LEARNING WITH AUGMENTED REALITY: A PLATFORM FOR HIGHER EDUCATION LEARNING APPLICATIONS

Thesis Project Presented

By

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LEARNING WITH AUGMENTED REALITY: A PLATFORM FOR HIGHER EDUCATION LEARNING APPLICATIONS

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ABSTRACT

Students in higher education face a lot of challenges with the conventional learning methods and there is a lot of scope for improvement. Technologies like Augmented Reality (AR) can be used to help them enhance their practical learning experience. Augmented Reality (AR), is a technology that allows computer-generated virtual imagery information to be overlaid onto the real-world environment in real time. The application and platform developed as part of this thesis project works as a proof of concept for having AR applications as a higher education learning tool. This project describes how AR can be utilized for education and training, and the potential impact on the future of education. A usability testing of the application developed was conducted with first and second year dental science students, focusing on dental anatomy. For this study, pre-experience and post-experience surveys data was collected, where the students experiences using the application for learning enhancements, its usability and the potential of AR technology was measured. The results of the usability study conducted shows that such AR tools would be very helpful for the students in higher education; also, the positive responses shows that there are good future prospects.

Keywords: Augmented Reality(AR); Platform; Learning Tool; Higher Education; Dental Science; Vuforia; Unity3D; Mobile Application; Android.
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INTRODUCTION

Learning and teaching kids in school and students in higher education is still mostly through conventional learning medium, through books and presentations, which are effective methods but have a lot of scope for improvement (Dunlosky et al., 2013). Humans are a very three-dimensional and visual creatures. Humans mostly learn, process and understand things or objects better when experienced in 3D. There is evidence supporting that visualisation techniques enhances learning in humans and can improve their memory (Klerkx, Verbert & Duval., 2014). According to Chien et al., 2010 study, when 3D data models were used, task times and error rates were lower than using the standard 2D models and mechanisms.

Conventional education systems are still very two-dimensional (2D) and can be improved drastically by teaching/learning in 3D. One way to achieve this without too much of expense is to work with computer-generated virtual imagery. There are two techniques which can do that: Virtual Reality (VR) & Augmented Reality (AR). Augmented Reality is a technology that allows computer-generated virtual imagery information to be overlaid onto a live direct or indirect real-world environment in real time (Azuma, 1997; Zhou, Duh, & Billinghurst, 2008). Virtual Reality creates a totally artificial environment, whereas Augmented Reality uses the existing environment and overlays new information on top it. Compared to Augmented Reality, Virtual Reality is much more immersive by taking the person off the real world and putting their presence elsewhere, but Augmented Reality takes our current reality and adds something to it to enhance it and provide more information. AR has the capability to bridge the gap between the real and the virtual world in a seamless way (Chang, Morreale, & Medicherla, 2010).
There is a lot of active work going on in the field of Augmented Reality to be used in education field. Mostly of the work is focusing on AR applications in the Primary and Secondary education sector. There is not much work which focuses on the higher education sector like Engineering, Medical, Technology etc. One major reason to that could be the content learning complexities of these study fields, another reason could be the expenses of developing complex applications which would help student to learn better and/or the educators to teach more effectively.

This thesis project is focused towards building a platform for such Augmented Reality (AR) based platform which would be capable of holding multiple learning applications for different fields of study; like Engineering, Medical, Technology etc. The platform developed for this project was designed and architected in a way that it should be capable of launching different applications from different fields of study. The main responsibility of this platform is to be one point of contact for the students or educators to be able to connect to their respective field of study AR applications. Also, this platform should be used as the launcher application for all the AR learning applications build for it.

Similar to other fields, medical students face challenges like, lack of visual image of the objects of study, a lot of complicated terminologies and understanding or recognizing the respective part of the human anatomy. Most students do not get access to the lab models because of the general ratio of the students to the available expensive physical models. An AR application will help every student explore, learn and practice complicated terminology with 3D virtual models at their own convenience and with ease. Such applications provide the students with the ability to practice anywhere, anytime with 3D virtual experiences. Dental science is one of the major fields of study under the medical sciences and has a huge potential of technologies like Augmented Reality to be incorporated as part of education process.
For the purposes of this thesis project, a proof of concept prototype application, along with the platform, focusing towards the first and second year dental students was created. The application(s) build focuses mainly on the Human Anatomy and Dental Anatomy in particular. This project also performs a usability study of using the AR educational applications with dental students. The goal of this project was to explore and understand the implications and usability of AR in the higher education fields. There is no intent to replace the existing/conventional educational system, rather the expectation is to improve them and use technologies like AR to improve student’s learning experience. Based on the results of the study performed with 32 dental sciences first year students from India, the reactions were very positive. Students and educators has responded in very optimistic manner calling this AR learning approach a new very innovative learning system.
BACKGROUND

“AR has strong potential to provide both powerful contextual, on-site learning experiences and serendipitous exploration and discovery of the connected nature of information in the real world.” (Johnson, et al., 2010). AR has been and being experimented over applications in various fields including school environments. In addition to that, now that the technologies that make AR possible are much more powerful than ever before and compact enough to deliver AR experiences to not only corporate settings but also academic venues through personal computers and mobile devices, several educational approaches with AR technology are more feasible. Also, wireless mobile devices, such as smartphones, tablet PCs, and other electronic innovations, are increasingly ushering AR into the mobile space where applications offer a great deal of promise, especially in education and training (Lee, K., 2012). There are some differentiations of AR approaches, like 3D viewers Augmented Reality which allow users to place life-size 3D models (virtual objects) in your real-world environment with or without the use of trackers. Trackers can be classified as simple images that 3D models can be attached to in Augmented Reality and generated using them. Other approach is Augmented Reality browsers which enrich users camera display with contextual information. For example, you can point your smartphone at a building to display its history or estimated value. There are many applications being developed and worked on using AR. The interactive catalogue of Ikea and a app called eBay Fashion are of great contribution and application of Augmented Reality (Johnson, et al., 2010; Dută et al., 2011).

Many research literatures show numerous attempts of implementing Virtual Reality/Augmented Reality (VR/AR) in educational systems; from virtual teaching classrooms environments by using
3D Virtual Worlds (3DVW) (Jarmon et al, 2009; McKerlich et al., 2011; Martín-Gutiérrez, et al., 2017), to other more specific experiences like a Virtual Reality (VR) vehicle driving simulation (Kuei-Shu, Jinn-Feng, Hung-Yuan, & Tsung-Han, 2016). The following are some more representative projects and applications towards augmented virtual educational systems:

- The Aumentaty project, developed by the Labhuman laboratory (http://www.labhuman.com) at the Polytechnic University of Valencia in Spain, and the BuildAR project, developed by the HITLabNZ laboratory (http://www.hitlabnz.org) at the University of Canterbury in New Zealand. Both projects aim to integrate AR in the classrooms by providing tools to create educational AR apps (Martín-Gutiérrez et al., 2017).

- Researchers have used Aurasma (http://www.aurasma.com) extensively as a tool in different learning strategies (Connolly & Hoskins, 2014).

- Science Center to Go project (http://www.sctg.eu) is another example of using AR to improve scientific education by manipulating and experimenting with virtual objects. (Martín-Gutiérrez et al., 2017)

- Magicbook (Billinghurst, Kato, & Poupyrev, 2001) is one of the first implementations of AR by using textbooks. This type of books can be used as regular textbooks, but visualizing virtual contents like 3D objects, animations or videos is possible by using a computer webcam or a mobile device.

- Element 4D, an AR educational application which lets students combine different elements to see chemistry in action and create new elements. This application help students visualize the chemical reactions. Teachers can print out and assemble blocks that become trigger images for an AR experience.
Quiver, an AR application meant for children, has a set of colouring pages that make the images pop off the page and let children enjoy and learn like, they can color and spin a globe in mid-air. Quiver lets students go beyond the pictures in their textbooks to interact with three-dimensional figures.

There have been some work in the dental sciences field as well utilizing virtual reality and/or augmented reality technology. Kim et al. (2005) proposed a dental training system with a multi-model workbench system which provides visual, audio, and haptic feedback to the user. Which allows drilling a tooth simulation, but it was limited to a spherical tools. Virtual Reality Dental Training System (VRDTS), which was developed by Novint Technologies in collaboration with the Harvard School of Dental Medicine, was a dental simulator system which uses VR technology for cavity preparation. This simulator system had a set of dental instruments and allowed for the virtual restoration of teeth (Welk et al., 2006). VirDenT system is another example of work done in this field. VirDenT is a system developed by the Faculty of Dental Medicine, University Ovidius of Constanta, Romania. The VirDenT uses virtual reality and augmented reality technologies to simulate the preparation of fixed dental prostheses (crowns and bridges) (Dută et al., 2010).
METHOD

Since an application was developed as part of this thesis project, there has been be a major emphasis on the development aspect. The technology stack would include multiple software and their plugins.

Technology Stack:

- **Unity3D:**

  The majority of the application was developed on Unity3D. Unity is a cross-platform game engine developed by Unity Technologies, which is primarily used to develop video games and simulations for computers, consoles and mobile devices. Unity also has a good community support which was proven to be very helpful during the challenges and technical issues of this project.

- **Vuforia:**

  Vuforia is a Software Development Kit (SDK) that is available as a plugin on Unity3D. It helps create applications or software related to Augmented Reality. It provides developers the ability to add advanced computer vision functionality to any application developed through Unity. One of such feature allows the application to recognize images targets and objects, and let the application interact with spaces in the real world.

  **Image Targets** and **VuMarks** are two of Vuforia features that are implemented in this project. Image targets is made up of images that the application’s vision functionality detects and help the system to generate the corresponding model attached with that image target. Unlike
other medium (like QR codes, for instance), these do not need any predefined pattern. VuMark is like a customized barcode which does not have any constraints.

- **C#:**

  C# is one of the most versatile object-oriented programming language. It is very often used as a scripting language with very high usage when it comes to development of games or interactive applications. It is extensively used in Unity3D.

- **LeanTouch:**

  LeanTouch is an input library which is used as a plugin for Unity which provides many library functionalities for integrating touch based functions to the 3D models. It is also a open-source set of libraries that can be modified and attached to models.

- **R Studio:**

  RStudio is an open-source IDE (Integrated Development Environment) for the R programming language. R is a programming language for statistical data computing and graphics. RStudio is a very useful tool to analyse and process the data collected from the survey questionnaire.

- **SketchFab:**

  SketchFab is a online community of 3D content creators, where people provide and share the work they have done. SketchFab provides multiple features to view and review the 3D content. It also provides options to freely download, buy and sell the 3D content created by community members. SketchFab is a tool used to search and make use of various models that are used for this application.
• **Maya:**

Autodesk Maya, or Maya, for short, is a computer 3D graphics software that can be used for a variety of things. These include creation of models, skeletons and animations. Maya was used only for the purpose of modifying/optimizing the 3D models appropriately that were collected from different online 3D model platforms.

• **Image Cards:**

The application comes with a set of cards. These cards contain 2D representations of all the respective models that they represent in the application. Application prompts to scan these cards with the mobile devices to access the 3D models that are associated with the card.

**Usability Study:**

A usability study was conducted to test the ease of usage and functionality of the applications. Study was conducted with the first and second year students of dental sciences from India. 32 students participated in the study. Participants used the application on their devices with their ease and comfort and went through a set of pre and post survey questionnaires. With the help of some of my friends from the dental science educational field (mentioned in acknowledgement), I was able to reach a university to get written permission to have their students participant in the study with given written consent and gather usability study data. The goal of the usability study was be to understand the need of students and how useful such AR educational applications and/or platforms can/would be for higher education students.

A comparative usability study of the applications, developed on the same platform as part of two different thesis projects, was also conducted. There is another thesis project build around and with this project on the platform developed (Gutti, S., 2018), which is a test of effectiveness of narrative
story-based learning through an AR learning application. The prototype applications on the platform are a story-based learning, designed to keep the learning control with application, and other application with direct search and learn any topic as it pleases the student, designed to keep the learning control with student.

**Project Description:**

The platform built in this project is capable of having many AR applications from different fields of study, like engineering, medical, technology etc. and further branches of those (figure 1). The platform is designed and build on a very minimalistic user interface design. The purpose of minimalistic design is to not overwhelm the users (students), as this system is designed as a helping tool in studying and minimalistic design would keep the navigation and usage simple and would not create distracting. An application called “Dental Wiki” was developed on this platform based on the similar user interface design structure intended to keep it simple for students. This application was created as a proof of concept prototype application to understand and explore the capabilities of such platform based system. This application is designed for students in the field of dentistry to learn and explore 3D virtual models of the oral cavity with the various anatomical landmarks of tooth (like dental lobe, fossa, cingulum, Fissures etc.), parts of tooth (like crown, enamel, pulp, cementum, dentin, root etc.), tooth surfaces and anatomical landmarks of Mandible and maxilla (lower and upper jaw). As this is just a prototype application, it was focusing mainly on the dental anatomy and some basic learnings of dentistry.
This application includes the feature of learning and exploring 3D virtual models by scanning the image cards, which contain diagrams and names of the model. An example of these image cards is shown in figure 2. Based on the scanned image card, the application generates the associated model on the user's mobile device screen for students to explore. Such an application can be considered as a virtual pocket 3D model dictionary or basic wiki application for students to learn about their respective field of study (in this case, dental).
The Dental Wiki application provides two basic modes (figure 3). One being “Study in Detail” where the student can select the model or the subsection of the dental anatomy to explore and learn. In this mode, application gives the player the prompt to select and scan the appropriate image card which is required based on the subsection they selected. Students are provided with multiple part information and the part markers on the model in this mode based on which part of the anatomical structure they selected and wants to learn about. Another mode the wiki application has is “Overview”. In the overview mode students have the ability to be able to scan any image card and look at any anatomical structure. This mode only provides the markers on the structure/model and does not provide further detail about each component of that structure. The purpose of this mode, as the name suggests, is to provide the overview of all the models and their components. This mode is mainly designed for the purpose of as a revision tool to quickly explore through all the available anatomical models.
Both the modes provide the students with the freedom of going into any category of their choice at any moment in the application. Also, the application does not put any limitation in the exploration freedom of the students allowing them to scan and learn about any model and/or its component at any time as it pleases them. There are no required tasks to be performed by the students on the application, it is all designed for the students to be able to freely explore. As this application is just designed as a proof of concept prototype, it does not intend to teach students about various tasks and surgical procedures in the field, as they are very complex implementations and can have any number of procedures, also they would take a lot of time and efforts which does not fall under the scope of this thesis due to time constraints.

**Challenges and Limitations:**

As this project utilizes a lot of 3D models, asset creation was one big challenge. Multiple online 3D model resources, like SketchFab and TurboSquid were utilized to find and build appropriate models which are anatomically correct. Making sure that all the models and structures are
anatomically correct was another challenge as this is a educational application and must provide correct information. With the help and consultation of the dental sciences practicing doctors who have been in contact and worked with us throughout the development process of this system, we were able to verify the authenticity and accuracy of the 3D modes used in this application.

The consulting doctors also helped in verifying the content markers placed on all the 3D modes/anatomical structures. The content provided and all the detail information provided through the application was on a regular basis verified with the doctors. This content authentication and verification process was a challenging process in terms of time, due to the irregular availability of the consulting doctors. The survey questionnaire designed for the usability testing purpose of this entire application were also verified and approved by the consulting doctors, because as the developer of this application, we do not have much knowledge what could be learned from such anatomical structures and how to design the questions around them to test students learning. The details about these consulting doctors is available in the acknowledgement section.

One major challenge around performing the usability test of this project was to get the authorisation from the university officials to be able to conduct the study with their first and/or second year dental students. As the study was to be conducted in India and not being physically present was a big challenge. To overcome this challenge, with the help of consulting doctors and faculties we got approval from the Head of Department and the Dean of the School of Dental Sciences of Santosh University, Ghaziabad were taken early. The reason for conducting the usability research study in India was the ease of reaching out to the students with the help of the consulting doctors, who also happen to be in the active educators.
Due the shortage of time for this thesis project work and to perform the usability study, the research had to be conducted during the March last week and April first week. Which happened to be the exam time of the first and second year dental students. This impacted the study in terms of the number of participants. The total number of students who could participate in this study was 32 students, which was broken down to two groups of 16 students each taking part in the study for each application being developed as part of two different thesis projects; the other thesis project (Gutti, S., 2018), where an application which focused on the narrative learning was developed.

The application was developed only to be used on android mobile devices. One of the reason to that is the constraint of developing applications for an iOS device, like testing can only be done on a iOS device and no test device was available with the developer. Also, as the research was to be conducted in India and most of the smart mobile devices used in India runs Android as operating system.

**Architecture:**

Below (Figure 4) is a basic system architecture diagram representing the components of the platform. Diagram also explains how the various components of the application connects with each other and operates. User uses a mobile device camera to search and scan an image card, then the application generates the appropriate 3D model of the object associated with that image card from the 3D model base..
Figure 4: System Architecture Diagram
DEVELOPMENT PROCESS

The development of the platform and the application was done in three phases. Being a proof of concept projects, there were many challenges during the whole development process, as discussed earlier.

Phase I:

In this phase, a prototype AR applications was developed which did not have any user-interface or features other than simply scanning a pre-programmed image target and generate a corresponding model attached with it. The purpose of this was to get familiar with the AR technology basics, the libraries used and their functionalities. The model used for doing this prototype was a character model downloaded from the Unity asset store as a free asset.

During this phase the list of all the models required for this application was also identified. The search for anatomically correct models to be used was also part of this phase. To search the correct models, some of the online resources were used like SketchFab and TurboSquid, as mentioned before. To make sure the models are anatomically accurate, help of the consulting doctors was taken. The doctors were in constant touch through emails and phone to help us do this correctly.

Also, there was no plan of building a platform for such applications, which would work as a launcher for the various applications from different fields of study. Building a platform was suggested by this thesis advisors, as a space which would be very helpful in terms of the scalability of such system where the plan is to build AR applications for different fields of study. Thus, a design
was created during this phase which was aligned with the concept of having minimalistic and simple interface design as described earlier.

Phase II:

This phase was the most important phase as most of the work was done during this phase. The User-Interface (UI) was created for the wiki application application was designed and created, which was based on the two mode design, the overview and the study-in-detail mode, as described in the project description. In overview mode, there was limited information provided with just the anatomical parts of the respective model. These parts were not explained in detail with any textual information about them.

Figure 5: Screenshot of application representing the marker labels, Wiki mode

All these parts were represented with marker labels on the models pointing to their correct position (as shown in the figure 5). In study-in-detail mode, all the marker labels were present as they were in the overview mode, along with that it had all the part explained with detailed information
about them as a pop-up information panel on the screen when selected a specific part through it’s button. As shown in the figure 6.

![Figure 6: Screenshot of the application from Study-in-Detail mode](image)

During this phase, another Unity project was also created as the platform system. This platform was designed to be able to direct the user to navigate to their respective field of study and open their respective application to work with. To maintain the scalability of the project the platform was
designed with multiple fields mentioned in it; Medical, Engineering, Art and Law. For the purpose of this thesis, the applications were developed under category of Dental which is placed under Medical.

As part of this thesis work only 5 models were used to represent multiple dental anatomical structures. The selection of these models was on the basis of the basic details provided by the consulting doctors about dental anatomy. All the models were verified by the consulting doctors to be anatomically accurate. Also, the information about each part and their label markers were consulted to be verified for their accuracy. The image target cards were also created for each model and anatomical structure with their name and some image on them. These image target cards are used to attach the models with them and are scanned by the application to generate respective models.

Testing of the platform and wiki application with all the models and placeholders for all the details was also done around the end of this phase. The application was deployed on Android test devices using the .APK (android executable file format) generated by building the project in Unity. These executables were also shared with the consulting doctors to get their reviews and to perform checks on the accuracy of the things.

**Phase III:**

Modifications and the corrections with the model marker labels were done during this phase in the beginning based on the review comments received from the consultants and the thesis advisors. There were many marker labels were found to be placed wrongly on some models. Specially, almost all the marker labels on the Tooth Surface model were not pointing as the correct part of the model.
The image target cards were also redesigned to improve the model fluctuation bugs faced during testing of the application. The new cards were designed to be in the landscape mode to provide more surface area for the application to scan and be more stable with the models generated.

The wiki application was also integrated with the platform system for the platform application to be able to launch the wiki application when selected. The other narrative (story-based/curriculum-based) application, which was part of other thesis project (Gutti, S., 2018), was also integrated. The issues and bugs generated during the integration process were resolved with the help of Unity developer communities and with the advice provided by the thesis advisors.

By the end of this development phase, the survey questionnaires were also designed and reviewed by the consulting doctors to have the understanding of the difficulty required for the knowledge check questions for the students, who will participate in the usability study.

**Survey Details:**

As advised by the thesis advisors, to perform the usability research for this proof of concept platform and AR applications three survey model was created. As the study was to be conducted in India and as developers we were not physically present there, the study was conducted with the help of the consulting doctors. Because of the shortage of time and exams, there were only 32 participating students which were divided between both the thesis project applications (16 students in one group and 16 in the other). The surveys were structured in a way the first survey would be taken by the students after they sign the consent forms and before they start with any application. Then they will go through one of the application and take the second survey after that. After that, they were given the second application followed by the third survey. For half of the students (16
students), wiki application was given first followed by the narrative application (Gutti, S., 2018); for the other half, this order was reversed. The tool used for creating and data collection was Qualtrics, which is provided access to by Northeastern University.

**Survey-1 (pre-survey):**

Survey-1 was intended to test the knowledge level and help us build the knowledge baseline of all the students participating. This was the reason it was provided before they test the applications. This survey questionnaire had 10 questions, which were designed as multi-choice and true/false questions. All the questions were basic questions about the dental anatomy. These questions were also verified by the doctors to be medically accurate and to make sure they were of the difficulty level of the first and second year dental students. Students were given about 10-15 minutes for this survey, followed by the 20-25 minutes of testing and exploring the application.

**Survey-2 (post-survey):**

This survey contained 15 questions in total which were divided in two sections. The first section was similar to the first survey had 10 basic questions based on dental anatomy; and the remaining 5 questions were about the application they were testing first. For this thesis, 16 people tested the Dental Wiki application first and were given the survey-2 designed for it. The second section of this survey with 5 questions had questions about the usability and their opinion on the application; these questions were using 5-point likert scale. Students were given about 10-15 minutes to complete this survey which was followed by the other application testing for 20-25 minutes.
Survey-3:

Survey-3 was intended to provide the data about the overall feedback of the complete application and platform system. This survey was provided to students after they had tested both the applications. This survey had total 14 questions which were also designed with most of the questions on 5-point likert scale with couple of open-ended questions. The questions about the students demographics were placed at the end of this survey. The only details asked from the student as their demographics were their gender and age. This survey had some questions designed to perform a comparative study between the two application developed for this project.
RESULTS

Knowledge Test:

From the Survey-1 responses received, a baseline of the students knowledge was drawn. Scores of all the 10 questions from survey-1 were averaged based on the number of correct answers and their frequency. The histogram drawn from that data is as shown in figure 7 (left).

Survey-2 also had similar students knowledge base questions and the scores from all 10 questions were calculated and averaged based on the number of correct answers and their frequency. The histogram drawn from that data is as shown in the figure 7 (right) above.

![Figure 7: Histogram of the Survey-1 (Left) and Survey-2 (Right) Results](image)

Scores of Survey-1 vs Survey-2

![Figure 8: Box-plot graph of scores from Survey-1 and Survey-2](image)
The mean and median from the survey-1 were calculated to be 6.56 and 6.5 respectively. The survey-2 mean and median were calculated to be 7.25 and 8 respectively. There is a considerable increase between the mean and median values but due to the limited participants in this study there cannot be any conclusion drawn from this. The Standard Deviation calculated for survey-1 was 1.75 and for survey-2 it was 1.69. The standard deviation reduction indicates that the scores from the survey-2 were closer than the scores from survey-1. The box-plot graph, as shown in figure 8, represents survey-1 and survey-2 scores with visualization of these values. The overlap in the whiskers of the box-plot graph also express that the increase in the median value is not credible enough to prove that the improvement in knowledge base of the participants was due to the use of the application. Although the results are promising, there is no concrete evidence that this change was not by chance. To have more credible results, this study needs to be conducted with many more participants to collect a bigger data set.

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<th>Survey 2</th>
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<td>Mean (μ)</td>
<td>6.56</td>
<td>7.25</td>
</tr>
<tr>
<td>Median (M)</td>
<td>6.5</td>
<td>8</td>
</tr>
<tr>
<td>Standard Deviation (σ)</td>
<td>1.75</td>
<td>1.69</td>
</tr>
</tbody>
</table>

*Table 1: Mean, Median and Standard Deviation values from Survey-1 and Survey-2*

**Application Evaluation:**

The second section of the Survey-2 was about the application evaluation consisting of 5-point likert scale questions, it had 6 questions. The results from those questions are combined with each other based on their similarities.
The above figure 9 represents shows the results of the questions about the usefulness of such AR educational application (in this case, Dental Wiki) for students Figure 10 shows the results of the questions about the user-interface and user-experience of the Dental Wiki application.

The overall rating provided by the students to the Dental Wiki application is represented in the below figure 11.
Survey-3 was about performing the complete application test and the evaluation of the AR technology and its usefulness in the higher education fields, in this case dental sciences. This survey was also intended to perform comparison between the wiki application and the narrative (story-based) application. Both qualitative and quantitative methods were used to understand which approach is beneficial in a certain scenario. The quantitative part directly compared both wiki and narrative approaches, while the qualitative analysis helped understand what can be improved in the application.

The evaluation provided by the students to the complete application system is presented in the below figure 12. Majority of the participants mentioned that the application was either excellent or great. There were two participants who seemed to be little dissatisfied with the application; this could be because they had some technical issue with the android mobile device they were using and had to restart the application couple of times, because their responses to most of the questions were positive.
Figure 12: Graph showing the overall users experience

On the questions about how often would they use such an AR application in their regular studies, most of the students mentioned that they would like to use such applications very often, as represented in the figure 13.

Figure 13: Representation of application usage expectancy

When asked about their preference between both type of applications (wiki and narrative), students mostly seem to prefer both the applications, as shown in figure 14. When asked about the
application preference for exams preparation about 90% of the students preferred wiki application over narrative application.

Figure 14: Representation of application preferences

Survey-3 also had couple of open ended questions, asking about their suggestions for future improvement purposes. The analysis for those responses is mentioned below:

Questions:

- What do you like or dislike most about this application?
- What about this application could be improved?

Responses:

- **Satisfied**: More than half of the students agreed that the application was very well developed and seemed satisfied, it was reflected in their comments. Most of the students mentioned the application to be “Very Innovative”; student commented “I like the models used. Easy to learn the markings”, “Very well made app already.”. This indicates they were very satisfied with the system and does not expect much improvement.
• **Constructive Criticism:** There were some students who mentioned about applications needing much more work and improvements, Specially many of them mentioned about the stories requiring improvements. They also mentioned about having more information in the applications; there were comments like “Very well done, but need more stuff in it”, “Stories can be improved.” and “Rotating the model was tricky, but it was amazing”. Some of the students gave good suggestions for the future work of this application like, “Adding the nervous system would make it very useful.” and “If Procedures be also included in this app. That Will be a good learning tool.”.

• **Unsatisfied or Unsure:** Few participants had some negative comments as well. But when compared with the overall results, there is no clear way to understand that what caused such comments. Some of such comments were, “There is no way to switch from story to wiki or wiki to story mode. You have to exit and open the app again.“ and ”Looks like we are in a game..”.
DISCUSSION

Based on the results, the participating students were very satisfied with the application. Results also showed that it helped them learn and understand better. Participants also mentioned that this application in current state does make the learning easier for them by exploration.

The results from survey-1 and survey-2 shows a clear increase in the scoring patterns for participants after exploring the application. This can be seen from the box-plot graph (figure 8) drawn from the results of the knowledge base questions from survey-1 and survey-2. The increase in the mean value of the scores (from 6.56 to 7.25) as shown in the box-plot graph with the dark line in the box represents some improvement in values but due to smaller data set collected nothing can be concluded from it. Also, it cannot be compared with conventional learning methods. One reason to that is that the number of participants were very little in this study to be able to represent any such credible statement. To get more credible results this study should be conducted with a large number of people which would establish a clear learning curve pattern.

The participants were informed before the study that this application is is a Proof of Concept prototype application. The purpose for this was to not receive too many comments about the application having very limited details and/or just a few models, instead they should be able to focus on the concept and be able to explore the AR technology used more efficiently. As a Proof of Concept the application does have the basic things necessary to for user evaluation.

As represented through the results, most of the students agreed that such application would be very useful for them to do more effective learning. Some of the students did have mixed feelings about the application and this learning style, but overall the responses were positive. About the User-Interface of the application, students suggested some improvements and called the application a moderately well-made application. Overall rating for the Dental Wiki application was very
positive. 10 out of 16 people gave the wiki application excellent rating (as shown in figure 11). One general comment received from the results was that participants called this learning application a very innovative concept and mentioned about having more details and information would be much more helpful.

While comparing both the applications approaches, the wiki application and the narrative application (Gutti, S., 2018), results represent that the students liked both the application. On the questions about which application would be preferred for the exam preparations given the limited time students have, they would prefer the Wiki application. But based on the questions about the which application would be preferred for their regular learning, they mentioned that they would like to use both the applications. This represents that the students liked both the approaches and would like to use them together for regular learning and would prefer wiki application when there are time limitations.
CONCLUSION

Students in higher education face a lot of challenges with the conventional learning methods and can make use of technologies like Augmented Reality (AR) for their practical learning enhancement. As proof of concept, an AR application and platform were developed as part of this thesis project, for first and second year dental science students, focusing on dental anatomy. The results of the usability study conducted shows that such AR tools would be very useful for the students in higher education. The positive response towards this AR application shows that there are good future prospects for it. As the follow-up to this thesis project work, and taking the improvement comments received during the study, I would like to continue working on this application to enhance it further. Also as future work, I would like to expand this work to more fields of study.
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APPENDIX A

★ Project Executable (Android device only):

○ [https://drive.google.com/file/d/1zZRQ0PLbB3MPzCAhdbWrWzsWewePf3Df](https://drive.google.com/file/d/1zZRQ0PLbB3MPzCAhdbWrWzsWewePf3Df)

★ Image Cards used by app to scan:

○ [https://drive.google.com/file/d/1odN09TqS6Bb2Tfbwtl-m_MQXVroWOVKc](https://drive.google.com/file/d/1odN09TqS6Bb2Tfbwtl-m_MQXVroWOVKc)

★ Proof of conducted study:

○ [https://drive.google.com/open?id=0B7gWqr8OaZIHRzhtDZVe4LWFBAWxRRDJbTBSTl6YVRPMjFV](https://drive.google.com/open?id=0B7gWqr8OaZIHRzhtDZVe4LWFBAWxRRDJbTBSTl6YVRPMjFV)

★ Letter of Approval to conduct study, from the University Dean:

○ [https://drive.google.com/file/d/0B7gWqr8OaZIHRzhtDZVe4LWFBAWxRRDJbTBSTl6YVRPMjFV](https://drive.google.com/file/d/0B7gWqr8OaZIHRzhtDZVe4LWFBAWxRRDJbTBSTl6YVRPMjFV)

★ Consent Form signed by the participating students:

○ [https://docs.google.com/document/d/1EmpE0Uzw2-uKtfDBJ7FkowPr3MPX8PTP-J4tFNiXSo](https://docs.google.com/document/d/1EmpE0Uzw2-uKtfDBJ7FkowPr3MPX8PTP-J4tFNiXSo)

★ Information provided to students about how to participate:

○ [https://docs.google.com/document/d/16vW2zjMAvAxCFAJM3Z2N_gM452FdVKOUX2bVhG0xaR8](https://docs.google.com/document/d/16vW2zjMAvAxCFAJM3Z2N_gM452FdVKOUX2bVhG0xaR8)
APPENDIX B

Thesis Survey-1 Questionnaire

★ Single plate forming the majority of the base underside of the cranium
  ○ Sphenoid bone
  ○ Frontal bone
  ○ Occipital bone
  ○ Temporal bone

★ One of four types of human teeth found in the posterior part of the maxilla and mandible, used to grind and crush food → Premolar
  ○ True
  ○ Neither true nor false
  ○ False

★ The hard, calcified tissue covering the root dentin of a tooth → Cementum
  ○ True
  ○ Neither true nor false
  ○ False

★ A general term to include both buccal and labial surfaces of teeth in both maxillary and mandibular arches
  ○ Facial
  ○ Palatal
  ○ Cusp
  ○ Groove

★ Toward or facing the midline (median line) anteriorly along the arch → Labial
  ○ True
  ○ Neither true nor false
The part of a natural tooth covered by cementum and normally embedded in the alveolar bone
- Root
- Crown
- Enamel
- Periodontal ligament

Pair of plates forming the top and greater area of the sides of the cranium → Temporal bones
- True
- Neither true nor false
- False

Teeth in the back of the mouth that include premolars and molars → anterior teeth
- True
- Neither true nor false
- False

The mandible is the only movable bone of the skull not counting the ossicles of the middle ear.
- True
- Neither true nor false
- False

Which are the longest teeth in Dental arch
- Incisors
- Premorals
- Molars
- Canines
Thesis Survey-2 Questionnaire

★ Single plate forming the majority of the base underside of the cranium
  ○ Sphenoid bone
  ○ Frontal bone
  ○ Occipital bone
  ○ Temporal bone

★ Pair of plates forming the top and greater area of the sides of the cranium → Temporal bones
  ○ True
  ○ Neither true nor false
  ○ False

★ A general term to include both buccal and labial surfaces of teeth in both maxillary and mandibular arches
  ○ Facial
  ○ Palatal
  ○ Cusp
  ○ Groove

★ Teeth in the back of the mouth that include premolars and molars → posterior teeth
  ○ True
  ○ Neither true nor false
  ○ False

★ Which are the longest teeth in Dental arch
  ○ Incisors
  ○ Premolars
  ○ Molars
  ○ Canines
One of the four types of human teeth found in the anterior part of the maxilla and mandible, used for incision (cutting)

- Molars
- Incisors
- Premolars
- Canine

The mandible articulates with the left and right temporal bones at the temporomandibular joints.

- True
- Neither true nor false
- False

The part of the root system of a tooth in which the root trunk divides into two separate branches

- Cusp
- Occlusal
- Root Furcation
- Buccal

Single plate at the back and partial underside of the cranium

- Temporal bones
- Sphenoid bone
- Parietal bones
- Occipital bone

Toward or facing the midline (median line) anteriorly along the arch → Mesial

- True
- Neither true nor false
- False

How positive or negative is your first reaction to this part (Wiki) of the application?
- Extremely positive
- Moderately positive
- Slightly positive
- Neither positive nor negative
- Slightly negative
- Moderately negative
- Extremely negative

★ How well made is this part (Wiki) of the application?
- Extremely well made
- Very well made
- Moderately well made
- Slightly well made
- Not well made at all

★ How easy was it to navigate through this part (Wiki) of the application?
- Extremely easy
- Very easy
- Moderately easy
- Slightly easy
- Not easy at all

★ How useful you think this part (Wiki) of the application is/would be for the student?
- Extremely useful
- Very useful
- Moderately useful
- Slightly useful
- Not at all useful
Rate your overall experience with this part (Wiki) of the application.

- Excellent
- Good
- Average
- Poor
- Terrible

Do you have any other suggestions or comments?

________________________________________

________________________________________

Thesis Survey-3 Questionnaire

How positive or negative is your first reaction to this complete application?

- Extremely positive
- Moderately positive
- Slightly positive
- Neither positive nor negative
- Slightly negative
- Moderately negative
- Extremely negative

How innovative is this complete application?

- Extremely innovative
- Very innovative
- Moderately innovate
- Slightly innovative
- Not innovative at all

★ How well made is this complete application?
- Extremely well made
- Very well made
- Moderately well made
- Slightly well made
- Not well made at all

★ How often do you currently use other similar applications?
- Extremely often
- Very often
- Moderately often
- Slightly often
- Not often at all

★ How helpful do you think such application is/would be for students to understand and help study?
- Extremely helpful
- Very helpful
- Moderately helpful
- Slightly helpful
- Not helpful at all

★ How likely would you be to purchase this application if it were complete with more details and available today?
- Extremely likely
- Very likely
- Moderately likely
- Slightly likely
When you think about this new application, how necessary and useful do you think it is for students today?

- Extremely necessary
- Very necessary
- Moderately necessary
- Slightly necessary
- Not necessary at all

Considering you are preparing for your exams, which mode of the application are you more likely to use?

- Wiki mode
- Neither Wiki nor Story mode
- Story mode

How effective do you think having a predetermined curriculum (represented as stories here) is in the process of learning?

- Extremely effective
- Very effective
- Moderately effective
- Slightly effective
- Not effective at all

What would you prefer?

- Having both the modes (wiki and story) in a single application
- Having separate applications for each mode
- Application with only wiki
- Application with only story
- Application is not very useful
★ What do you like or dislike the most about this application?

________________________________________________________________
________________________________________________________________

★ What about this application could be improved?

________________________________________________________________
________________________________________________________________

★ What is your gender?
   ○ Male
   ○ Female
   ○ Choose not to disclose

★ Please mention your age.

________________________________________________________________

====================================================================