bottom of the screen let you to switch off and on different organ systems. You can focus just on the digestive system or on the muscular system for instance.

Anatomy 4D is an AR mobile application released in 9 November 2012 in iTunes for iOS and in Google Play for Android. Results[1] surpassed daqri's expectation and continue to astonish:

- 250,000+ downloads from the App Store and Google Play
- 3,200+ hours (134 days) spent by users in the app in its first three weeks of release
- Has garnered the attention of dozens of professors and universities - including Stanford, The University of Illinois, and Trinity College - who plan to adopt its capabilities as part of coursework
- Enthusiastic and global self-generated user community
- Anatomy 4D was featured by Business Insider Australia as an "App That Makes You Feel Like You're Living in The Future"

[1] Case study realized by Qualcomm Vuforia https://www.vuforia.com/case-studies/anatomy-4d. August 22, 2013.

We can see in Figure 2.1 the marker used by the Anatomy 4D and in Figure 2.2 a screenshot taken with our mobile device using Anatomy 4D.

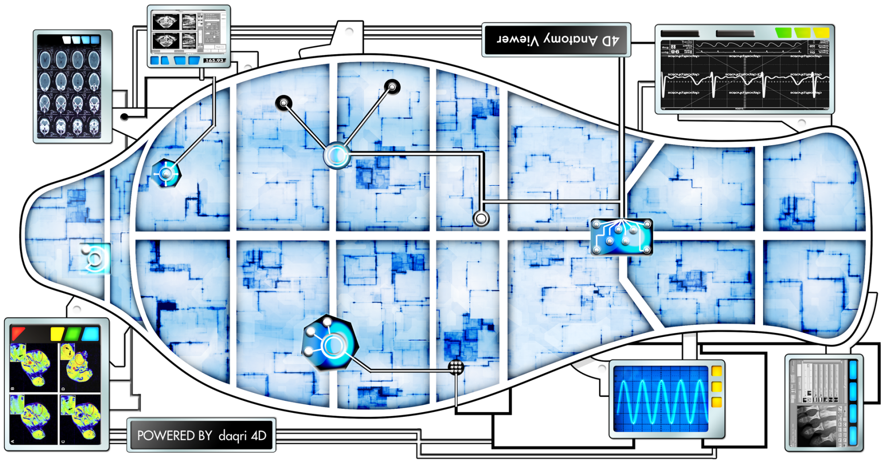

Figure 2.1: AR Tracking Marker used by Anatomy 4D.

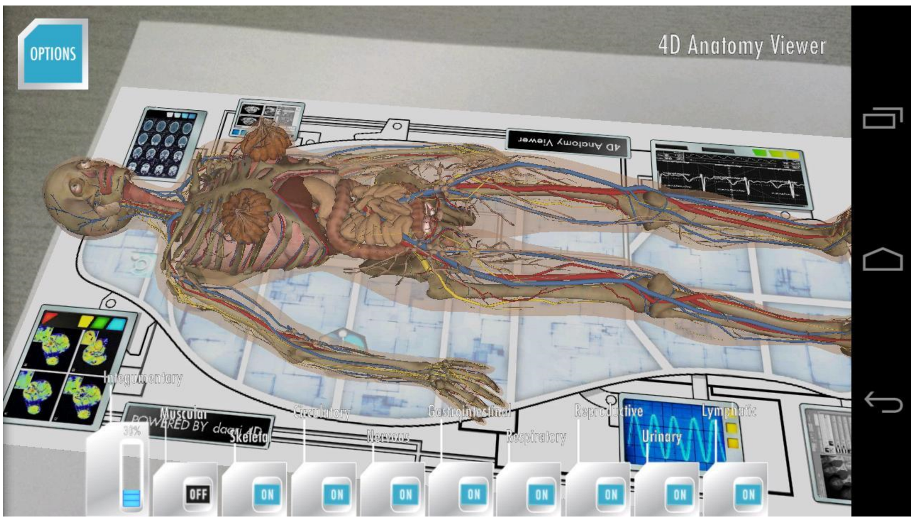

Figure 2.2: Screenshot using Anatomy 4D.

2.1.2 Augmented Reality in Dental Implant Surgery

According to Katic et al. [16] in dental implant surgery is very important for the surgeon to see the position of the implants in the real context or in similar context to the real one, before of the operation. In their research, they developed and evaluated a context-aware Augmented Reality system which facilitate this. Patient and instrument position are tracked and interpenetrated, so the operation phase of the operation is recognized. According with the operation phase is generated a virtual operation. The system provided an appropriate visualization about 85% of the time. From the point of view of the medical usability, the surgeons feedback was favorable. For the most part, the system fit well in the existing workflow and provided quick and reliable assistance. For the experiments, they use two different AR-goggles: Sony Glasstron head mounted display and a device made by Trivisio. In Figure 2.3 we can see the initial visualization during idle phases, the approaching of planned implant position, the drilling and a risk situation.

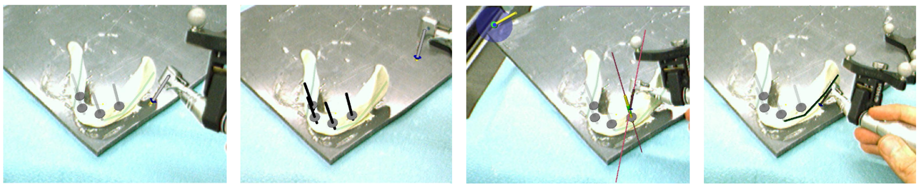

Figure 2.3: Various images taken during the Dental Implant Surgery simulation by the authors.

2.1.3 Haptic Augmented Reality Dental Trainer

The system designed by Rhienmora et al. [28] allows students to practice surgery in a real environment combining a 3D tooth and a specific tool for dental surgery. The surgery results are displayed through a head mounted display (HMD). With the data acquired the system monitors all the important features: tool movement and applied forces, giving a feedback against the quality of the procedure. The system feedback, such as force utilization in three axes of each procedure and tool/mirror movements is displayed on the HMD screen. We can see in Figure 2.4 the marker tracked by the application, the tool used and a screenshot of the LCD Screen during a surgery session.

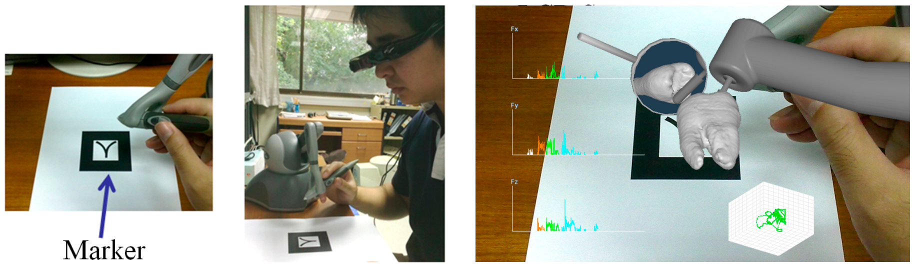

Figure 2.4: Haptic Augmented Reality Dental Trainer Images.

Surgery performance are determined by comparing student procedure with the best matching expert. One year before Rhienmora et al. [29] have made a study with five novices (forth-year dental students) and five experts in prosthodontics using the same system. The main objective of that experiment was to test the overall acceptability of the training feedback generated by the simulator. During the experiment 65 tutoring feedback messages were generated. The expert had to note the acceptability of each feedback message on a scale of 1-5, where 1 implied unacceptable, 2 implied not quite acceptable, 3 implied not sure, 4 implied close to acceptable and 5 implied acceptable. The score obtained by the system is presented in Figure 2.5.

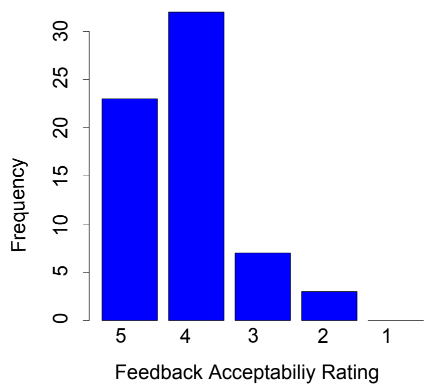

Figure 2.5: Distribution of feedback acceptability ratings for 65 generated feedback messages. The average score was 4.154 ± 0.8.

2.1.4 Learning geometry with collaborative augmented reality

Kauffman and Schmalstieg have designed for mathematics and geometric learning, Construct3D - a fully functional educational AR application for mathematics and geometry education [17]. The system can be composed by several head mounted displays and stereoscopic video projectors. They implemented three methods: independent mode (every student can only see the elements constructed by himself), collaborative mode (everything is visible for everybody) and teacher model (the teacher can switch his construction to independent and after that, each student can perform without being influenced by the work of another user).

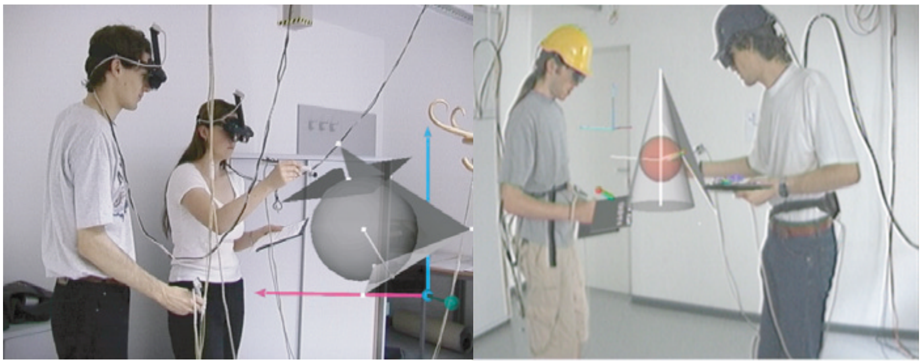

Figure 2.6: Students working with Construct3D

To complement the diverse teacher – student interaction they present and evaluate hybrid different setups:

- **The augmented classroom** system is composed by two AR kits. One of these kits is for the teacher and the other can be used by a student. With an additional computer and a video projector the rest of the class can watch the whole constructing procedure. In Figure 2.7 left, the teacher is working in Construct3D with the mobile AR setup while a live monoscopic video of his current construction is projected onto a projection screen behind him.

- **Projection screen classroom** is a semi-immersive technique which uses a large screen projection shared by a group of users, typically showing stereoscopic images using active or passive stereo glasses. Like a disadvantage of this method we can mention the distorted images for different viewpoints. But of course the system complexity/costs make it suitable for semi-immersive classroom use - Figure 2.7 middle.

- **Distributed hybrid classroom** Just like the hybrid AR classroom, this setup may use personal HMDs for realizing AR for the teacher and selected students. All students are equipped with a personal workstation display desktop and watching in this way the construction process - Figure 2.7 right.

Figure 2.7: The augmented classroom presentation

2.1.5 Instruction for Complex Machines

The Augmented Anesthesia Machine (AAM) [25] is a Mixed Reality system that augments an anesthesia machine with an abstract simulation of the machine's internal workings. It was prepared for the students who have to learn the functions of a complex machine. The users are using a complex system which combines efficiently a Computer and a Tablet with a magic lens role interconnected by an outside-looking-in optical tracking technique. They propose two different visualization ways:

- **Concert visualization** takes full advantage of a MR technique and displays spatially registered content. It displays animations of the component behind the tablet as if it is see-through. The user can see the effect of his interaction while turning the knob as shown in Figure 2.8.

- **Abstract visualization** is showing a 2D graphs illustrating abstract information. The tablet shows in real time the corresponding effects of the user controls interactions as shown in Figure 2.9. The user interacts with the real machine and the results are showed on an untracked tablet.

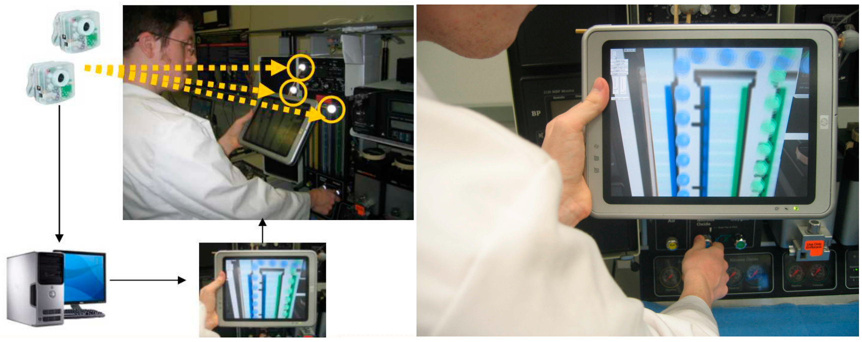

Figure 2.8: Concrete Visualization: tracking and user interaction

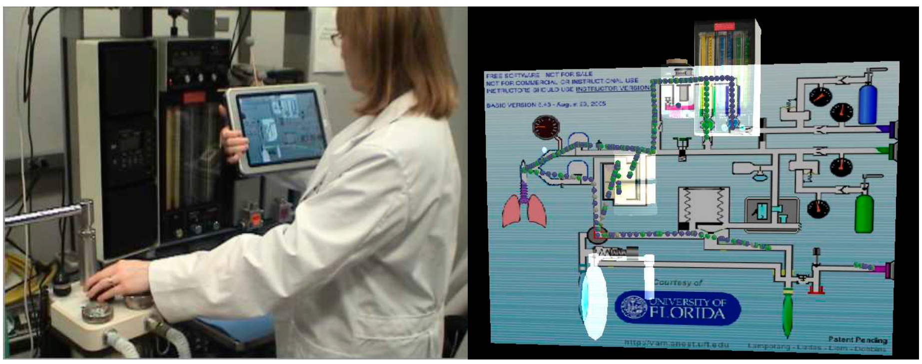

Figure 2.9: Abstract Visualization: user interaction and data visualization

A user study was conducted to evaluate if MR's merging of real and virtual spaces can effectively enable to help the users to understand better the machine and it functionality. Two groups of users used different visualization techniques to perform exercises, and then completed a hands-on machine fault test and a written test about the machine's mechanism. The result shows that the combined visualization is more effective in teaching concrete concept and it helps to bridge abstract and concrete knowledge.

This case study present the benefits of the Mixed Reality in the educational field. The spatially registered instructions helps students during the learning process of a complex machine.

2.2 Augmented Reality Tools

This section is presented as a brief survey of selected AR development frameworks, focusing on their capabilities, barriers to entry a costs, and the platforms they support. I found a lot of useful information about the latest AR in the survey made by Rovelo et al. [30] and in the master thesis of Resch [27].

2.2.1 Vuforia[2]

For many reasons, Qualcomm's Vuforia AR framework is the one we chose to use for this experimental application. It is a free library, has a cross platform and it is very well documented. It has a very strong developers community, where we can found a lot of information and tips. The most important is that we can link the library with Unity 3D, the best game development engine. About the advantages of this library we will talk in detail in the next chapters.

2.2.2 Layer Vision[3]

Layer Vision is a free library for developers, but on the publish moment you have to pay, and the price is not really small. The price is 15 € for every image used and published like a marker. Layer Vision has a package offer: 999 € for 100 marker images.

[2] Vuforia home page: https://www.vuforia.com/. August 22, 2013.
[3] Layar home page: http://www.layar.com/. August 22, 2013.

2.2.3 Moodstocks[4]

Moodstocks is similar with Layer. It is free for non commercial use. Anyway, if you want to use it you have to pay monthly, according to the image number uploaded (299 € for 1000 images, 599 € for 10,000 images and 1599 € for 100,000 images).

2.2.4 ARToolkit[5]

ARToolKit is not being actively anymore. It was the first in this area and it was the standard in AR, but now only some variations of it are still used by researchers.

2.2.5 Metaio[6]

Metaio is similar with Voforia. We can also link the library with Unity 3D. It is available for Android and iOS, but it is not free for developers. The cheapest license is 325 $.

2.2.6 Junaio[7]

Junaio is similar with Layar, but contrary to this one, it is a free library. Among the iOS (iPad and iPhone) users is popular, but on the Android mobiles presents some hardware issues. It uses the Metaio platform and it is quite easy to use if you just want to "stick" a 3D model to a real life image.

2.2.7 Satch[8]

Considering all the aspects of this work, we can say it has similar features with Vuforia. Is a Japanese product, and has a strong developers community. At the first look, the development platform is not very friendly, but according to the experimented developers this is not true. The Augmented Reality marker generator from Vuforia is missing, which can be considered as a minus.

[4]Moodstocks home page: http://www.moodstocks.com/. August 22, 2013.
[5]ARToolKit home page: http://www.hitl.washington.edu/artoolkit/. August 22, 2013.
[6]Metaio home page: http://www.metaio.com/. August 22, 2013.
[7]Junaio home page: http://www.junaio.com/. August 22, 2013.
[8]Satch home page: http://satch.jp/en/. August 22, 2013.

2.2.8 ARmsk[9]

ARmsk is a free open source. It is available only for Android which is not desirable in our case. The developers community is absent, something necessary in our case.

2.2.9 Look![10]

ARmsk is a free open source library. It is still at the beginning and the developers community does not exist, what is normal considering the fact that just Spanish documentation is available and the beginning of the library is in 2010/2011.

2.2.10 KHARMA[11]

KHARMA (KML/HTML Augmented Reality Mobile Architecture) is a tool for creating AR applications under the paradigm of an Internet browser. It uses an extended version of the KML language, called KARML, to share information stored on traditional Web servers and display it in the browser. This framework builds on existing Internet standards to create an infrastructure to share information from different sources into a single application of AR. For example, it allows the developer to define 3D models of the buildings surrounding the area in which the application will be used (called server infrastructure). Thus, the application of AR may use this knowledge about the environment to calculate occlusion models from real objects in the scene and the virtual content is displayed to the user.

2.2.11 AndAR[12]

AndAR is an open source library, but is still under development. It is free for both, developments and commercial purpose. A big minus represents the fact it uses the old type of markers (black squares with a sign in the middle).

[9] ARmsk home page: http://armsk.org/. August 22, 2013.
[10] Look! home page: http://lookar.net/. August 22, 2013.
[11] KHARMA home page: https://research.cc.gatech.edu/kharma/content/home/. August 22, 2013.
[12] AndAR home page: http://code.google.com/p/andar/. August 22, 2013.

2.2.12 Mixare[13]

This tool is an open source browser which is available for iOS and Android. The original version shows the points of interest POIs, stored in Wikipedia, surrounding the user of the device on which the application is installed. In the latest version, the tool can load a different data source. It is also possible to use the functionality of the Mixare browser in the application, the code can be reused and modified freely, because the tool is licensed under the GPLv3. The browser allows the user to obtain more information about the POIs you have on screen by clicking on any of them. Thus, the browser displays the corresponding Wikipedia input. It also allows you to define the distance range for the POIs which are displayed.

[13] Mixare home page: http://www.mixare.org/. August 22, 2013.

Chapter 3

System Architecture

Our system architecture combines perfectly the hardware properties of a very potent mobile device with a cross-platform game engine Unity and the versatility of Vuforia.

3.1 Hardware Platform

How we mentioned above, our hard structure is the mobile phone. In particular we use the MOTOROLA XOOM^{TM} 2. The important features of the mobile device are the CPU -Dual-core 1.2 GHz Cortex-A9; internal memory - 16GB storage and 1 GB RAM; GPU - PowerVR SGX540; Display - 800×1280 pixels, 10.1 inches (149 ppi pixel density) and a 5 MP camera. The operational system is Android OS, v3.2 (Honeycomb). Android is an open source mobile operating system developed by Google. In Figure 3.1 we can see the mobile device.

Figure 3.1: MOTOROLA XOOM^{TM} 2.

3.2 Software framework

3.2.1 Unity3D

Figure 3.2: Unity3D Logo.

For the develop process we use Unity (also called Unity3D). Unity is a game development ecosystem, a cross-platform game engine. There are two main licenses for developers: Unity and Unity Pro. The Unity Pro version is available for $1500, and the regular version is a free download. Both versions include the development environment, tutorials and sample project for beginners and a very good support via web forums.

The game engine was developed in C/C++ and is able to support code written in JavaScript, C# or Boo. More than one million developers from the entire world program their applications using Unity. We use the 3.5 version with student license. It is used to develop video games for web plug-in and mobile devices in generally, but for consoles and desktop platforms too. Unity supports files imported from Autodesk 3ds Max, Maya, Softimage, Blender, ZBrush, Cinema 4D, Adobe Photoshop, Adobe Fireworks, and many more.

3.2.2 3ds Max

Figure 3.3: 3ds Logo.

In our case we have used 3D models created in 3ds Max and also 3D meshes provided by Folguera Vicent Dental Prosthesis School. The 3D meshes were provided in STL (STereoLithography) format with a very large number of polygons. This large number of polygons was reduced in Autodesk 3ds Max with ProOptimize (predefined function). To obtain a surface with no edges, we had to use a Smooth function (predefined function). In the Figure 3.4 we can see the tooth number 47 during the graphic treatment process.

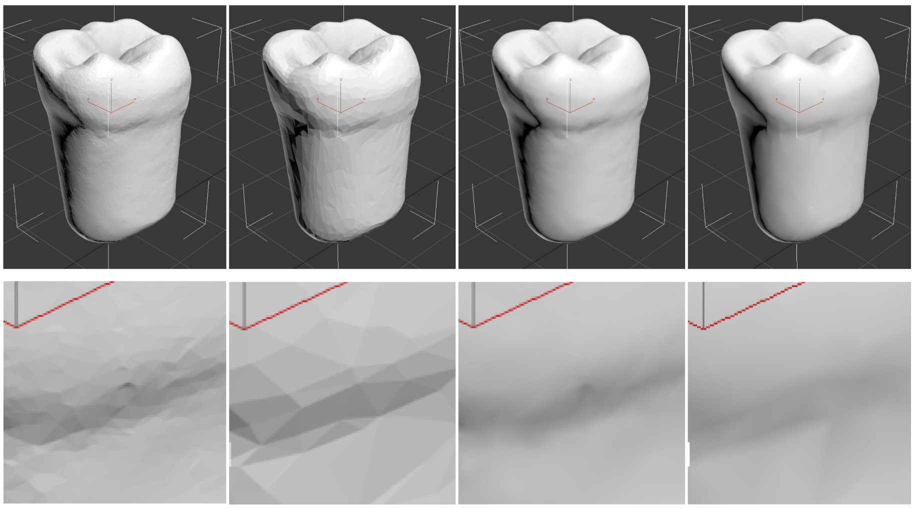

Figure 3.4: Left to right: Original model (.stl); ProOptimize function; Smooth function; Final model.

3.2.3 Vuforia

Figure 3.5: Vuforia Logo.

It is written in Java and C++. The SDK has an extension for Unity 3D, which allows the user to create animation and very complex scenes. It uses Computer Vision technology to recognize and track: Image Targets (photos, magazine covers, books pages, posters or any image), Frame Markers (particular type of 2D images) Multi-Targets (simple 3D objects, rectangular shapes), Virtual Buttons (rectangular regions on the Image Target or the entire Image Target) or Text (which represent textual elements printed in books, magazines or other media) in real time.

A Vuforia SDK-based AR application uses the display of the mobile device as a "magic lens" or looking glass into an augmented world where the real and virtual worlds appear to coexist. The application renders the live camera preview image on the display to represent a view of the physical world. Virtual 3D objects are then superimposed on the live camera preview and they appear to be tightly coupled in the real world.

According to Serrano in her Master Thesis [34], the advantages of using Vuforia against other AR libraries are:

1. Marker/target occlusion; We have a good tracking even the occlusion is bigger than 70% of the tracker surface.
2. Perspective distortion of the camera capture; Offers a good tracking with a camera angle distortion between 15^o and 90^o.

3. According with original size marker; Good results with markers starts with 25% of the original size.

4. Polygons number of rendered model; High performance up to 20,000 faces.

5. Number of augmented objects; High yield up to 50 items.

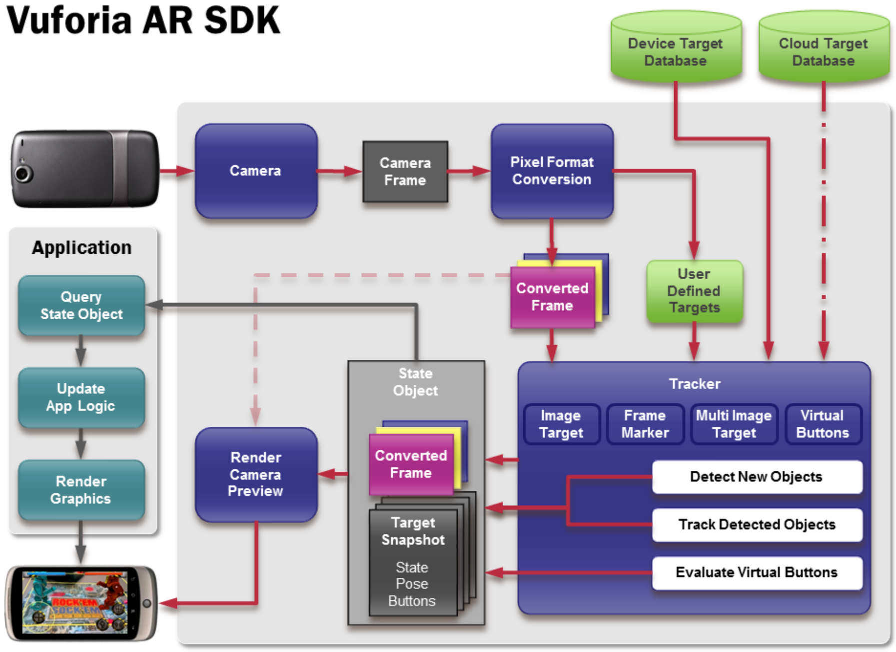

Figure 3.6: Data flow diagram of the Vuforia AR SDK in an application environment. Image taken from Vuforia web-page:https://research.cc.gatech.edu/kharma/content/home/. August 22, 2013

Vuforia SDK Architecture main components are the following:

- **Camera:** This component captures the frames and passes them to the tracker. The format and the size are dependent of the mobile device.

- **Image Converter:** Converts from the camera format to a format appropriate for the intern tracker of Vuforia.

- **Tracker:** This module contains the vision algorithms that deal with the detection and tracking of objects in each frame. Different algorithms are responsible for detecting new “targets” or “markers”. The results are stored in a state object that is used by the video background render. The tracker can load multiple data sets at the same time and activate them.
- **Video Background Render:** This module processes the image stored in the state object. The rendering performance background video is optimized for specific devices.
- **Application Code:** The developer has to initialize all these components presented above. Every frame, the state object is updated and the render is called.

3.3 Implementation Details

Working with Unity and Vuforia offered me a different programming experience. The first step on this way was the integration of Vuforia in Unity. Thanks to the demos and basic applications, presented by Qualcomm on the Vuforia web-page, it was possible to achieve their integration. Once Vuforia libraries are imported in Unity we can start to build our application.

The component-based architecture of ARDental: hardware platform and software framework, is presented in Figure 3.7. The classes and the scripts used for the presented thesis project: designed and implemented, or the ones imported from Vuforia libraries are grouped by their functionality. All functionality groups and the relative classes will be described more in detail in the following subsections.

3.3.1 Vuforia Components

The first component added is the ARCamera. The ARCamera prefab is responsible for rendering the camera image in the background and manipulating scene objects to react to tracking data. If we run the application just with the ARCamera on a

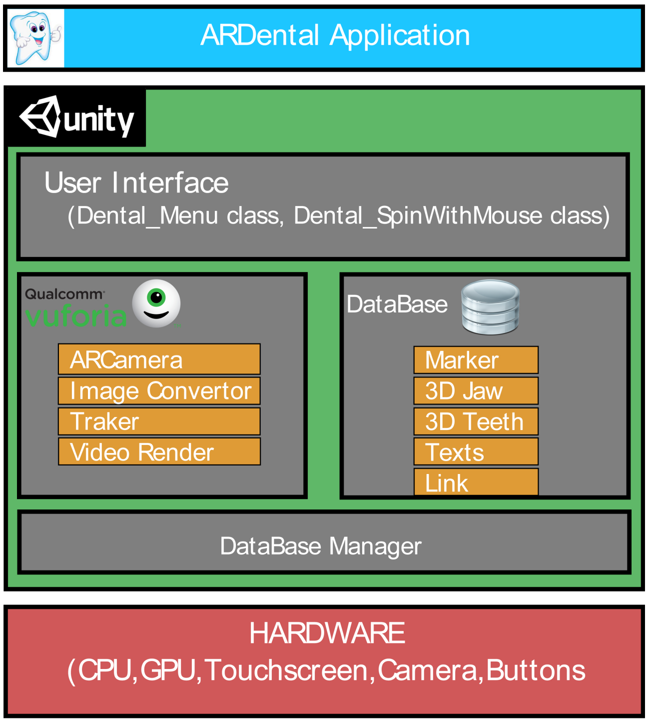

Figure 3.7: Component-based architecture of ARDental: hardware platform and software framework

mobile device, we are able to capture and see the live video in the background. In Figure 3.8 we can see all the components. In the Data Set Load Behaviour we have to set and activate the images that we want to be recognized like targets, by the camera. We can do this after we add the ImageTarget into the scene.

Importing the ImageTarget is the next step. This prefab represents a single instance of an Image Target object and in Figure 3.9 we can see all the components and features. In the Inspector of the ImageTarget we can see the Image Target Behaviour attached, with a property named Data Set. This contains a list with all the available Data Sets for these projects. When a Data Set is selected, the Image Target property drop-down is filled with a list of the targets available in that Data Set.

As the name implies, Image Targets are images that the Vuforia SDK can detect and track. Unlike traditional markers, data matrix

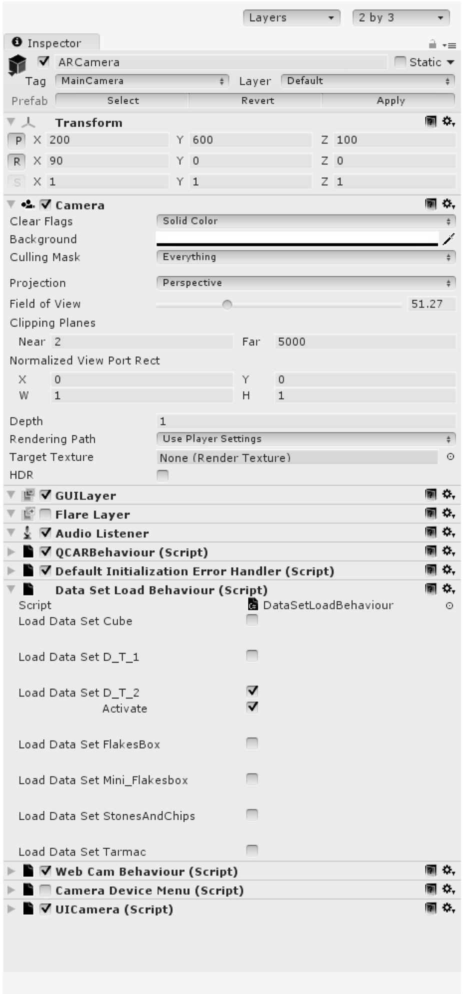

Figure 3.8: View of the ARCamera Inspector.

codes and QR codes, Image Targets do not need special black and white regions or codes to be recognized. The Vuforia SDK uses special and sophisticated algorithms to detect and track the features which are naturally found in the image itself. The Vuforia SDK recognizes the image target by comparing these natural features against a known target resource database. Once the Image Target is detected, the SDK will track the image as long as it is at least partially in the camera's field of view.

Figure 3.9: View of the ImageTarget Inspector.

3.3.2 User Interface Components

To create the User Interface we have defined two classes. One for the application menu and another for the interaction with the 3D models. Now we have two scripts: `Dental_Menu` and `Dental_SpinWithMouse`. The first one is responsible for the visual User Interface. Seven buttons are displayed at the bottom of the screen when one of the 14 teeth sensors is activated (Shown in Figure 3.10). The first six buttons are designed to show the six anatomical tooth parts, and the seventh button serves to return to the previous model, which is the lower jaw. `Dental_SpinWithMouse` script is responsible for the horizontal rotation or the 3D model showed on the screen. This script records all the finger movements on the screen and if the finger position gets in collision with the 3D model collision's box. If the collision is detected, a new angle for the 3D model position is calculated. The finger position and the model angle are registered and recalculated in every frame.

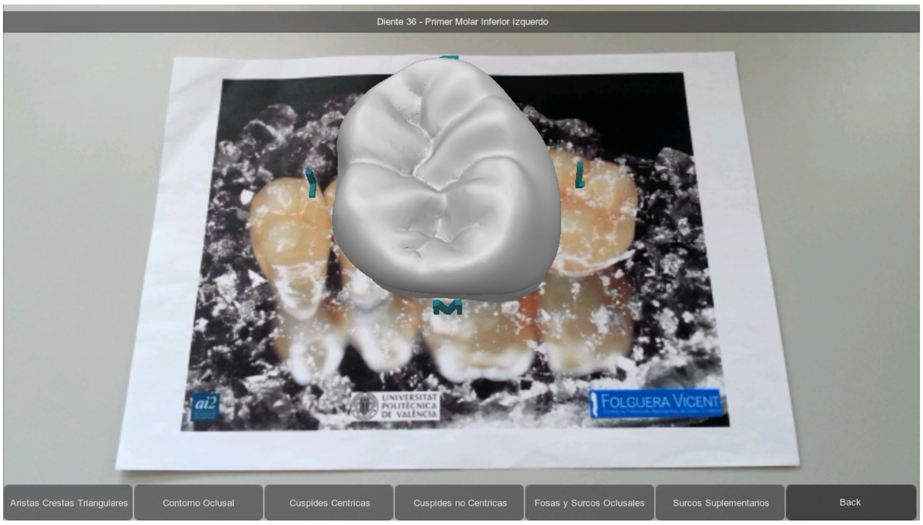

Figure 3.10: Menu with all the seven buttons. Screen-shot.

3.3.3 Data Base Manager

The Data Base Manager can be considered the `Dental_Menu`. The script has to manage all the 3D models and the moment when they are projected into the real world. This management is made according user selections. Each simple tooth has six extra 3D models, one for each part of the tooth anatomy. We can see in Figure 3.11 the drop-down list of the models for tooth number 36: Element 0 → Element 6. I mention again: during the experiments we have used a beta version of the ARDental where the students could just select the lower left permanent first molar.

With all the components into the scene project we can compile and build the .apk for our application. APK (application package file) is the file format used to distribute and install application software on a device with an Android operating system.

In Figure 3.12 we can see the flowchart, designed in `Dental_Menu` class and how the application function. The flowchart presents the case for tooth number 36. For teeth number 34, 35, 37, 44, 45, 46, 47, the diagram has the same structure and components like the one presented in Figure 3.12. For teeth number 31, 32, 33, 41, 42,

Figure 3.11: View of the User Interface Inspector.

43, the first six buttons are missing. The Prosthesis specialist from Folguera Center decided that are not necessary external structures to the study of these teeth.

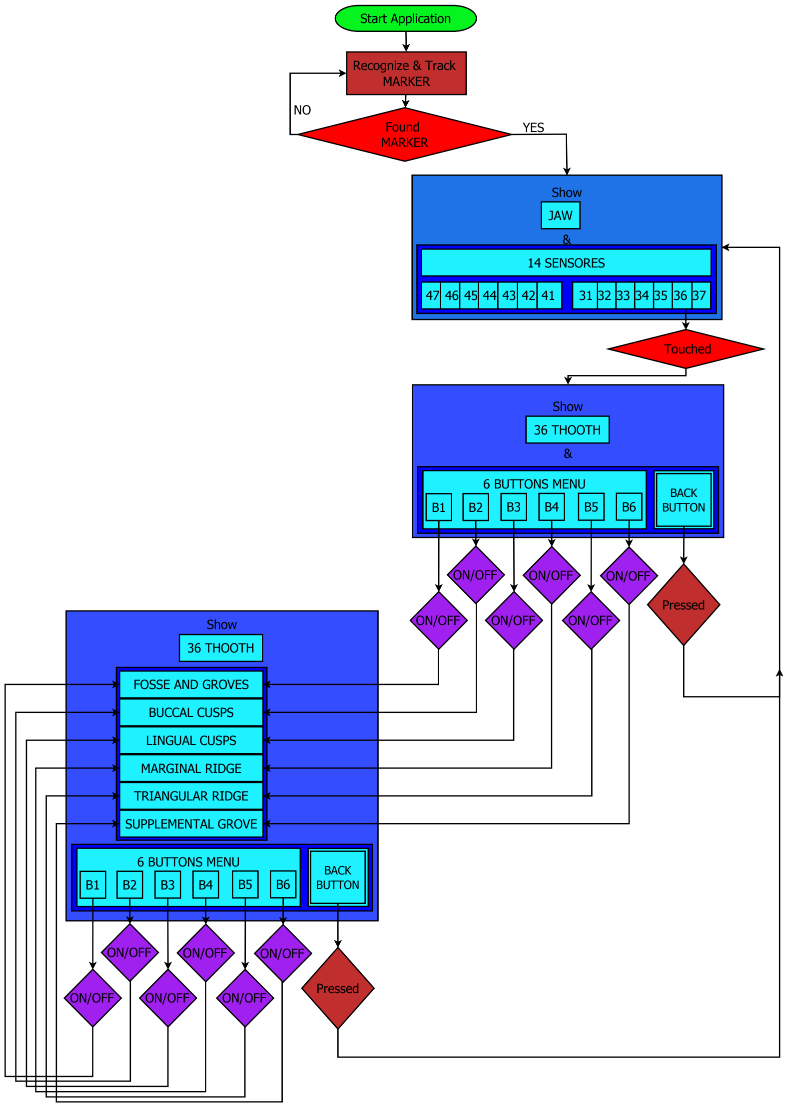

Figure 3.12: Flow chart of ARDental produced by `Dental_Menu class`.

Chapter 4

ARDental Experimental Application

Generally speaking, there is a shortage of user studies for AR techniques lack AR techniques. Before an AR system could go from the user studies laboratory to the industry, there are many questions to be answered concerning its usability and acceptance.

Is the knowledge which is acquired for using the application at least the same as the knowledge which is acquired in a normal class? Is the information proportioned with the help of AR in a 3D-space able to provide enough extra information? It is worth to introduce this new method in the learning process? What are the advantages of this new learning method?

Although AR has been proven to be helpful in the learning process, how we showed in related work the use of a mobile lens as the AR display instead of an HMD makes a huge difference regarding to usability. The fields where the mobile devices was used like a magic lens, and their big success makes me want to contribute in a significant way into the learning environment with my study.

A controlled experiment was designed and conducted to answer our questions. The goals were to assess the benefits of introducing the AR in the students learning process, knowing for them, it is very important to have a 3D-vision of the models.

In this chapter, I will introduce the application, and the experiment design with the procedure of the case study. This part of work was conducted in collaboration with my adviser teacher and the professors from the Folguera Vicent Dental Prosthesis School.

4.1 Design

ARDental was designed to provide the information presented by the teacher in his classes. I also want to mention that after the class, students could access the same information by using sketches or drawings (Shown in Figure 4.1 and Figure 4.2). Of course they could have their own 3D models of the teeth but this is a little bit difficult for them. I have been driven by the goal of developing an application that can provide the teacher with a means of communicating a curriculum piece in a novel and interesting manner while, at the same time, enabling students to download the application and use it as a study enhancement in their own time.

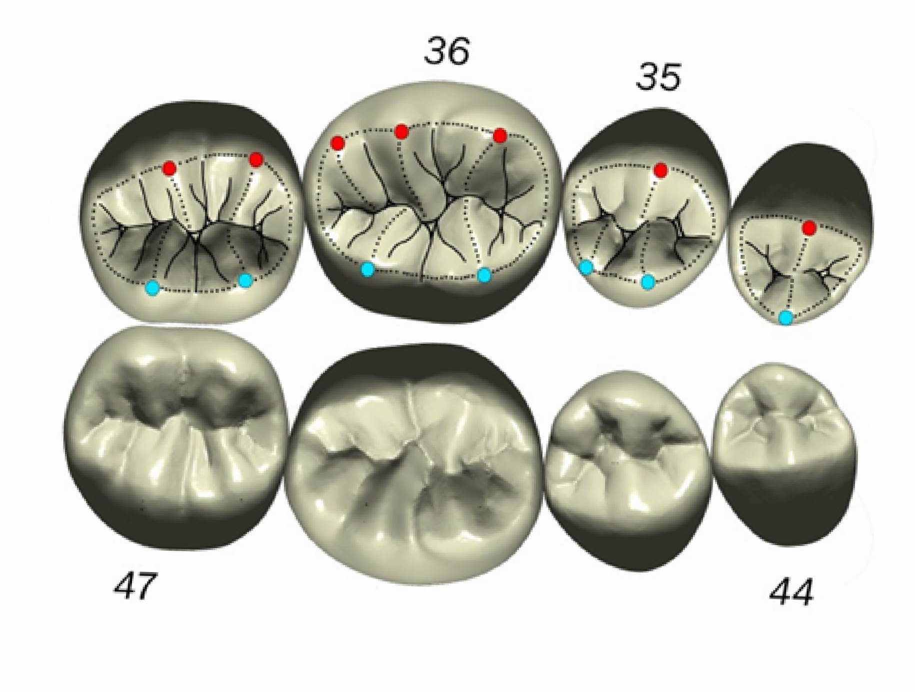

Figure 4.1: Learning draw 1.

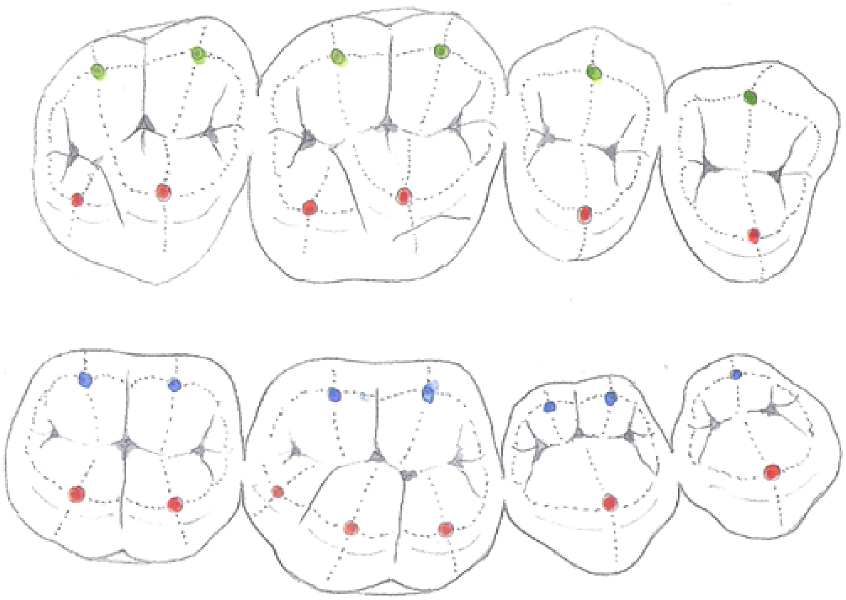

Figure 4.2: Learning draw 2.

This application allowed students to visualize a tooth in a 3D format through the mobile device screen. Now is the moment when the 3D AR models take the place of the 2D boards. The ARDental application comes to the aid of the teacher too. It gives him a new tool into the teaching process. Through the buttons, which are placed at the bottom of the screen it is for the user possible to select/deselect different 3D structures which reproduce perfectly the tooth morphology.

Each one of the buttons activates and deactivates a 3D wire which defines a structure. I have to mention that it is very important for the prosthesis and hygiene students to recognize and delimit these areas. They also need to recognize and differentiate each tooth individually. The application includes all the teeth from the lower jaw (mandible), but for this experiment we have used a version with just one tooth: number 36 - Lower Left First Molar. The initial AR model projected when the Image Target is recognized is the mandible which can be seen in Figure 4.3.

Figure 4.3: Initial Jaw View. Screen-shot.

Once the image target is recognized and the jaw is visible the student starts to acquire information. Through the touch screen, the application provides an easier and intuitive user interface. The 3D Model can be rotated around his own y-axis for a better view, using a simple drag and drop gesture to the model. The Lower Left First Molar can be selected and in this way the viewed model change into the 36 tooth (Figure 4.4).

Figure 4.4: Lower Left First Molar View. Screen-shot.

User can move the phone further away to see an overview of the hole jaw or selected tooth, or move it closer to zoom in. On this way he can focus on one area of the showed model. We did not implemented a screen zoom action, because we wanted to see how the participants are using the 3D space like in a natural interaction.

Now, the student can select/deselect the structures which he wants to see and chooses the required combination for its study. In Figure 4.5 we can see all the six structures ON: Fosse and Groves, Buccal Cusps, Lingual Cusps, Marginal Ridge, Triangular Ridge and Supplemental Groove activated.

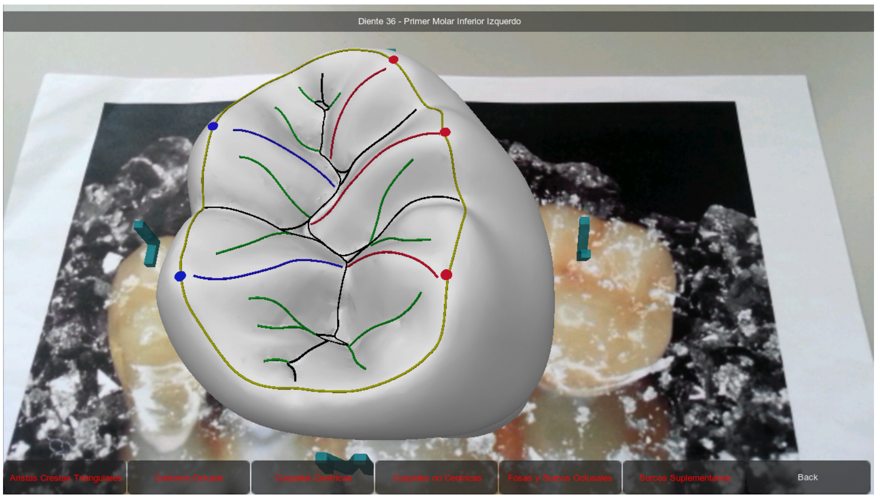

Figure 4.5: Lower Left First Molar with all structures ON. Screen-shot.

4.2 Procedure

With this study we do not want to measure just the knowledge acquired by the students. We want to collect insights, critiques, and suggestions for how an effective material-virtual paradigm shift might enhance educational environment design. On this way to achieve our goals, we designed five tests and questionnaires. Each one of them has been written in collaboration and under the supervision of my teacher adviser. For the evaluation knowledge questionnaires we consulted Folguera School teachers and respected the classic evaluation.

Before to start the procedure, we recorded a teacher from the Dental Prosthesis School during the teaching act while he was explaining the 36 tooth morphology. This video was used to simulate a normal lesson during our protocols. A real teacher-student experience for each one of the students was not possible. The film takes a little more than two minutes and the number of times that the participant can watch it, is unlimited.

4.2.1 Participant Information

In our study participated 38 students from Dental Prosthesis School. The students were from two different classes: dental hygiene and dental prosthesis. Through this we have separate the participants in four groups: A1, A2, B1, B2. In the hygiene class were 21 students, while in the prosthesis class were just 17. To balance the number we have divided the students and we made the following groups presented in Table 4.1.

Table 4.1: Initial Students Number and Groups Separation

Group	Prosthesis	Group	Hygiene	Total
A1	9	B1	11	20
A2	8	B2	10	18
Total	17		21	38

4.2.2 Questionnaires

The five questionnaires used in the study are:

- **Q1** is a pre-test. All the participants had to fill in this questionnaire. In this test, students had to draw on the surface of a tooth the morphological structures required. This test was used to evaluate the student's knowledge before they started to use ARDental or to watch the Video class. Also all the students had to complete their personal data: name, age, gender, class and group.

- **Q2** has the same question like Q1, but it considered a post-test. Comparing the results from the Q2 with the results from Q1 helps us to determine if there was a knowledge increase after the learning moment, regardless of the protocol followed.

- **Q3** is a usability questionnaire. We want to capture the users feedback after the use of ARDental. The student has to answer 14 questions related to different aspects of his experience using ARDental.

- **Q4** includes a comparative question between the two methods. It also has free answer questions where the participants can give us their critics and suggestions. That is in this area very important for us if we want to release the product on the market.

- **Q5** had the questions from the Q3 and additional the questions from Q4. It helps us to evaluate and compare the two learning methods and application usability.

4.2.3 Protocols

The two protocols which are used are explained in the following lines:

- **Augmented Class Protocol:** On this procedure, after the student perform the first test, he get some explication about the ARDental application and then he is free to practice with the application as long as he wants. After that, he has to complete the pos-test questionnaire Q2 and the usability Q3. After finishing these two questionnaires the participant watches the video and completes the last questionnaire Q4, giving us his critiques and suggestions.

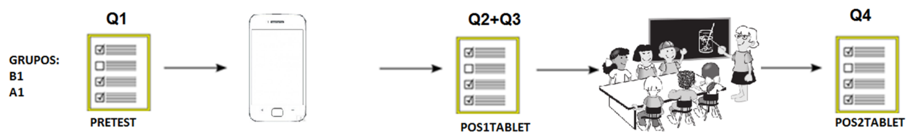

Figure 4.6: Augmented Class Protocol. A1 and B1 groups.

- **Real Class Simulation Protocol:** The second protocol, which is for the A2 and B2 groups, measures the knowledge acquired during a normal class session video simulated. The Q1 and Q2 have the same purpose as the previous protocol. To complete the protocol, the student practices with the ARDental and answers in the end to the question from Q5.

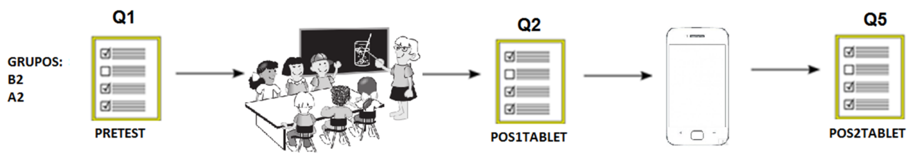

Figure 4.7: Real Class Simulation Protocol. A2 and B2 groups.

Chapter 5

Analysis and Results

Learning is a complex process and the assessment of how students have assimilated knowledge from the learning materials presented to them, will also be complex. After collecting the experimental data, a statistical analysis was performed.

In this chapter we present the results of the statistical analysis. We explain the concluded effects of the analysis methods and we discuss the reasons and issues based on observations and participant's comments.

5.1 Prepared Data

We started our study with 38 participants. Unfortunately, when we started the data analysis, three students have not filled in all the questionnaires, so the final number of the analyzed participants is 35. The new number of participants and groups distribution can be seen in Table 5.1. In the prosthesis class we have the same number of students: 17. In the hygiene class we have now 18 students. The gender percentage is 51% men and 49% women. Their age is between 18 and 35 with a mean of 23.37 ± 4.37 years.

5.2 Analyzed Data

First off all, we are interested to see the learning outcomes, the way how the users react to the teaching methods.

Table 5.1: Final Students Number and Groups Separation

Group	Prosthesis	Group	Hygiene	Total
A1	9	B1	10	19
A2	8	B2	8	16
Total	17		18	35

5.2.1 Learning outcomes

The tests Q1 and Q2 were performed to determine if there were significant differences in the acquired knowledge. In these tests, the knowledge variable was analyzed. To evaluate the students answers, we respected the classical evaluation which was made by a Folguera School teacher. In Figure 5.1 we can see the box plot for the knowledge level of the students before and after the learning process, according to the protocol followed.

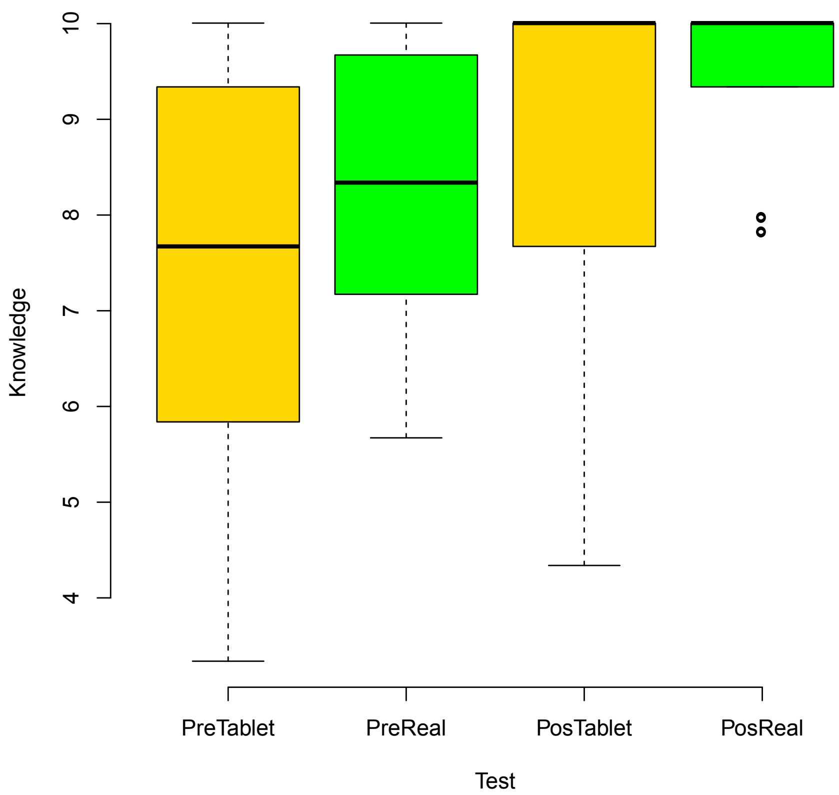

Figure 5.1: Box plot of knowledge variable in the Pre and Pos questionnaires for AR Protocol and Real Class Protocol.

In both cases we can see a knowledge improvement. Students who had to practice with the AR application, obtained an average mark improvement from 7.54 to 9 and the students who followed the classical teaching method, had an average mark improvement from 8.23 to 9.47 (shown in Table 5.2). The presence of ** in the analysis indicates statistically significant differences.

Table 5.2: Means and standard deviations of the knowledge scores obtained in PreTest(Q1) and PosTest(Q2) for both methods, *t*-test analysis, and Cohen's *d*.

#	Q1	Q2	t	p	d
Real	8.23 ± 1.43	9.48 ± 0.81	-5.23	< 0.001**	-1.31
AR	7.54 ± 2.00	9.00 ± 1.56	-6.08	< 0.001**	-1.40

In Figure 5.2 we see that the difference in acquired knowledge by the students who followed the AR Protocol is a little bit higher than the students who followed the Real Class Protocol: 1.46 for the AR Protocol and 1.25 for the Real Protocol. Delta value represents the difference between Pos Test score and Pre Test score.

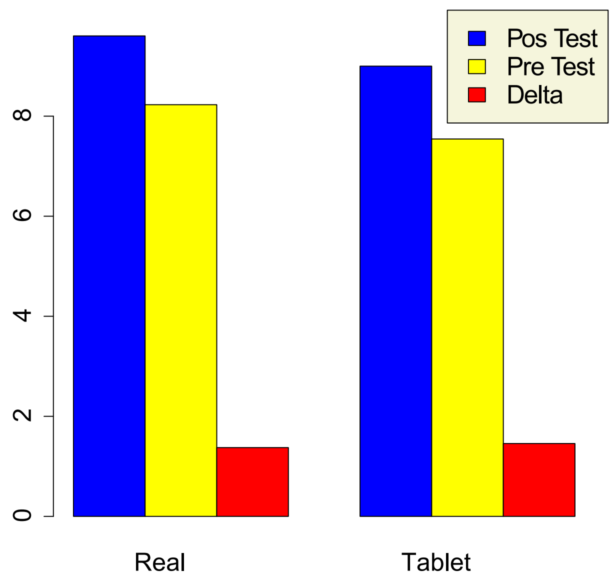

Figure 5.2: Knowledge information: Pos Test, Pre Test and acquired information: Delta value.

We also made a t-test in which we compare the initial knowledge level between the two groups. These results revealed that there was no statistically significant difference between the initial knowledge of the two groups (shown in Table 5.3). To determine whether or not there was difference between the acquired knowledge in the two groups, a t-test was performed between the pos-knowledge of the two groups. The analysis reveals that there are no statistically significant differences between the pos-knowledge of the two groups (shown in Table 5.3).

Table 5.3: Means and standard deviations of knowledge of the Real Class group and AR Class group, *t*-test analysis, and Cohen's *d*.

#	Real Protocol	AR Protocol	t	p	d
Q1	8.23 ± 1.43	7.54 ± 2.00	1.11	0.274	0.38
Q2	9.48 ± 0.81	9.00 ± 1.56	1.08	0.288	0.37

A multifactorial ANOVA was performed to analyze the effect of several combined factors. This ANOVA studies the knowledge variable in correlation with the type, gender and class of the students. The variable "type" represent the protocol followed. According to Olejnik and Algina [21], in this type of analysis it is very appropriate to take into account eta squared factor (η_G^2). The p-values revealed that the most influential factor was the class. In the final knowledge also the class had a significant effect. This statistical consideration can be seen in Table 5.4 and Table 5.5.

Table 5.4: Multifactorial ANOVA for the initial knowledge variable. $N = 35$.

Factor	Sq	Df	F	p-value	η_G^2
type	0.37	1	0.19	0.6702	0.004
gender	5.01	1	2.51	0.1251	0.054
class	24.84	1	12.42	0.0015 **	0.268
type:gender	5.96	1	2.98	0.0956	0.064
type:class	0.01	1	0.01	0.9379	<0.001
gender:class	0.96	1	0.48	0.4951	0.010

Based on the previous results, obtained from ANOVA test, we present the interaction knowledge-class and knowledge-gender for the two protocols. In Figure 5.3 we can see that the initial and final

Table 5.5: Multifactorial ANOVA for the final knowledge variable. $N = 35$.

Factor	Sq	Df	F	p-value	η_G^2
type	0.94	1	0.70	0.4110	0.02
gender	0.37	1	0.27	0.6043	0.01
class	10.85	1	8.06	0.0085 **	0.20
type:gender	2.56	1	1.90	0.1792	0.05
type:class	0.20	1	0.15	0.7056	<0.001
gender:class	0.71	1	0.53	0.4729	0.01

knowledge level of the prosthesis students is higher, but we can also see that the knowledge gained is higher for the hygiene students.

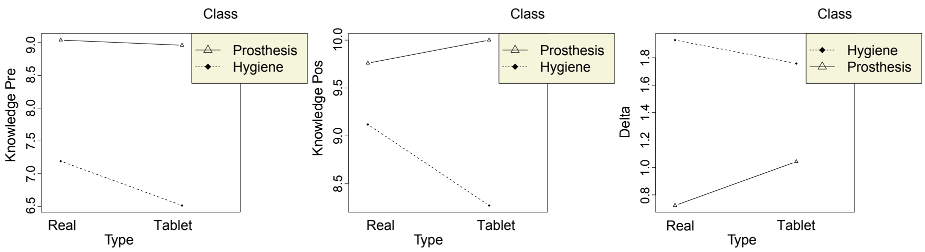

Figure 5.3: Interaction Knowledge-Class for the two groups.

Knowledge-gender interaction is shown in Figure 5.4. The initial knowledge level of the boys is higher in both groups. After the learning process we can observe that in the Real group, the position of girls and boys is switched.

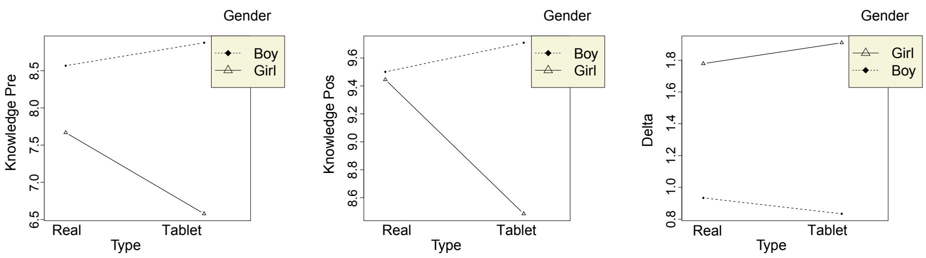

Figure 5.4: Interaction Knowledge-Gender for the two groups.

5.2.2 Users experience

To capture the user experience, we analyzed the answers from Q3 and Q5. We performed a t-test between unpaired samples and no statistical differences between the answers of the two groups were found. So we calculated the average and typical deviation of the answers for all the users (shown in Table 5.6).

Table 5.6: Means and standard deviations for questions from the user experience questionnaire Q3 and Q5.

Question	$\mu \pm \sigma$	Max Value
Q301/Q501	4.54 ± 0.49	5
Q302/Q502	4.82 ± 0.38	5
Q303/Q503	4.37 ± 0.59	5
Q304/Q504	4.51 ± 0.55	5
Q305/Q505	2.97 ± 0.17	3
Q306/Q504	4.42 ± 0.54	5
Q307/Q507	4.22 ± 0.59	5
Q308/Q508	4.42 ± 0.55	5
Q309/Q509	4.64 ± 0.54	5
Q310/Q510	4.42 ± 0.55	5
Q311/Q511	4.05 ± 0.67	5
Q312/Q512	5.25 ± 1.38	7
Q313/Q513	5.37 ± 1.17	7
Q314/Q514	8.80 ± 0.95	10

Q303 asked the users if they would like to use the AR application in their classes. The results, obtained by this question, were 43% - very much, 51% - much, 6% - regular, 0% - a little and 0% - very little. The AR experience, analyzed in question Q308 obtained a very good score: 97% of the users answered much and very much, and just 3% answered regular. To the question Q304: “How easy it was to use the system?”, the users responded in proportion of 54% - very easy, 43% - easy, 6% - regular,0% - difficult and 0% - very difficult. To the question Q306: “How easy it was to select different elements?” the answer was: 46% - very easy, 51% - easy, 3% - regular, 0% - difficult and 0% - very difficult, which means we designed a friendly UI and ARDental is was easy to manipulate. We can observe from Q312 that the 3D models looked very real and from Q313 that the depth perception is high. The percentages expressed above are presented graphically in Figure 5.5.

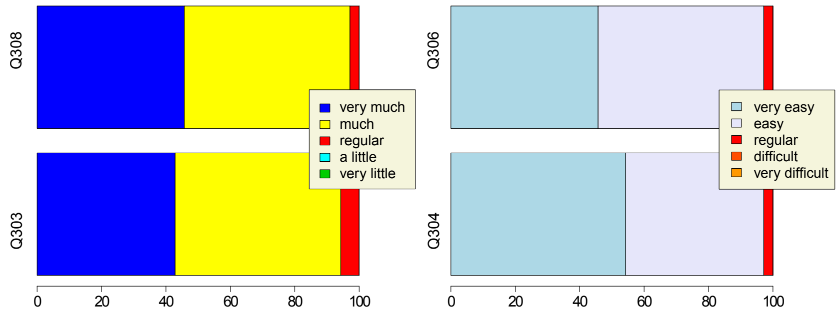

Figure 5.5: User's answers to the questions: Q303, Q304, Q306, Q308. Expressed in percentage.

Finally, we studied the correlations among the answers of the questions and we found a correlation between Q301 and Q314 and also between Q312 and Q313 (shown in Figure 5.6). The first correlation reveals that if they had a good time using the system, the score they gave to the application would be higher. Q312 was related to depth perception and Q313 was related to the sense of presence. This result indicates that viewing the augmented elements on the table is closely related to the feeling of being able to touch these elements.

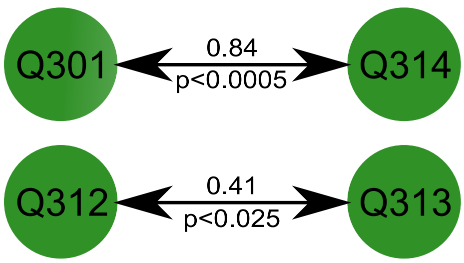

Figure 5.6: Significant correlations between questions Q301⟷Q314 and Q312⟷Q313.

5.2.3 User preferences

To see which system the users liked the most, the participants had to answer to the question: "Which learning method you prefer?". They had to choose between AR class and Real class. Even they had to choose a single answer a few students chose both answers. In Figure 5.7 we can see their preferences if we consider all tree answers. A correct analysis involves only the answers of the students who have chosen only one answer, Real Class or AR Class (shown in Figure 5.8).

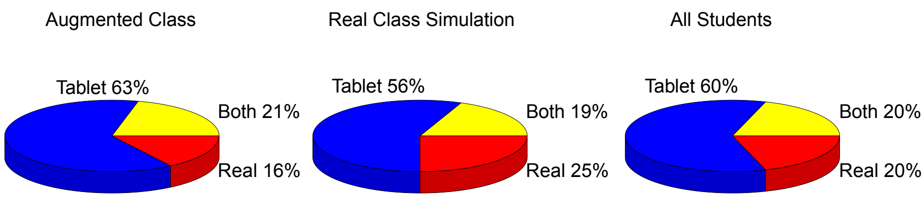

Figure 5.7: Students preferences: AR Class vs. Real Class vs. Both.

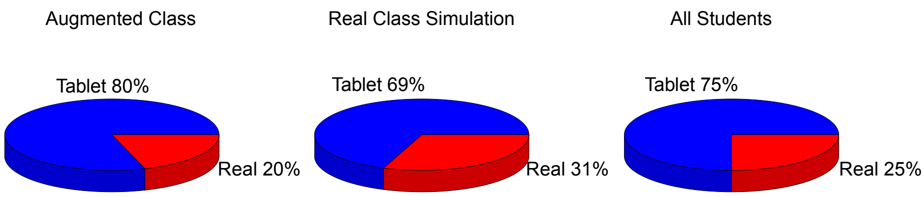

Figure 5.8: Students preferences: AR Class vs. Real Class.

This question had a second part where the students had to motivate their election. Many of the answers "Real class" were accompanied by the explanation: "the teacher is very important" or "You need someone to answer to your question". They were seeing the application like a complement to the real classes. The answers "AR class" were accompanied by "The 3D view and movement", "The tooth looks very real" and "I can study at home too". The last category of answers "Both" were accompanied by the answer "The tablet system is a very good learning tool, but we need the teacher to answer to our questions".

Chapter 6

Conclusions and Future Work

6.1 Conclusions

This thesis presents the first analysis about the usability of the first mobile AR application which has been developed for learning dentistry and has been tested with students. The purpose of this work was to provide for the students an innovative tool into the learning process. Using our prototype, ARDental, a controlled experiment was conducted to evaluate the benefits in the learning process. Because this is the first work on this field and we did not had another system or mobile application to compare with. We compared our AR mobile application with the classical learning method.

We have carried out an exhaustive analysis of the acquired data. Following the analysis results we can say that the students achieved similar knowledge improvements using ARDental as participating to a real class simulation. Furthermore 97% of the participants would like to use ARDental in the classroom like a learning tool, which also was one of our hypothesis. We consider these results more than encouraging. Therefore, ARDental could help the teacher during the teaching process.

This method opens new opportunities for learning, students can study anytime, anywhere, not just in the classroom. The user needs just a mobile device to install the application and a printed marker. We can say that our application is the equivalent with all the didactic material used in classes by teacher. This material is represented by 3D models, sketches and drawings for all the teeth and are used by the students to learn the teeth morphology. Considering that mobile devices are increasingly used in our daily life, in our opinion these applications have a very high potential into the educational field.

As the major contribution, we designed a innovative mobile application for the learning dentistry. ARDental can be used in the classroom complementing the teacher explanations but also individually by each student.

In the near future we want to design more AR applications, not only for learning but also for the evaluation process. A new mobile device for the AR applications could be the Google Glasses. Pending of the Google Glasses release, we keep working in this field, improving our skills and techniques.

6.2 Scientific Contribution

L. Alexandrescu, M.C. Juan, F. Folguera, A. Herrero. Introducción a una nueva dimensión: ARDental (Realidad Aumentada Dental). *Gaceta Dental*. Accepted. To be published in 2013.

We have transferred all the intellectual property of this work to the Universitat Politècnica de València with the code registration in "CARTA".

6.3 Future Work

This work can be extended and refined in several aspects. We present here some possible extensions and future works.

We received a very good feedback from the user and we decided to complete the application with all the teeth from the upper jaw.

Some of the users preferences and suggestions can be found in the UI changes from the final version.

In the academic year 2013-2014, Folguera Vicent Dental Prosthesis School will start to use ARDental into the teaching process.

Based on the work presented in this master thesis, we will write an article to submit to the *Journal of dental education* (journal indexed in JCR).

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Appendix A

ARDental Marker


ai2
INSTITUTO DE AUTOMÁTICA E INFORMÁTICA INDUSTRIAL
MIARFID
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UNIVERSITAT POLITÈCNICA DE VALÈNCIA
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CENTRO DE FORMACIÓN PROFESIONAL DE GRADO SUPERIOR

Appendix B

Questionnaires

Q1 Pretest
Q2 Postest
Q3 Usability Questionnaire
Q4 Comparative Questionnaire
Q5 Usability and Comparative Questionnaire

Q1 CUESTIONARIO INICIAL (ANTES DE UTILIZAR EL SISTEMA) (Tablet)

Código: ☐ Nombre:

Edad: ☐ Chico ☐ Chica ☐ Prótesis ☐ Higiene

Grupo: ☐ A1 ☐ A2 ☐ B1 ☐ B2

1. En el diente siguiente, indica mediante distintos colores:
   1. Fosas y surcos oclusales (boli negro)
   2. Cúspides céntricas (boli azul)
   3. Cúspides no céntricas (boli rojo)
   4. Contorno oclusal (boli amarillo)
   5. Aristas de cúspides triangulares (boli rojo y azul)
   6. Surcos suplementarios (boli verde)

CUESTIONARIO **2 (Tablet)**

Q2

Código: ☐ Nombre: 1º Real ☐ 1º Tablet ☐

1. En el diente siguiente, indica mediante distintos colores:
   1. Fosas y surcos oclusales (boli negro)
   2. Cúspides céntricas (boli azul)
   3. Cúspides no céntricas (boli rojo)
   4. Contorno oclusal (boli amarillo)
   5. Aristas de cúspides triangulares (boli rojo y azul)
   6. Surcos suplementarios (boli verde)

Q3 USABILIDAD **1 (Tablet)**

Código: [ ] Nombre:

1º Real [ ] 1º Tablet [ ]

Te vamos hacer unas preguntas para conocer que te ha parecido el sistema que has utilizado. Señala con una cruz tu respuesta:

1. **¿Cómo te lo has pasado utilizando el sistema?**

   [ ] MUY MAL [ ] MAL [ ] REGULAR [ ] BIEN [ ] MUY BIEN

2. **¿Recomendarías este sistema a tus compañeros de clase?**

   [ ] A NINGUNO [ ] A CASI NINGUNO [ ] NO LO SE [ ] A ALGUNOS [ ] A TODOS

3. **¿Te gustaría que este sistema lo utilizara tu profesor en clase para aprender más cosas?**

   [ ] POQUÍSIMO [ ] POCO [ ] REGULAR [ ] MUCHO MUCHÍSIMO

4. **¿El sistema te ha parecido....?**

   [ ] MUY DIFÍCIL [ ] DIFÍCIL [ ] REGULAR [ ] FÁCIL [ ] MUY FÁCIL

5. **¿Has entendido lo que tenías que hacer en cada momento (reglas de funcionamiento)?**

   [ ] NO [ ] NO SIEMPRE [ ] SÍ

6. **Seleccionar los distintos elementos ha sido....**

   [ ] MUY DIFÍCIL [ ] DIFÍCL [ ] REGULAR [ ] FÁCIL [ ] MUY FÁCIL

7. **¿Te han gustado los modelos/imágenes que has visto?**

   [ ] POQUÍSIMO [ ] POCO [ ] REGULAR [ ] MUCHO [ ] MUCHÍSIMO

8. **¿Te ha gustado ver cómo aparecían dientes encima de la mesa?**

   [ ] POQUÍSIMO [ ] POCO [ ] REGULAR [ ] MUCHO [ ] MUCHÍSIMO

9. **¿Te ha parecido útil verlos desde distintas posiciones y acercarte/alejarte?**

   [ ] POQUÍSIMO [ ] POCO [ ] REGULAR [ ] MUCHO [ ] MUCHÍSIMO

10. **¿Te ha resultado fácil verlos desde distintas posiciones y acercarte/alejarte?**

    [ ] POQUÍSIMO [ ] POCO [ ] REGULAR [ ] MUCHO [ ] MUCHÍSIMO

11. **¿Crees que has aprendido con este sistema?**

    [ ] POQUÍSIMO [ ] POCO [ ] REGULAR [ ] MUCHO [ ] MUCHÍSIMO

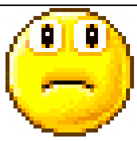
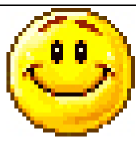
12. **Valora de 1 a 7, si hubo momentos en los que creíste que los dientes eran modelos de escayola reales y que estaban sobre la mesa**

En ningún momento	Casi en ningún momento	Una pequeña parte del tiempo	Parte del tiempo	Bastante parte del tiempo	La mayor parte del tiempo	Todo el tiempo
1	2	3	4	5	6	7

13. ¿Te ha parecido que podías tocar algunos dientes?

Nada en absoluto	Casi Nada	Ligeramente	Un poco	Bastante	Mucho	Totalmente
1	2	3	4	5	6	7

14. Puntúa la experiencia de 1 a 10.

1	2	3	4	5	6	7	8	9	10
POQUÍSIMO		POCO		REGULAR		BASTANTE		MUCHÍSIMO	
									

Q4 USABILIDAD 2 + COMPARATIVO **(Tablet)**

Código: [ ] Nombre:

1º Real [ ] 1º Tablet [ ]

Ahora me gustaría que compararas los dos sistemas que has utilizado

1. **¿Qué forma de aprender te ha gustado más?**

[ ] Tablet [ ] Clase en vídeo

¿Por qué?

2. **¿Qué es lo que más te ha gustado de toda la experiencia? ¿Por qué?**

3. **¿Qué es lo que menos te ha gustado de toda la experiencia? ¿Por qué?**

4. **¿Qué cambiarías en el sistema del Tablet?**

5. **¿Para qué crees que se podrían utilizar el sistema del Tablet?**

6. **Añade los comentarios que quieras**

Q5 USABILIDAD 2 + COMPARATIVO **(Tablet)**

Código: ☐ Nombre:

1º Real ☐ 1º Tablet ☐

Te vamos hacer unas preguntas para conocer que te ha parecido el sistema que has utilizado. Señala con una cruz tu respuesta:

1. **¿Cómo te lo has pasado utilizando el sistema?**

   ☐ MUY MAL ☐ MAL ☐ REGULAR ☐ BIEN ☐ MUY BIEN

2. **¿Recomendarías este sistema a tus compañeros de clase?**

   ☐ A NINGUNO ☐ A CASI NINGUNO ☐ NO LO SE ☐ A ALGUNOS ☐ A TODOS

3. **¿Te gustaría que este sistema lo utilizara tu profesor en clase para aprender más cosas?**

   ☐ POQUÍSIMO ☐ POCO ☐ REGULAR ☐ MUCHO MUCHÍSIMO

4. **¿El sistema te ha parecido....?**

   ☐ MUY DIFÍCIL ☐ DIFÍCIL ☐ REGULAR ☐ FÁCIL ☐ MUY FÁCIL

5. **¿Has entendido lo que tenías que hacer en cada momento (reglas de funcionamiento)?**

   ☐ NO ☐ NO SIEMPRE ☐ SÍ

6. **Seleccionar los distintos elementos ha sido....**

   ☐ MUY DIFÍCIL ☐ DIFÍCL ☐ REGULAR ☐ FÁCIL ☐ MUY FÁCIL

7. **¿Te han gustado los modelos/imágenes que has visto?**

   ☐ POQUÍSIMO ☐ POCO ☐ REGULAR ☐ MUCHO ☐ MUCHÍSIMO

8. **¿Te ha gustado ver cómo aparecían dientes encima de la mesa?**

   ☐ POQUÍSIMO ☐ POCO ☐ REGULAR ☐ MUCHO ☐ MUCHÍSIMO

9. **¿Te ha parecido útil verlos desde distintas posiciones y acercarte/alejarte?**

   ☐ POQUÍSIMO ☐ POCO ☐ REGULAR ☐ MUCHO ☐ MUCHÍSIMO

10. **¿Te ha resultado fácil verlos desde distintas posiciones y acercarte/alejarte?**

    ☐ POQUÍSIMO ☐ POCO ☐ REGULAR ☐ MUCHO ☐ MUCHÍSIMO

11. **¿Crees que has aprendido con este sistema?**

    ☐ POQUÍSIMO ☐ POCO ☐ REGULAR ☐ MUCHO ☐ MUCHÍSIMO

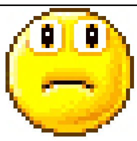
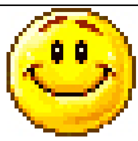
12. **Valora de 1 a 7, si hubo momentos en los que creíste que los dientes eran modelos de escayola reales y que estaban sobre la mesa**

En ningún momento	Casi en ningún momento	Una pequeña parte del tiempo	Parte del tiempo	Bastante parte del tiempo	La mayor parte del tiempo	Todo el tiempo
1	2	3	4	5	6	7

13. ¿Te ha parecido que podías tocar algunos dientes?

Nada en absoluto	Casi Nada	Ligeramente	Un poco	Bastante	Mucho	Totalmente
1	2	3	4	5	6	7

14. Puntúa la experiencia de 1 a 10.

1	2	3	4	5	6	7	8	9	10
POQUÍSIMO		POCO		REGULAR		BASTANTE		MUCHÍSIMO	
									

Ahora me gustaría que compararas los dos sistemas que has utilizado

15. ¿Qué forma de aprender te ha gustado más?

☐ Tablet ☐ Clase en vídeo

¿Por qué?

16. ¿Qué es lo que más te ha gustado de toda la experiencia? ¿Por qué?

17. ¿Qué es lo que menos te ha gustado de toda la experiencia? ¿Por qué?

18. ¿Qué cambiarías en el sistemas del Tablet?

19. ¿Para qué crees que se podrían utilizar el sistema del Tablet?

20. Añade los comentarios que quieras