Master's Thesis
Computer Science
Thesis No: MCS-2012:20
September 2012

# LANGUAGE LEARNING VIA AN ANDROID AUGMENTED REALITY SYSTEM

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This thesis is submitted to the School of Computing at Blekinge Institute of Technology in partial fulfilment of the requirements for the degree of Master of Science in Computer Science. The thesis is equivalent to 20 weeks of full time studies.

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# ABSTRACT

Augmented Reality (AR) can be described as one of possible steps between real world and fully virtual reality. Into this mixed reality we can make an overlay with virtual objects onto the real world typically by capturing camera images in real-time to produce a new layer to the environment with which we can interact. Mobile Augmented Reality (MAR) is a term used when equipment through which we achieve AR is small in size and typically easy to carry e.g. a smartphone or a tablet. The concept of using AR in facilitating learning and improving its quality seems to attract more attention in the academic world in recent years. One of the areas that receive much attention is AR language learning. In this thesis an experiment on a group of 20 people was conducted to answer the question: "Is MAR language learning system a viable solution for language learning?" For the purpose of the experiment an AR Language Learning Tool was designed for Android smartphones. This AR Language Learning Tool facilitated vocabulary learning by displaying 3D objects along with their spelling and providing audio of pronunciation. Participants were divided into an equal control group and test group. The control group learned new vocabulary through classic flashcards while the test group used the previously designed AR Language Learning Tool. The Vocabulary Knowledge Scale questionnaires were provided for both groups right after learning and one week later. By performing statistical analysis with Student's t-test on gathered data it was discovered that there is a positive improvement in long term recall rate in the AR Language Learning Tool group when compared with the flashcards learning group. No difference was found in short term recall rate between both groups. Participants also provided feedback about their quality of experience and enthusiasm for new learning methods. Their answers were very positive and provided proof that mobile AR is a viable method of learning vocabulary.

**Keywords:** Augmented Reality, Mobile Augmented Reality, Android, Smartphones, Vocabulary Learning, Vocabulary Knowledge Scale

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# LIST OF ABBREVIATIONS

| | |
|---|---|
| 3D | three dimensional |
| AR | augmented reality |
| MAR | mobile augmented reality |
| VKS | vocabulary knowledge scale |
| ANCOVA | analysis of covariance |
| OS | operating system |
| SDK | software development kit |
| API | application programming interface |
| IDE | integrated development environment |
| GPS | global positioning system |
| MP | mega pixels |
| FPS | frames per second |
| SIFT | scale invariant future transform |
| SURF | speed up robust futures |
| POI | point of interest |
| QR Code | quick response code |
| ARM | advanced RISC microarchitecture |
| MIPS | microprocessor without interlocked pipeline stages |

# 1. INTRODUCTION

## 1.1.BACKGROUND

Augmented Reality (AR) can be described as one of possible steps between real world and fully virtual reality (Milgram et al. 1994). Into this mixed reality we can make an overlay with virtual objects onto the real world typically by capturing camera images in real-time to produce a new layer to the environment with which we can interact. In the beginning of AR the use was constrained to head mounted displays and heavy processing units typically placed in backpacks. With the advancement of technology we have seen an increase of processing power in personal devices which also counts for mobile phones. The introduction of smartphones with greater computing power, hardware for environmental interaction and also fully functional operating systems has allowed implementation of AR in more compact size solutions. With this advancement AR steps out from researchers laboratories into real world applications and mass market.

Mobile Augmented Reality (MAR) (Doswell et al. 2006) is a term used when equipment through which we achieve AR is small in size and typically easy to carry e.g. a smartphone or a tablet. As the technology of augmented reality is becoming increasingly mature we can see its appliance in many different areas of life, from transport through medicine ending at entertainment (Azuma et al. 2001). A smartphone equipped with a proper application can help us navigate from point A to point B, find local attractions, present us with extra information just by looking at the world through its display. You can even play games taking place in real world or try out virtual clothing without the need to go shopping.

The possibilities for AR applications seem to be endless and it also seems to be reflected in an increasing number of applications available for mobile devices (Bernardos & Casar 2011). In King´s article he states that in year 2010 the smartphone users spent less than 2 million dollars on AR applications but in year 2015 it will be 1.5 billion dollars (Danny King 2011). As the market and possible profits increase, people´s interest in AR will follow, therefore it is a valuable piece of information to know what solutions and techniques which are available and more importantly how they stand against each other and what functionalities they offer.

There is also a new emerging markets related to AR such as Serious Games that aim to teach new knowledge and skills for users in the form of playable interactive games.

The whole concept of using AR in facilitating learning and improving learning quality seems to attract more attention in the academic world in recent years. A search on following keywords: ”Augmented Reality” AND ”learning” show steady improvement in databases as Compendex and Inspec in number of papers on this topic with its peak in recent years. One of the areas that receive much attention is AR learning, language learning.

## 1.2.PURPOSE OF MASTER THESIS

There seems to be many papers describing systems for AR language learning (Chien-Hsu Chen et al. 2007) (Wagner & Barakonyi 2003) (Jung & Lee 2008) (Min-Chai Hsieh & Jiann-Shu Lee 2008) (Juan et al. 2010). But I haven’t found any research answering such questions as:

- Is AR valid option for language learning?
- Is the quality of experience higher than in traditional learning?
- Does the usage of AR for language learning yield better results than traditional methods?
- What are the benefits of using AR for language learning?

When we come to the field of MAR learning, currently there are no applications available on the Android Market. Search for Augmented Reality Learning typically find us AR points of interest (POI) browsers, or AR games. This seems to be rather strange while learning software can have a real potential on a big market, especially if it has something new/special to offer. Hopefully by introducing my own demo AR Language Learning Tool there will be more people interested in pushing this concept further on.

Therefore the main purpose of this master thesis is to present the basis for determining that mobile augmented reality on Android is a viable tool for vocabulary learning. To do this a demo tool will be demonstrated which I will call the AR Language Learning Tool. It will have the functionality of AR vocabulary learning and will be used during later conducted experiment. This will serve as an engineering part of the master thesis as a proof of concept and will later on be used in conducted experiment. The experiment part aims to provide a mathematical basis so the results achieved will show the difference between learning via a mobile telephone with its AR Language Learning Tool and a traditional learning method, here Flashcards.

## 1.3.SCOPE OF THE WORK

In this thesis an experiment is conducted that will compare language learning using a traditional method and an AR Language Learning Tool on an Android device. This Language Learning Tool is aimed to be used in the experiment. It will use some of the techniques and technologies for AR and which also are available for the Android operating system. To be able to develop the Language Learning Tool following factors had to be elaborated.

- What are the factors and necessary components for AR?
- How does Android OS help to facilitate this process?
- What are the available background tools and techniques for achieving AR on Android devices?

A detailed comparison of available techniques and technologies were done to be able to obtain AR as a result of the AR Language Learning Tool development. This type of information could be useful for developers and other researchers to quickly grasp differences in available solutions so they can choose according to their needs without checking each solution thoroughly.

The initial part of this thesis is focusing on the evaluation of a design and implementation of an AR system using capabilities of Android devices. This Mobile Augmented Reality (MAR) device allows users to learn new words in a foreign language by use of marker based AR techniques. It displays a 3D model object e.g. a car, its spelling and its pronunciation, in a Spanish language, therefore facilitating learning of new words.

Later part of master thesis focuses on performing an experiment. The evaluation of the Language Learning Tool was conducted via an experiment in which 20 people provided their feedback. They were divided into two equal groups in which a control group used the traditional learning method namely physical flashcards and the other group used the developed AR Language Learning Tool. Both groups were given a constrained time of 15 minutes to learn 20 words in Spanish language and right after the learning and one week later their recall rate was checked by a questionnaire with multiple choice test. This questionnaire was based on the Vocabulary Knowledge Scale (VKS) introduced by Wesche M. & Paribakht T.S. which is a well-known and established method of assessing learner's vocabulary (Wesche & Paribakht 1996). Using this data and statistical analysis previously stated research questions were answered.

By performing analysis of the hypothesis using Student's t-test on the results of both test groups the answer was found to the question if there is any significant difference in recall rate of words for both groups. The test also asked users about the quality of their experience which here meant asking open-ended questions about the quality of augmentation, the quality of the 3D objects and the overall advantages compared to classic learning.

The results of the experiment showed that there is a real difference in long term memory recall rate in favour of the application group. This was proved by using Student's t-test on data representing users recall rate one week after their learning session. The statistical significance level was set as $p = 0{,}05$ and the resulting value for the test was $p = 0{,}031$ .This led me to believe that there is a real improvement in long term recall rate using the AR application in comparison with the flashcards. Also all users of the AR application gave positive feedback to open questions. This all makes my claim more viable. Users regarded the AR application as something new and interesting to use. They were happy with the use of additional senses and interaction with augmented reality. This all is a strong proof that AR especially as a mobile language tool is a viable method for vocabulary learning and probably it does not stay there. Finally I have provided possible directions for future work such as, expanding the AR tool, conducting an experiment with larger test groups, or expanding research to other languages, longer experiment period and more thorough testing.

# 2. PROBLEM DEFINITION, RISKS, AND GOALS

## 2.1. PROBLEM AREA

In this thesis we are dealing with topics such as Augmented Reality, Android OS, Language Learning and Experiment Design. Therefore each one of them should be closer examined to provide a definition and a better understanding to what they are so the later part of this master thesis is clearer and easily understood. Each part is related with the next one in a logical manner, everything done leads to properly answered research questions. It is crucial that every step is explained and we know why it was taken.

### 2.1.1. AUGMENTED REALITY

Augmented reality has many different definitions, but the general concept is to enhance the real world vision with additional digital information or digital objects. To project these objects typically computer screens or projectors are used, with use of a camera the image of the real world is captured quickly and processed (typically in real time) and redisplayed on the digital screen with extra information or objects in it. Ivan Sutherland with his “Sword of Damocles” first augmented reality with a head mounted display which often is considered being the inventor of the augmented reality (Sutherland 1968). Lately with advancement in technology and processing power AR has wandered out of researchers’ labs into commercial use in personal computers, also appearing on smaller devices. In recent years the new type of mobile phones namely smartphones provide all necessary components to produce AR. Augmented reality relies heavily on image processing and ideally should take place in real time, because of those constraints it requires high amount of processing power. Until recent years it was impossible to achieve satisfying results on mobile devices, but nowadays the phones even have multiple processor cores which are up for the task.

**Figure 1: Samsung SARI AR SDK marker less tracker used in the AR EdiBear game (Android OS) Source: Wikipedia**

### 2.1.2. ANDROID OS

Android OS is a Linux based operating system designed mainly for smartphones and tablets due to its high popularity nowadays it can also be seen on other types of devices such as e-readers, netbooks and more. The project was started by a small company called Android Inc. but was bought in 2005 by Google seeking to join the phone market (Elgin 2005). The expansion of Android OS started in 2007 along with Google founding Open Handset Alliance as a consortium focused on building more user friendly mobile phones with Android OS on them. Due to its Open Source nature Android OS allows users to program applications without much restriction. The Android Software Development Kit (SDK) provides all necessary libraries and the Application Programming Interfaces (API) and the compiler are the facilitators to be able to make these Android applications. The preferred Integrated Development Environment (IDE) is Eclipse for which there is a special plug-in facilitating the work but still there are other possibilities to use other solutions. The SDK is available on Linux, Mac OS and Windows. Typical features found on Android devices mentioned in the documentation of Android Open Source Project[1] are as following:

[1] Android Open Source Project, Dev-Guide section: What is Android?, in: http://developer.android.com/guide/basics/what-is-android.html

**Features**

- Application framework enabling reuse and replacement of components
- Dalvik virtual machine optimized for mobile devices
- Integrated browser based on the open source WebKit engine
- Optimized graphics powered by a custom 2D graphics library; 3D graphics based on the OpenGL ES 1.0 specification (hardware acceleration optional)
- SQLite for structured data storage
- Media support for common audio, video, and still image formats (MPEG4, H.264, MP3, AAC, AMR, JPG, PNG, GIF)
- GSM Telephony (hardware dependent)
- Bluetooth, EDGE, 3G, and WiFi (hardware dependent)
- Camera, GPS, compass, and accelerometer (hardware dependent)
- Rich development environment including a device emulator, tools for debugging, memory and performance profiling, and a plugin for the Eclipse IDE

According to this set of features we can conclude that Android OS has all necessary perquisites for achieving Augmented Reality. This is better described in a later chapter 2.2. “How android facilitates achieving AR”.

### 2.1.3. LANGUAGE LEARNING

Language learning is very important because people want to communicate. In modern societies and especially in Europe the number of foreign languages we speak is in a sense, an indicator of our knowledge. The more languages we speak the more attractive we are for employers and we also have more opportunities in life. Nowadays the predominant language is definitely English and in many occupations it is at least required to know basics while in other occupations you have to be rather good at it when applying for a job, and by saying “job” I don’t necessarily mean being an English teacher. Perhaps one good example is an IT specialist who needs to keep up with the latest technology and be able to work and communicate with colleges from all around the world.

Since it is so important to know foreign languages in today’s society, naturally the process of learning will be given the same importance. Language learning or more professionally is to say language acquisition is a field where much attention is focused on research. Researchers try to break down the learning process into its components and while this may be hard for syntax and phonetics it is rather clear for vocabulary. If you have the knowledge how to make sentences in a given language the next most important thing is your vocabulary. The more words you know the easier it is for you to communicate what you want to others.

Vocabulary learning is often considered as a separate part of language learning. Starting with simple noting of learned words with their meaning going through mnemonics to other advanced learning methods. Mnemonics is a form of association which helps in remembering things in a form which is easier to retain by a human brain. There are many ways to develop ones vocabulary. Mobile augmented reality is one of such possibilities with the potential that it gives us where we can engage the learner into new more exciting ways of increasing their vocabulary. Typically the more senses we engage in the process of learning -the better results we get. Considering AR in this learning process becomes a really good choice. With the augmented reality system we are talking about here we can engage the user into seeing, hearing and making it possible interacting within the augmented world. Another benefit of “M” in MAR is in its mobility the users don’t really forget to bring the Language Learning Tool along because who forgets to take his/her phone (or at least it doesn’t happen too often). With this comes the opportunity to learn everywhere even in short durations of time but more often allowing users to more freely manipulate their time. Although the demo AR application designed for the experiment purpose was limited, because it required specially prepared marker, there are other type of AR which aren’t limited in such a way.

## 2.2.HOW ANDROID FACILITATES ACHIEVING AR

Android OS is one of the leading operating systems on mobile devices today. It has some requirements for devices that will use it but overall we can assume that devices running it have one of the better hardware available for mobile phones out there. According to the previously mentioned futures we have the camera, the compass, the GPS, the accelerometer, the 3D graphics engine, the application framework and the overall high processing power provided typically by the ARM processor. Not all components are necessary but each one of those components helps us when aiming for AR. We will now go through them in more detail.

**The Required Components are:**

- Camera – this component is required to catch the real world vision for later on processing, without it -it would be impossible to augment reality as there would be no possibility to capture its image. Nowadays cameras in Android smartphones are at least 3.2 Mega Pixels (MP) but you will typically have a 5 MP and even up to 12 MP in high end models. Those cameras also allow for constant image capturing (video) in typical speed of 30 FPS allowing for smooth augmentation.
- Processing Power – this is not really a part of hardware but AR requires processing of the captured image and applying new layer of augmented objects to it, this task is mostly dependant on CPU. Android devices up until recently were only supported on Advanced RISC Machine (ARM) architecture, but recently there have been also projects porting it to MIPS (Microprocessor without Interlocked Piped Stages) and x86 architectures. The porting process which allows software to run on different processor architecture, started just recently in 2011 for both MIPS and x86 architectures and currently (early 2012) all available smartphones with Android OS have ARM based CPU. With that said in most cases producers give their devices a decent CPU taking into account that it will run a full operating system and users want to have smooth experience on their devices.
- Screen – this component is so obvious that it is sometimes forgotten but you actually need to project the augmented reality for the user to see it. Android devices come in different types of screen sizes and ratio, for smartphones they can be anywhere between 2,5 inch and 4,5 inch with most typical size between 3,0 and 3,5 inches. In most cases the screen provided has a good quality and a higher resolution than in normal phones. With a big screen and a high resolution the comfort for the user increases but it also requires quite more processing power to process higher resolution images.
- 3D libraries – without any graphic libraries it would be a very difficult task to introduce any type of objects into the augmented image, as the programmer would need to start with very low level drawing which would significantly increase the development time if not stopping the whole project. Android OS with its support for OpenGL ES 1.0 gives the programmer a well-established API which allows for easy manipulation of 3D spaces and objects in it.

**Additional Components:**

- Compass and Accelerometer – those two devices allow to better calculating position and orientation of the device. With compass we can with some accuracy predict the direction the device is facing. Combining that with accelerometer allows us to determine device orientation. This kind of information isn't necessarily needed in augmented reality but can help especially in applications that provide some directions to the user.
- Global Positioning System (GPS) – with GPS we can pinpoint device location in the world with some accuracy, this kind of information becomes useful when our augmentation provides information that is location sensitive for example using our position we can easily query database for local restaurants within 100 meters and if we also have their location. With the use of compass and accelerometer we can show only those restaurants that are in the direction that the device and its camera are facing.

## 2.3.RESEARCH QUESTIONS

As the topic of AR is a novelty it receives a lot of researchers' attention. Most of this attention focuses on implementing new solutions to problems but still few of those papers try to compare performance of implemented solutions with its old counterparts. The papers mentioned in the introduction show us that language learning is one of the fields in which researchers try to use AR. There seems to be a lot of attempt to use AR in facilitating language learning but no solid proof that it is actually better that other methods. This paper tries to fill that gap and is studying the actual performance differences in language learning or more precisely vocabulary learning between a traditional method and an AR tool. With this background and that the author of this thesis also carries an own interests in AR language learning the following research questions are formed:

- R.Q.1: What makes AR a valid option for language learning?
- R.Q.2: What are the differences in quality of experience compared to traditional learning?
- R.Q.3: Does the use of AR for language learning yield different results than traditional methods?
- R.Q.4: Are there any benefits of using AR for language learning?

Answering those questions will give us insight into suitability of AR solutions in language learning. It will be a solid direction whether there are any benefits to use AR and if this approach should be taken further. Also the created Language Learning Tool could have some future use in other papers or experiments.

## 2.4.RISKS

Upon each major sub project there are some risks to take which can increase the money cost such as code complexity, time or even lead to total failure. From the project management point of view it is always important to identify those risks and to have some countermeasures ready for each scenario if failures would occur. Based on this approach here the most major risks to this master thesis are presented and what countermeasures to fight them.

**Table 1: Risks to the master thesis and countermeasures to fight them**

| RISK | COUNTERMEASURES |
|---|---|
| **Not enough information about solutions and techniques for AR on Android devices available after SLR** | Use other information sources such as: Google search, Wikipedia, projects own Wikipedia, mailing authors, checking manually for given functionality. Those resources cannot be regarded as scientific but will provide a starting point in research |
| **3D models of objects not available as open source, or incompatible data with Android OS** | Use some method for transforming 3D objects into format supported by Android OS, worst case is to use 2D images or a 3D cube with images of objects on it |
| **Problems with AR implementation in language learning device** | Depending on problem nature:<br>If programming problems occur then I will refer to Android SDK, android developer's forum<br>If problem with AR solution then ask its developers or change solution to a different one |
| **Problem with gathering 20 people to participate in experiment** | Advertise software on different Android forums, ask people from student dormitories to participate, put language learning software onto Android market and allow users to complete survey within the application |

# 3. RESEARCH METODOLOGY

Research experiments should be carried out systematically so that each and every step can be easily reproduced. In order to achieve this each of those steps needs to be clearly described and extra effort needs to be put in to this so that there are not any misunderstandings. There are many methods and techniques used in research methodology but perhaps most often we can hear about quantitative and qualitative research. Those two types of research differ considerably in their essence. Quantitative research is focused on matters that can be measured or described with mathematical formulas it is a more tangible form of research. An example of its use can be seen when we have a large number of gathered data. In contrary to the Qualitative research focuses on quality of matter or phenomena which cannot be simply described in a quantitative manner. In my master thesis both of those research methodologies are used to gain deeper understanding of the problem and to better answer the research questions.

In this chapter we will describe what kind of research methodology which will be used to be able to produce this master thesis. How the master thesis topic was formulated, and how the whole process has been divided into smaller sub-projects for easier management and estimation. Each of those smaller steps will be discussed, explained, motivated and steps behind it that have been taken to complete it.

## 3.1.FORMULATION OF THE RESEARCH TOPIC

At the beginning of the master thesis the research topic was “Tools and techniques for achieving augmented reality on Android OS”. This in itself was an interesting topic because of the researcher’s interest in developing software on Android devices, and augmented reality is another interesting concept in itself. I already had the knowledge of what augmented reality is but I did not know the inner works behind this mechanism, this was a great opportunity to gain insight into both of those worlds ‘Android’ and ‘augmented reality’. But with this alone it was hard to do a proper research progression because just exploring the mechanisms does not count as a contribution to existing body of knowledge. To contribute some actual knowledge a test of hypothesis of casual relationship between variables in case of learning via new kind of device, was conducted.

In order to fill this requirement and with help of my supervisor we approached learning as major theme and in relation to this theme being able to use an AR learning software which could be implemented on Android device. With this facility there would be room for a real experiment where research questions/hypotheses could be answered using its dependent and independent variables to gain statistical results and answers to those questions/hypotheses. After making some initial assumptions about what this learning application would look like and what could be tested, I have started with a literature review to check if anyone has done similar research in the past. There were some similar cases (Chien-Hsu Chen et al. 2007), (Wagner & Barakonyi 2003), (Jung & Lee 2008) of using AR on mobile devices to facilitate overall learning or just vocabulary learning, but I have not found any research trying to answer the question if there are any benefits to such a learning method.

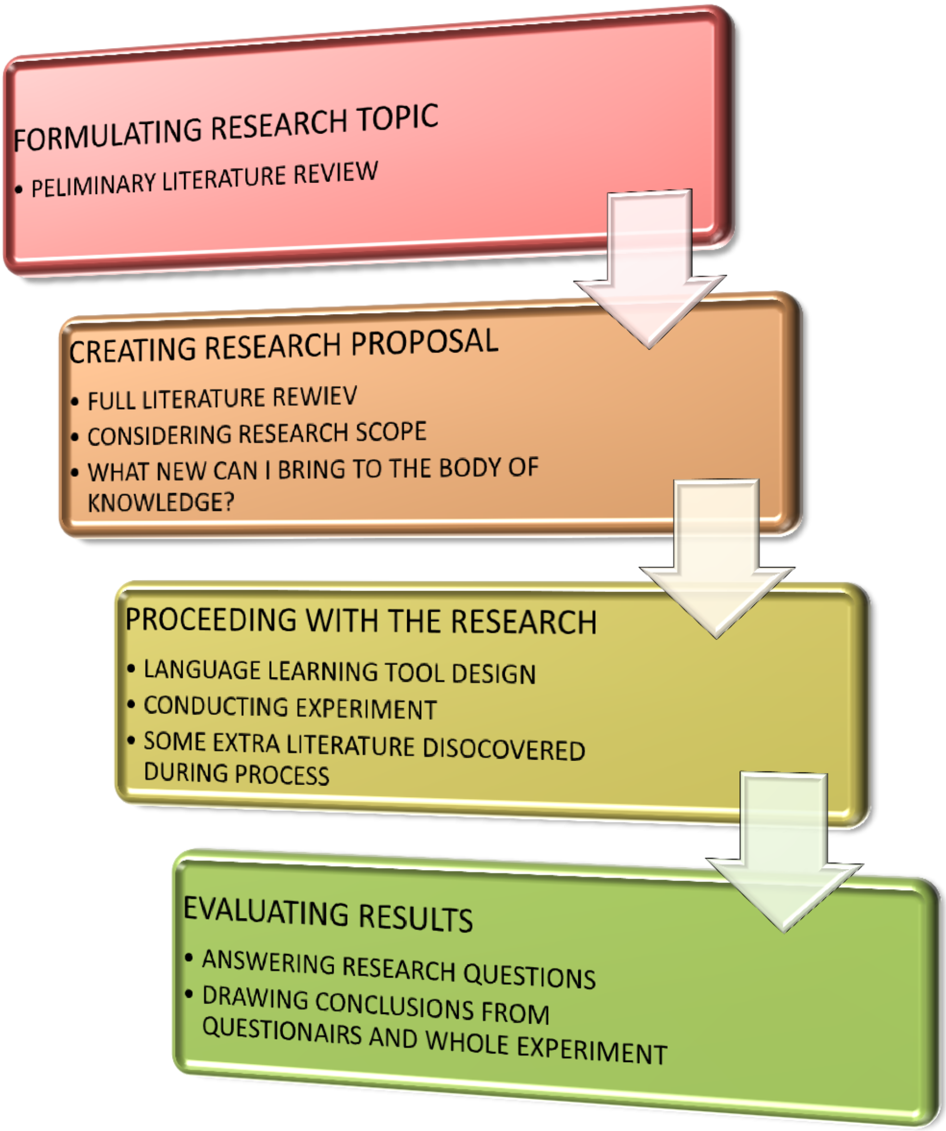



**Figure 2: Decomposing master thesis into smaller parts**

## 3.2. SYSTEMATIC LITERATURE REVIEW

In order to gain better insight into the current body of knowledge of given research area, one needs to perform a systematic literature review or in short SLR. It is one of the most basic methods to gain knowledge and understanding of given topic, and is often a starting point in any research. A good systematic literature review can point a researcher into good direction, shed a light on what was done and what still remains a mystery, it can also protect from making same mistakes as in previous researches. Sometimes just gathering information from SLR is a research itself, by comparing different papers one can draw conclusion from facts that are unavailable for the authors of each paper but when gathered together and compared the papers can introduce some new knowledge.

In my case at the beginning I was searching topics related to language learning, vocabulary learning, augmented reality and Android. Through repeated search and errors, the search criteria were sometimes changed, some papers pointed me into different research directions to get more data. When I have found some interesting papers I have checked its references. If there was an interesting topic related to my research I would add it to searched keywords.

In the whole process of the literature review I have used the following keywords:

- Language Learning
- Vocabulary Learning
- Augmented Reality
- AR
- Mobile Phones

As for the choice of databases to search through research was limited to those that are free to use or that are provided by BTH Library. I have used my previous knowledge from courses like Research Methodology and Advanced Topic in Computer Science to know which databases to use and which are storing computer science papers.

Following databases were used:

- ACM Digital Library
- Google Scholar
- IEEE Xplore Articles

- ISI Web of Science (ISI)
- Springer Link

For a typical search result the ten first paper´s abstracts have been read and later on the whole content of those that have been related to the research was read. During that time answers to some of the previously stated questions were found such as:

- Were there any previous experiments with AR language learning?
- Was there any experiment trying to compare learning efficiency between AR learning and other methods of learning?
- What are the techniques to achieve AR?
- Is AR possible on mobile devices?
- Were there any mobile AR applications developed?

After examining through many papers current “state of the art” in the area of mobile AR became more apparent. Older papers focused just on the topic of Augmented Reality, how it can be achieved and what is needed. There were rare cases dedicated to AR on mobile devices in old papers because those devices did not have enough processing power at that time. Coming up to later papers, there was much more attention paid to mobile AR. Most papers focused on user cases of mobile AR mostly by providing some application that solved a specific task. Some of the newer papers were considering mobile AR as a learning tool but rarely did they provide comparison with other methods of learning. This may be because it is hard to compare such a different method of learning with other more traditional methods. In the examined papers there were some papers dedicated exactly to language learning but they only provided demonstration of use and no hard proof if the solution would be really viable in real world. This was the gap which I decided to explore.

Although the knowledge gained by systematic literature review was valuable it could not answer all research questions. The scope of the Master thesis is to be able to demonstrate or investigate the inner working of a system and/or its limitations so a statistical outcome can show its pros and cons. In providing the basis for interaction with a Language Learning Tool, I also had to find information how to achieve AR. In the investigated papers it was hard to find information about such frameworks. In those cases it was easier to search information on the Internet, outside the academic search engines.

Google Search was one such non-academic search direction and my keywords in these cases yielded better results. Although most of those results were more of commercial use but it was not hard to discover what the AR frameworks were behind those applications.

The process of the literature review did not end although the systematic literature review typically is conducted somewhere at the start of project. At any given time in the master thesis work if something was not clear or required more insight a search on required topic was the basic action taken to find answers. Some new literature was added later in the project when the learning tool was under development, during the experiment or at the end when conclusions were drawn from gathered data.

## 3.3.EXPERIMENT DESIGN

After formulating the research topic and conducting a proper literature review one has quite good understanding what direction to take. The next step is to describe a possible plan in most detail and how you will proceed to accomplish your goals. In this case the goal was to compare how effective AR vocabulary learning could be. In order to make a comparison and compare something you always need to have two or more parts that you can compare with one another.

The first thing in this comparison was to look into traditional learning method. There are quite a few different learning methods but overall I wanted to compare it with methods where you write the vocabulary yourself and learn by reading it through simple repetition also called rote learning. For this part to be more specific and exact it was decided to compare with learning using physical flashcards. This is a good example of traditional learning technique which was used before computers were even used for vocabulary learning.

The second thing was to develop the learning tool, the AR Language Learning Tool. As this application was only a tool to accomplish my goals I decided not to go into too many details with its design and implementation see my polish master thesis for more details: “Android OS jako element systemu Rozszerzonej Rzeczywistości (AR)” (available to read in Wroclaw’s university of technology library). The development had to be very constrained in time so the experiment and it´s analysis could be carried out as well within given timeframe. The main part of my Master thesis is an experiment comparing learning differences between two test groups which relates to my research questions RQ1-RQ4

It is always hard to determine sample size (number of participants) appropriate for an experiment without any prior data. In Mark Mason's review of sample sizes in PhD studies he states that there are many factors which can influence the determination of size of a sample and this is why researchers rarely suggest fixed numbers (Mason 2010). However in the seven guidelines he found there are different suggestions ranging from 5 to 60 samples. In the case of my experiment I decided to bring in 20 participants as this would be a realistic number of participants to find and on the other hand I think this number of participants will be enough to draw some initial conclusions from. The Student's test which I decided to use is designed for small samples n<30. The Student's test is a mathematical tool for hypotheses testing, which allows us to say that certain hypothesis is true with given degree of confidence.

Participants will be divided into two equal groups in which the control group will use a traditional learning method namely flashcards and the other group will use the developed AR learning device. They will be given a constrained time of 15 minutes to learn 20 words in the Spanish language. At first, the time was decided to be 30 minutes but after preliminary testing with some users it was found that most of them were bored or already felt confident in learned vocabulary after about 10 minutes. Hereafter it was decided that 15 minutes would be appropriate not to get participants bored but also to give everyone enough time to learn the material. It was to balance enough material to learn (eg.20 words) but avoiding perfect recall rate. The threshold needed to be set high enough so that the differences in recall rate can be shown.

Immediately after the learning and one week later the participants recall rate was checked by a multiple choice test. This test was based on the Vocabulary Knowledge Scale with some changes to make it more suited for the experiment. By performing Student's t-test on the results of both test groups it was answered if there is any significant difference in recall rate of words for both groups. The test also asked users about their quality of experience, by asking open questions about quality of augmentation, quality of 3D objects, overall advantages compared to classic learning. After the familiarisation with the learning device users answered open questions which were aimed to reveal if they saw any benefits in AR learning tools (RQ4). In the experiment following variables have been distinguished:

1. Independent

    a. Learning Method (traditional flashcards vs. AR device)

2. Dependant

    a. Recall of words (is there any difference in recall between classic and AR learning)

    b. Quality of experience (how users evaluate new learning method compared to classic learning)

3. Controlled

    a. Participants gender (both groups will be divided equally)

    b. Learning time (same for both groups)

    c. Participants age (approximately same in both groups)

    d. Learning material (previously chosen material to learn same for both groups)

    e. Prior experience with learning material (participants who had prior knowledge in the language they will be learning were be excluded from experiment)

For the purpose of the experiment I have gathered 20 participants, as it was mentioned earlier. Most of them are students and have agreed to participate in the experiment. Each of them spent 15 minutes learning vocabulary by one method depending on which group they were assigned to. The most important part when choosing participants was to assure that previously decided controlled variables were met:

**Table 2: Managing controlled variables in experiment**

| | |
|---|---|
| **Participants gender (both groups will be divided equally)** | I managed to create two almost equal groups with 4 females and 6 males in each group. This means that the group weren't equal in gender but in both groups gender ratio was the same |
| **Learning time** | For each participant I have controlled the learning time so that it wasn't longer than 15 minutes, participants were allowed to finish learning faster if they wanted to |
| **Participants age** | Most of the participants were students, although not all. The age of all participants are between 20-26, this ensures that the age difference is not a factor (or minimal) in achieved results |
| **Learning material** | I have chosen 20 Spanish words for learning material |
| **Prior experience with learning material** | Every participant was asked before experiment if he had some prior experience with Spanish language, if so he was disqualified from experiment and replaced by another person |

To evaluate learning of participants I have used and modified the Vocabulary Knowledge Scale. It was introduced by Wesche M. & Paribakht T.S. and is a well-known and established method of assessing learner's vocabulary (Wesche & Paribakht 1996). To use it in my experiment I have modified it by changing the definition of "5 points" on VKS, from "I can use this word in a sentence, e.g.….." to "I know this word and its spelling very well ……" This was needed because my participants had no prior experience with learned language and they could not possibly create sentences knowing words alone. Below is the part of survey responsible for testing participants recall rate, the modified VKS.

### VKS (Vocabulary Knowledge Scale) below:

1. **I don't remember having seen this word before.**
2. **I have seen this word before but I don't know what it means.**
3. **I have seen this word before and I think it means…(fill in English word)**
4. **I know this word: it means…(fill in English word)**
5. **I know this word and its spelling very well…(fill in English word)**

*(ref: Wesche M. & Paribakht T.S. (1996) "Assessing second language vocabulary knowledge: depth versus breadth", The Canadian Modern Language Review 53, 1:28)*

**Table 3: VKS survey**

| Spanish word | 1 to 5 | English word |
|---|---|---|
| Tetera | | |
| Castillo | | |
| Coche | | |
| Guitarra | | |
| Edificio | | |
| Cuchillo | | |
| Hormiga | | |
| Casa | | |
| Serpiente | | |
| Encendedor | | |
| Granada | | |
| Silla | | |
| Rana | | |
| Teléfono | | |
| Reloj | | |
| Martillo | | |
| Submarino | | |
| Libro | | |
| Planta | | |

Participants answered how well they recall each word (using provided below scale) right after experiment and one week later which provided the basic data for further research. Also open questions were added for the participants in the AR device (The Learning Language Tool) group. Below is the table with open questions used in experiment:

**Table 4: Open questions used in VKS survey**

**1 – very negative** **2 – little negative** **3 – neutral**
**4 – little positive** **5 – very positive**

| Question | 1 to 5 | Place for your opinion/remarks |
|---|---|---|
| How would you describe the quality of experience compared to traditional learning methods (e.g. flashcards)? | | |
| Do you think that AR (Augmented Reality) can be a valid form of vocabulary learning? | | |
| What are the benefits of using AR for language learning when compared with traditional methods | N/A | |
| Other comments on AR device or experiment | N/A | |

The full questionnaire used for gathering data from participants can be seen under **Item 1** in Appendix.

## 3.4.PROJECT EVALUATION AND CONCLUSIONS

In case of an experiment with real participants the most valuable data is their feedback provided typically through questionnaire designed by the researcher but optimally with former validated scales. In this case the modified Vocabulary Knowledge Scale questionnaire was used, this questionnaire is used to check learner's level of knowledge for a given word. The VKS was also modified to include open questions about the AR device and its usefulness. This was needed to have data necessary to answer the research questions. In this way the data gathered from the participants are both quantitative (VKS scores learner with 1-5 scale for each word which represent how familiar a learner is with a given word) which allowed to test hypotheses using mathematical reasoning, and qualitative (with open questions that can't really be described in terms of mathematic numbers but are a valuable insight and can also be used to answer research questions). But the researcher's role is also important; depending on methods s/he uses to extract information from acquired data and his/her prior experience in life and/or academic discipline sometimes the drawn conclusion can vary between researchers. Therefore in order to produce reproducible results independent to life versus academic background it is important to use the most unbiased methods as possible and in my opinion statistics and theory of probability should be used when possible, as they provide solid evidence to given fact which later can unambiguously be checked by other researchers.

# 4. IMPLEMANTATION OF LANGUAGE LEARNING APPLICATION

From the learning perspective and to create the AR device which will be used in the experiment, following AR implementation had to be done so the traditional learning method and the AR device could become concretized. This chapter will be a review of available techniques used for achieving AR. This is limited only to techniques which have been implemented on Android OS. Libraries, toolkits, and applications which use given technique are found. Later on in this chapter there will be a description of actual development and the approach taken in that part of the master thesis.

## 4.1.TECHNOLOGIES FOR ACHIEVING AR ON ANDROID DEVICES

In order to achieve AR one typically does not reinvent the technology itself but rather uses already created tools that help out in the process. By the term “technology” in this thesis we understand common and tested ways to solve a particular problem. Tools in this sense usually use this technology but can be implemented in different ways, those tools are materialization of the concept of given technology. An example of technology would be a fiduciary marker which is a special object placed into the field of view for easy recognition by the application. Ronald Azuma distinguishes two types of environment in his paper on augmented reality: prepared and unprepared (Azuma et al. 1999). By the term prepared environment the author describes environments in which the user has full control and can modify it accordingly e.g. by adding AR markers. On the other hand we have unprepared environments which cannot be modified in any way thus requiring more robust and accurate AR methods.

### 4.1.1. FIDUCIAL MARKERS TRACKING

In papers describing AR language learning fiducial markers tracking is the most often used technique to achieve AR. This is one of the easiest to implement techniques and it doesn’t require controlled environment. When user can provide markers for the used application this is the most reliable method to use.

Fiducial markers have been used in many fields of modern science. In AR they are used for easy recognition in the field of view and typically have high contrast. By using them we can not only relate to point in space but we can also calculate distance and the angle at which we look. Typical markers used in AR are black and white squares with geometric figures. The use of black and white gives high contrast compared to background environment and can thus be quickly recognized. Typically every kind of 2D object can be used as a fiducial marker but for better accuracy almost always some kind of distinctive black and white figures are used.


**Figure 3: Sample marker from ARToolkit Source: http://www.artoolworks.com**

A typical AR application that uses fiducial markers technology may support some predefined marker patterns or allow teaching the software new markers. This kind of markers can be printed out by a standard home printer and thus are very cheap to produce and use. The marker is typically used to project some kind of object in its place in the augmented reality view but it can also serve as a global position. One of the obvious downfalls in fiducial markers technology is that they always have to be seen and cannot be obscured by other objects during the augmentation. This problem can be partially alleviated by remembering marker position and refreshing its position accordingly with device movement.

### 4.1.2. HYBRID BASED TRACKING

With hybrid based tracking users could be learning new language by exploring different places that would have some points of interest bound to them or learning sessions. Also the points of interest could be displayed in parallel both in learned and native language.

This kind of tracking usually combines two or more data sources such as GPS, compass, accelerometer to calculate actual position and orientation. The Global Positioning System allows pinpointing current location of the device, with this information we can find objects in our area that are to be augmented. With the use of compass we can tell the direction the device is pointing to and check if that path has any objects to be augmented. The accelerometer is used to calculate orientation of the device using gravitation to its advantage. Combining all information we can calculate what should be augmented in the field of view without any actual processing of the real image but of course the real image is used for placing the layer of augmentation. A good example to this tracking technique is Layar which is a mobile application which shows points of interest based on location and point of view of the user. Layar provides its own API for defining points of interest grouped in so called layers. Anyone can develop their set of interest points and make them accessible to others as a layer in the Layar browser.


**Figure 4: Exemplary Screenshot from Layar application Source: http://androidcommunity.com**

### 4.1.3. MODEL BASED TRACKING

Model based tracking is still a novelty in AR and especially in mobile AR but with its ability to track and recognize objects it would be possible to tag objects in uncontrolled environment with their foreign language name. This could lead to a very efficient method of learning where one needs to just point the phone at the thing which s/he wants to learn in foreign language.

This tracking method is a novel approach and also a current state of art in AR for uncontrolled environments. While the AR in controlled environments seems to be already mature enough for commercial use, uncontrolled environments that require full position tracking in 6 degrees of freedom are still problematic. Without any “certain” points in space with provided markers the prediction of device position is still unreliable with current methods. A model based approach uses prior knowledge of 3D objects in the environment along with their appearance. Using geometrical representation of 3D objects we can manipulate their position and orientation matching them to their counterparts in the field of view. The model based approach has been featured in number of publications such as (Bray 1990), (Stephens 1989), (Lowe & others 1991).

G. Reitmayr and T. W. Drummon provide a good description of when the model based approach is applicable (Reitmayr & Drummond 2006):

*“Model-based tracking approaches appear to be the most promising among the standard vision techniques currently applied in AR applications. While marker-based approaches such as ARToolkit [14] or commercial tracking systems such as ART provide a robust and stable solution for controlled environments, it is not feasible to equip a larger outdoor space with fiducial markers. Hence, any such system has to rely on models of natural features such as architectural lines or feature points extracted from reference images.”*

As they state this approach it is currently one of the most promising for uncontrolled environments, typically outdoors. In most cases model approach works using edge detection for construction of 3D models, in some cases the model is provided to track resemblance in relation to its object in the environment e.g. tracking a moving car on a street. This approach usually requires much more processing power than previously mentioned ones but with proper optimisations and assumptions there have been cases of implementation on mobile devices.

#### 4.1.4. NATURAL FUTURE TRACKING

This is another technique for achieving AR which in context of language learning can be seen as an extension to fiducial markers. It allows using objects in real world as markers by recognizing their natural characteristics; therefore it provides the same possibilities as fiducial marker when it comes to language learning.

Natural future tracking is one of the methods that work for uncontrolled environments. In it we find “interesting futures” of the image that are highly distinguishable typically based on some mathematical algorithm. Then the “future descriptor" of given image is saved for further recognition. Based on this future set we can recognize the same image from different distances, orientation, and illumination levels even with some occlusion as the descriptor is invariant to those changes. One of the leading researchers in this area David Lowe introduced Scale-invariant feature transform (SIFT) a well-known algorithm for natural future tracking (Lowe 1999). There are a number of different algorithms that provide scale invariant object recognition that focus in some concrete applications. Speed Up Robust Future (SURF) is another algorithm that uses future tracking, it was first presented in 2006 (Bay et al. 2006). Researches indicate that SURF provides similar performance to SIFT but is faster to compute. There have been also natural future algorithms designed specifically to work with constraints of mobile devices in mind, such an algorithm was presented in "Pose tracking from natural features on mobile phones" (Wagner et al. 2008).

## 4.2.LEARNING APPLICATION DESIGN AND IMPLEMENTATION

The purpose of this language tool is to be able to see how such a tool can be used and how people may perceive it in relation to former experience of language learning processes. In the process of Language Learning Tool design in this study I started out with three main requirements which needed to be fulfilled in order to guarantee a successful development and to finish the development with a useful learning device:

- Free for non-commercial purposes – all the components used in the AR device should be free to use so no laws are broken. Only free to use on at least non-commercial or private level materials should be used. Furthermore if some components are free only for non-commercial use application should never be published commercially on internet, Google Play, or other similar places.

- Quick Development – this is a demo tool to be used in the experiment and as such it shouldn't take too much time from the overall master thesis work. Because of this well documented frameworks with ease to use were preferred.

- Stable, Reliable, Well Documented – to develop quickly on needs well documented stable and reliable software, in most cases this disqualified small or community maintained frameworks for achieving AR. In most cases the best software quality comes from big companies with well-established development process, and great quality documentation. In most cases this also meant some kind of constraint in use of such software, in most cases it was somehow limited (in functionality, time of free use)

Meeting those requirements limited choice of available frameworks as most of them had some limitation such as watermarks or paid license to use. But one of well-established AR frameworks came absolutely free for commercial and non-commercial use. It was Vuforia SDK, it met all requirements being a well-developed framework with a big company name behind it (Qualcomm). This framework has benefits of great documentation and stable software, the team behind it puts real effort for it to be competitive on mobile market. It has been used in more than hundred mobile applications with most emphasis on games. Associated with it is Vuforia Developer's Portal (https://ar.qualcomm.at/qdevnet/projects) on which we create our trackable markers to be further used in the learning tool. To create a "trackable" we need to provide an image and width of the real marker, the software will then calculate the height by itself using the image height to width ratio. After providing that information the software will use its algorithm to find points of interest in the image (typically high contrast points for easy recognition) and will provide you with a 5 star score of how good the provided image for purpose of tracking is. After the image is processed you can download it in two forms one is for standalone use with Vuforia source code, and the other one is in form of Unity package with all necessary components to track the image in the Unity engine.

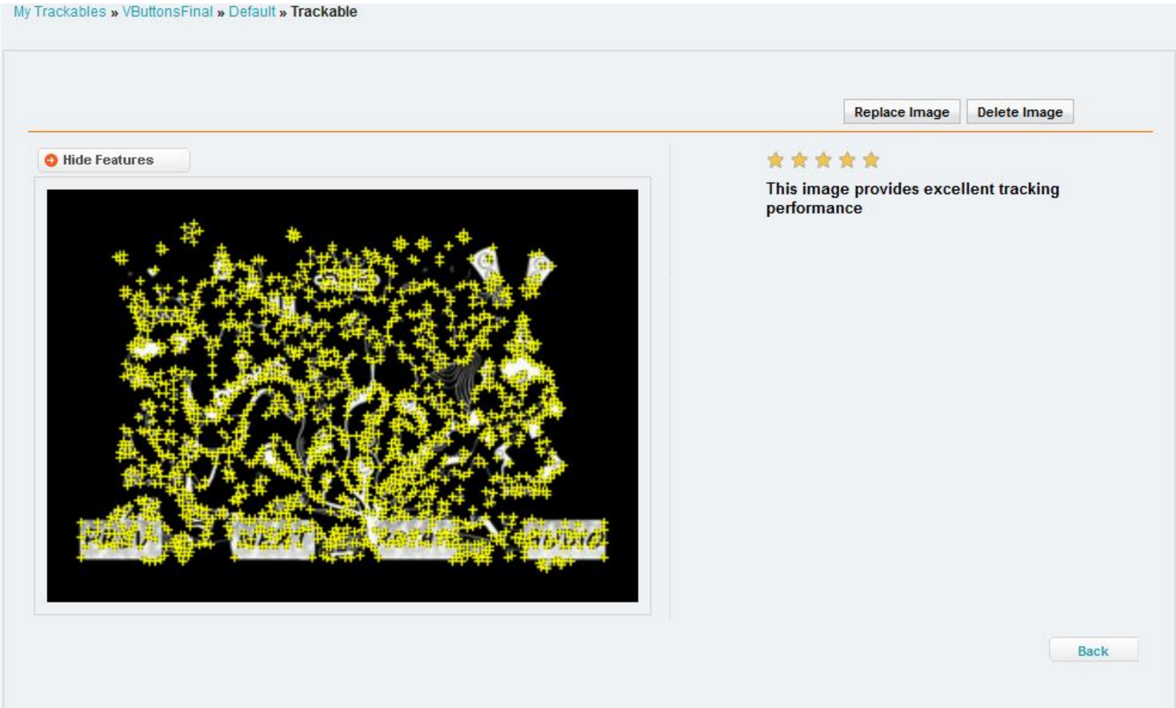



**Figure 5: Vuforia Developer portal - assessing value of new trackable**

Another great feature which really caught my attention was the ability to use virtual buttons which can act as real physical buttons compared to a user interface displayed on screen of the phone. It is a feature provided in Vuforia SDK and works by detecting an occlusion point on the whole marker. If the system recognizes the overall marker by its characteristic point but the part with the button is unrecognizable it assumes that the button is pressed and therefore covered by something else.


**Figure 6: Screenshot of application - virtual buttons on physical marker for interaction with user**

But the framework for AR was not enough alone to smoothly create a demo learning tool. Alone it was enough to recognize the marker by the phone's camera and place it accordingly in OpenGL 3D space. But this would mean that I had to manage the 3D scene by myself, write proper loaders for 3D models, 3D subtitles, handle the objects textures and lighting and also worry about sound effects. This would mean at least 1 month of solid developer work for which really wasn't in focus for this master thesis. Because of that I decided to use another framework namely a game engine to speed up the development process.

Luckily Vuroria is not only distributed as a standalone source to compile for Android and iOS, it is also provided in form of a plugin for the Unity 3D game engine. Unity 3D is a game focused engine or rather a whole development environment and it allows a developer to create applications that are mostly platform independent. The development environment is supported by Windows, Mac OS and platforms for which you can deploy applications starting from Windows and Mac but end at Playstation3, Xbox 360, Wii, IPhone and Android. One of the biggest questions was if the Unity 3D was free to use for non-commercial purposes. Luckily it was and because of that I decided to combine both Vuforia SDK and Unity 3D in the development of my demo tool.

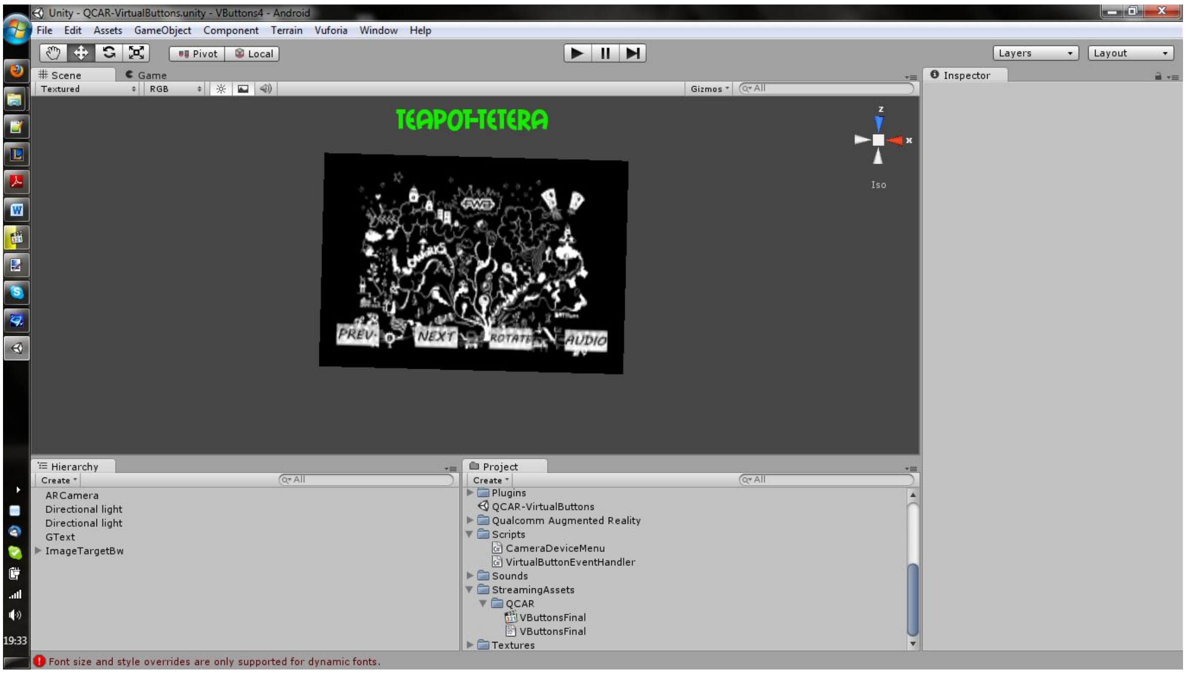



**Figure 7: Development of demo application in Unity 3D**

Combining those two frameworks I had to create my demo learning tool but I still needed content to use for vocabulary learning. I needed 3D models with textures, and also sound of a Spanish lector reading those words. For those two resources I also needed materials that were free at least for non-commercial use.

For 3D models along with textures I found a web service called Turbo Squid (http://www.turbosquid.com/), it is a web service which provides a market for 3D objects creators and buyers. There is a sophisticated system to sort models by price or format they are provided in. For my purposes I was searching for free objects that had texture and preferably in .obj format which can be easily loaded into OpenGL or are in .blend format which is specific to Blender™ software which is a very popular free tool for 3D modelling and animation. As for the quality of free models I must say that it wasn't always the best you could find on the web but with proper search you could find really interesting models that had textures provided and were quite detailed. Increasing the search scope to also

.blend objects helped a lot too because it widened my possibilities for 3D model sources. All 20 3D models used in the demo learning application were taken from TurboSquid website and were free to use.

For the sound effects I have decided to use Google Translator's built in feature of reading translated text. Google Translator is also open source software and its reading service can be used for free in non-commercial purpose. The sound files were recorded in .mp3 files and later on further compressed by the Unity engine.

Having all the necessary resources to create the demo learning tool, I've started the development with deploying Vuforia's VirtualButtons example application. After familiarising myself a little with the source code and Unity IDE, the first thing I've decided to change was to add another 3D object to the starting "Teapot model" that was provided. I found a model of a castle which was added next to the demo application. One of the problems was to hide and show 3D objects in Unity and to do that you have to iterate over all its children objects (each object can have its child objects in a tree like structure, one 3D model typically consists of many smaller 3d objects which are its children) which was not that clearly explained in the Unity documentation. For programming in Unity I have used C# language as it was set by default but one can also use JavaScript and Boo. After familiarising myself with how virtual buttons work and how to add new objects I've decided to add a user interface and screen buttons because although AR buttons were fun to use they tended some times to be unreliable or just tiring to use. Another step in creating the language learning application was to find an appropriate marker for the software to track. For that purpose I looked through webpages with free wallpapers to find a suitable image for functioning as a marker. During the development it became obvious that the tracking software recognized the black and white images better than the coloured ones. Also the tracking preferred high contrast rather than blurry images. The choice fell on graffiti like image with high contrasts to be used as a marker for the software. I had to edit this image and add a visible place for the virtual buttons.


**Figure 8: Final marker with augmented buttons used in demo application**

At the time I finished the following tasks in the Language Learning Tool development:

- Find a suitable marker for software to track and add virtual buttons
- Find 20 objects to be used in Spanish vocabulary learning integrate them into the project scale them and place accordingly in the AR view
- Record sound for those 20 objects using Google Translate, normalize the recorded sound and bind it to 3D objects
- Add touch interface as a second mean to interact with application, as the virtual buttons although were funny and interesting to use were not always reliable
- Tested the application with some friends to get early feedback and do some improvements

With above subparts finished I decided that it was time to end development and focus on the other part which is the experiment where my variables are of great concern. The Language Learning Tool design was closed at this point and no future improvements were made even if some major flaws were to be discovered, the reason for this was to provide every user from the experiment group with exactly the same piece of software and therefore not to introduce any bias into the experiment.

To better understand the application and how it works, below are some exemplary screenshots demonstrating the user interface and learned words. With the help of buttons placed in the corners user can interact with the application, rotate the 3d object, listen to lector's pronunciation, or change to next/previous object. The same functionality is provided also with augmented buttons which are visible on the marker, to use them user simply touches the virtual buttons on marker. Additionally application is aware of its orientation and rotates screen accordingly to current orientation. User can also set camera focus by touching the lower part of phone screen between the next/previous buttons.


**Figure 9: Exemplary screenshot demonstrating word Chair**


**Figure 10: Exemplary screenshot demonstrating word Frog**

# 5. EXPERIMENT RESULTS

As a part of contribution to the body of knowledge it was chosen to compare if there were any significant learning differences when learning foreign language vocabulary when using two different learning methods. For that comparison the mobile augmented reality tool and a standard learning method with flashcards were used. Primary motive was to test if there were any significant differences in vocabulary recall rate just after the experiment was done (short term memory) and one week later (long term memory). To do this a mathematical analysis was conducted on gathered data to disapprove a null hypothesis which could show that there was negative or no difference when learning with an AR device when comparing learning with flashcards.

After the data was gathered it was time to organize it in a logical matter and start to infer some knowledge from it. I started by creating an excel workbook where I have created tables that summed up scores from all participants in both test groups. The whole table with detailed score for each participant can be seen under **Item 2** and **Item 3** in Appendix. Here I present a smaller table with summed up scores for each participant.

**Table 5: Summarized experiment results**

| AR Language Learning Tool | | | | | Flashcards | | |
|---|---|---|---|---|---|---|---|
| Person NR | After learning | 1 week later | Question 1 | Question 2 | Person NR | After learning | 1 week later |
| 1 | 97 | 100 | 5 | 5 | 1 | 100 | 94 |
| 2 | 87 | 88 | 5 | 5 | 2 | 100 | 64 |
| 3 | 94 | 86 | 4 | 5 | 3 | 83 | 77 |
| 4 | 91 | 88 | 5 | 5 | 4 | 39 | 39 |
| 5 | 91 | 87 | 5 | 5 | 5 | 76 | 59 |
| 6 | 64 | 61 | 4 | 4 | 6 | 93 | 75 |
| 7 | 66 | 61 | 4 | 4 | 7 | 77 | 63 |
| 8 | 77 | 70 | 4 | 4 | 8 | 83 | 70 |
| 9 | 89 | 88 | 5 | 5 | 9 | 95 | 80 |
| 10 | 92 | 86 | 3 | 5 | 10 | 79 | 72 |

In this form it is rather hard to put forward any conclusions. We can only say that in most cases the AR Language Learning Tool users gave positive feedback to questions 1 and 2. Also the fourth person in the Flashcard group seems to stand out in a negative way but he shows no deterioration in his recall rate 1 week later. In case of the AR Language Learning Tool users Person nr 1 and 2 demonstrated higher recall rate 1 week later than right after the experiment, with an increase of 3 respectively 1 point. To understand the data more deeply I have created graphs demonstrating average recall rate for each word after experiment and 1 week later for both groups.

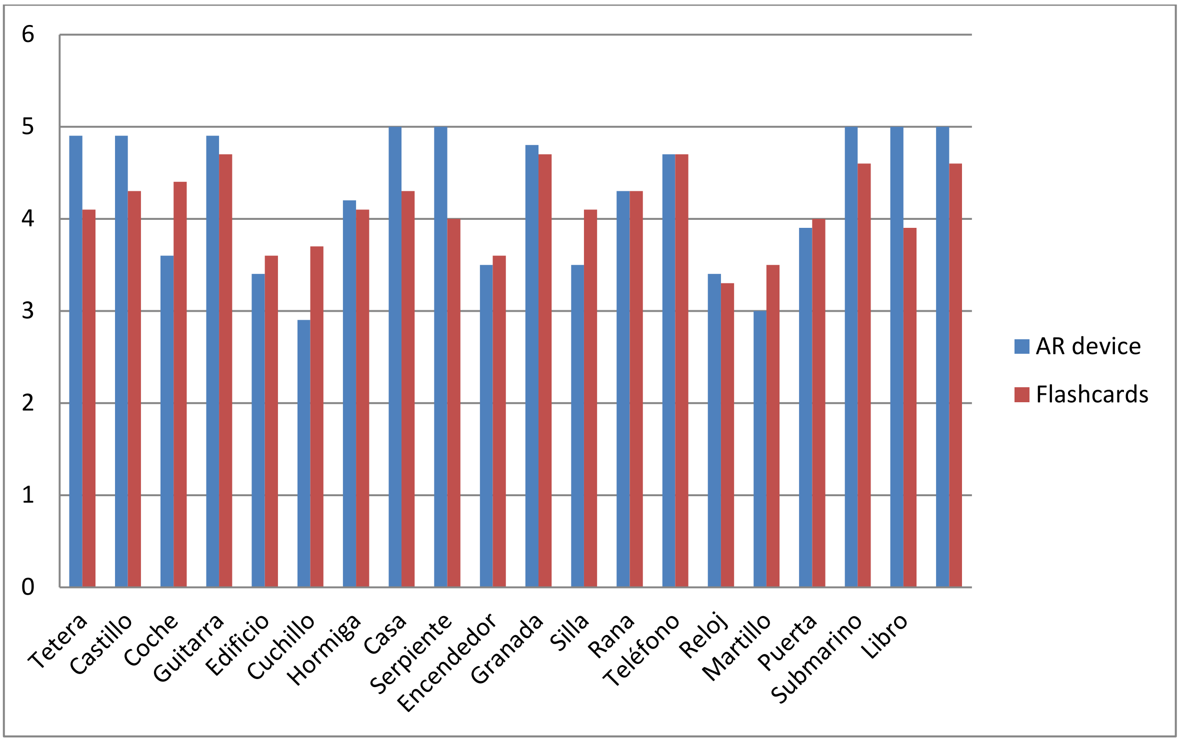



**Figure 11: Average score for each word after experiment**

Here we can see the difference in average score right after the experiment. The AR Language Learning Tool group has higher score in 11 cases but for two cases “Rana” and “Teléfono” the average for both groups are the same. This means that the Flashcards group had higher scores in 7 cases. This could give us a weak feeling that learning with flashcards give better results. To discover if there really is any statistical difference between the average score of those two populations we will use Student’s t-test.

What we are interested in is the average difference in score between those two populations. We will denote this parameter as$\mu_D$:

$$\mu_D = \mu_1 - \mu_2 \quad (1)$$

Where $\mu_1$ is an average score in the AR Language Learning Tool population and $\mu_2$ is an average score in Flashcards population. These values should not be confused with average of our test group as they represent a whole population not just our test groups. We will also define two hypotheses:

$$H_0 \colon \mu_D \leq 0, \tag{2}$$

$$H_1 \colon \mu_D > 0 \tag{3}$$

$H_0$ is also called a null hypothesis, stating that the difference is less or equal to 0 which would mean that the AR Language Learning Tool group score is worse or the same as the Flashcard group. This would mean that there is none or a negative impact in learning with AR device when comparing with flashcards. In contrary $H_1$ states that there is a positive difference between both averages which would mean that there would be a real "learning boost" when using the AR Language Learning Tool..

To test those hypotheses I will use Independent two sample t-test, this test is valid only if we assume two requirements:

- the two sample sizes (that is, the number, n, of participants of each group) are equal;
- it is assumed that the two distributions have the same variance.

Under those assumptions the T statistic can be calculated as follows:

$$t = \frac{(\bar{x}_1 - \bar{x}_2) - \mu_D}{\sqrt{\frac{s_1^2 + s_2^2}{n}}} \tag{4}$$

Where $\bar{x}_1$ and $\bar{x}_2$ are average from our test groups and $s_1$ and $s_2$ are standard deviations from our test groups, n denotes number of participants. We will also take statistical significance at level $p = 0.05$ which means that we are willing to reject null hypothesis with 95% confidence. This means that we are agreeing to have 5% chance of committing Type 1 error which is discarding null hypothesis while in fact it is true.

$$t = \frac{(\bar{x}_1 - \bar{x}_2) - \mu_D}{\sqrt{\frac{s_1^2 + s_2^2}{n}}} = \frac{(84{,}9 - 82{,}5) - 0}{\sqrt{\frac{11{,}72319638^2 + 17{,}81541156^2}{10}}} = 0{,}355869201 \quad (5)$$

Now if we use mathematical tables for Student's T test we can check the $p$ value or better calculate it in excel using T.TEST macro. For this $t$ and one tailed test $p = 0{,}363037581 \approx 0{,}363$ this is way higher than our assumed significance level of 0,05 and therefore we cannot reject hypothesis $H_0$. This means that there is probably no significant difference in recall rate between two test groups right after the experiment.

But the more interesting part is to compare average scores 1 week after experiment. I suspect that AR which allows using more senses and interacting with the device will yield better results in long term. This graph is analogical to previous one but has average values from 1 week after the experiment.

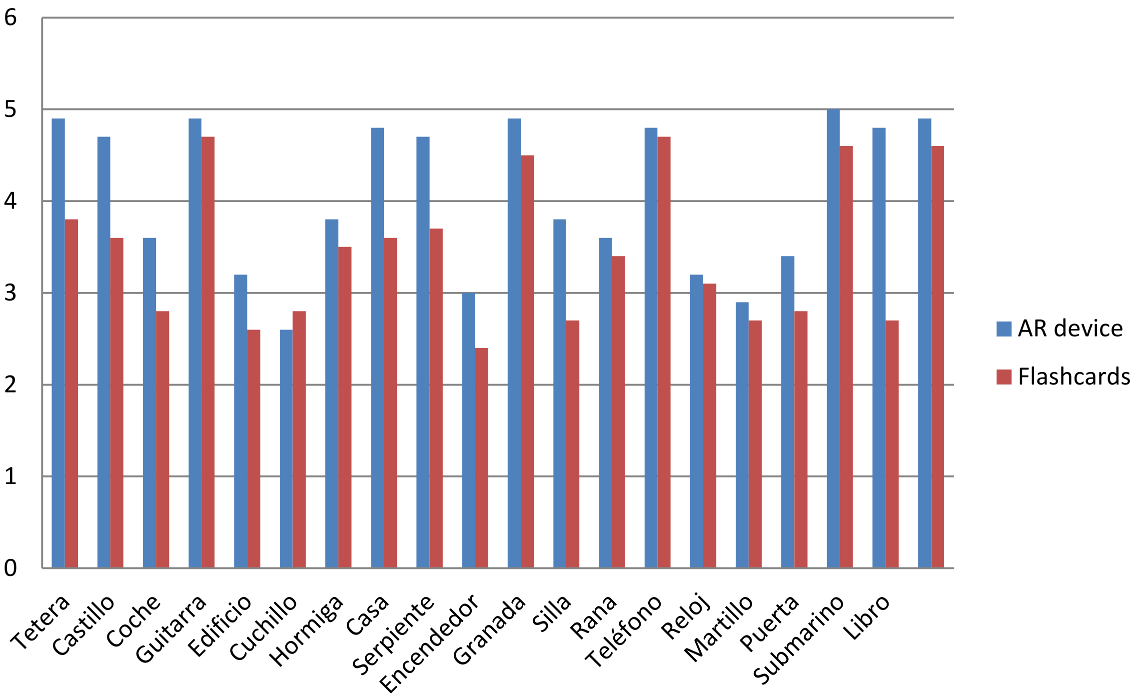



**Figure 12: Average score for each word one week after experiment**

As we can see this time the AR Language Learning Tool group has much higher scores in some cases. There is only 1 word for which the Flashcard group had higher score and that is “Cuchillo – Knife”, this time it looks like there might be real difference between those two groups. To check this I will again use Student’s T Test.

Now I will calculate the $p$ value using the same formula as in previous case but this time I will be checking if there is any statistical difference between means in both groups recall rate 1 week after the learning. I will use the same statistical significance level of $p = 0.05$

$$t = \frac{(\bar{x}_1 - \bar{x}_2) - \mu_D}{\sqrt{\frac{s_1^2 + s_2^2}{n}}} = \frac{(81{,}5 - 69{,}3) - 0}{\sqrt{\frac{12{,}963624322^2 + 14{,}59109317^2}{10}}} = 1{,}976617677 \quad (6)$$

If we now reed the $p$ value from the mathematical tables for 1 sided T test or use excel to calculate this we get $p = 0{,}031805879 \approx 0{,}031$ this is below our significance level and therefore we reject null hypothesis $H_0$ in favour to $H_1$ hypothesis. This means that there probably is a difference in vocabulary recall rate in favour of the AR Language Learning Tool group when the long term memory is considered.

When we simply compare average from both groups it becomes more apparent that there is bigger difference in recall rate one week later than just after the experiment. From this and previous results of Student’s Test I can reason that AR vocabulary learning yields better results mainly because it allows for more senses to be used and there is more interaction and interest from user than compared to flashcards.

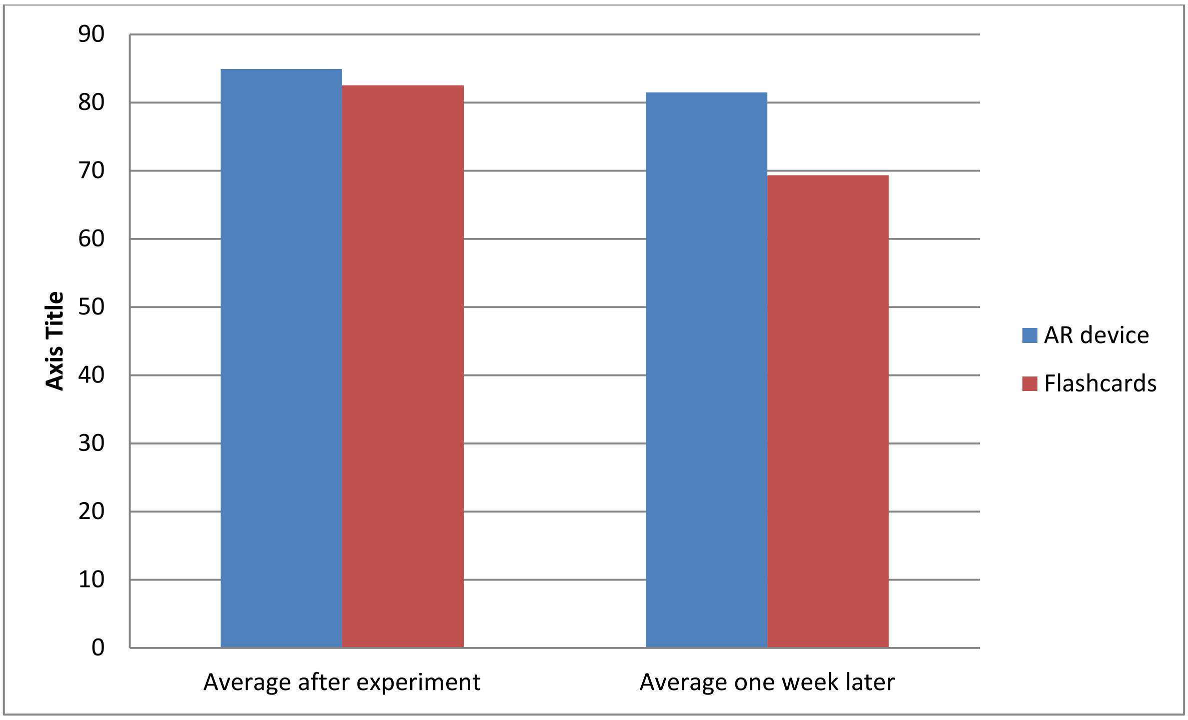



**Figure 13: Average experiment score after experiment and one week later**

Another interesting thing is to look at the average score of each word but with sorted data. This way we can see which words had highest score (were easiest to remember) and which ones had lowest score. Data was sorted according to the AR Language Learning Tool group score and the results are shown below:

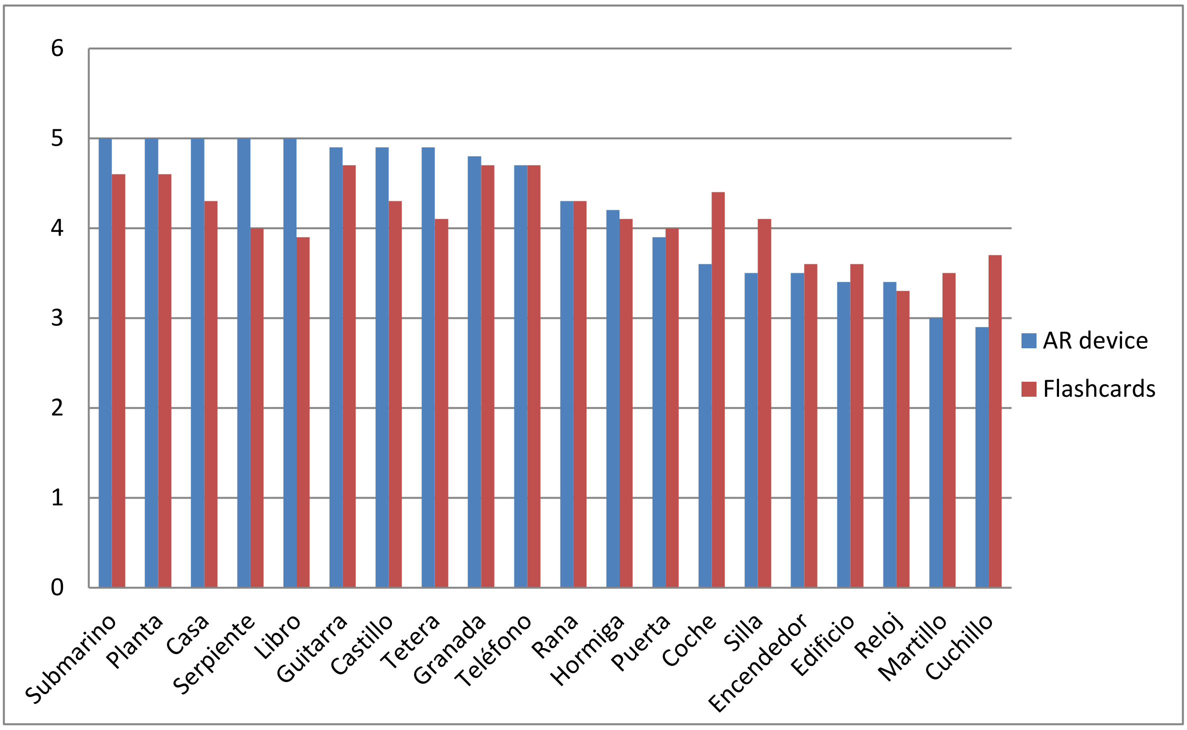



**Figure 14: Average score for each word after experiment (sorted)**

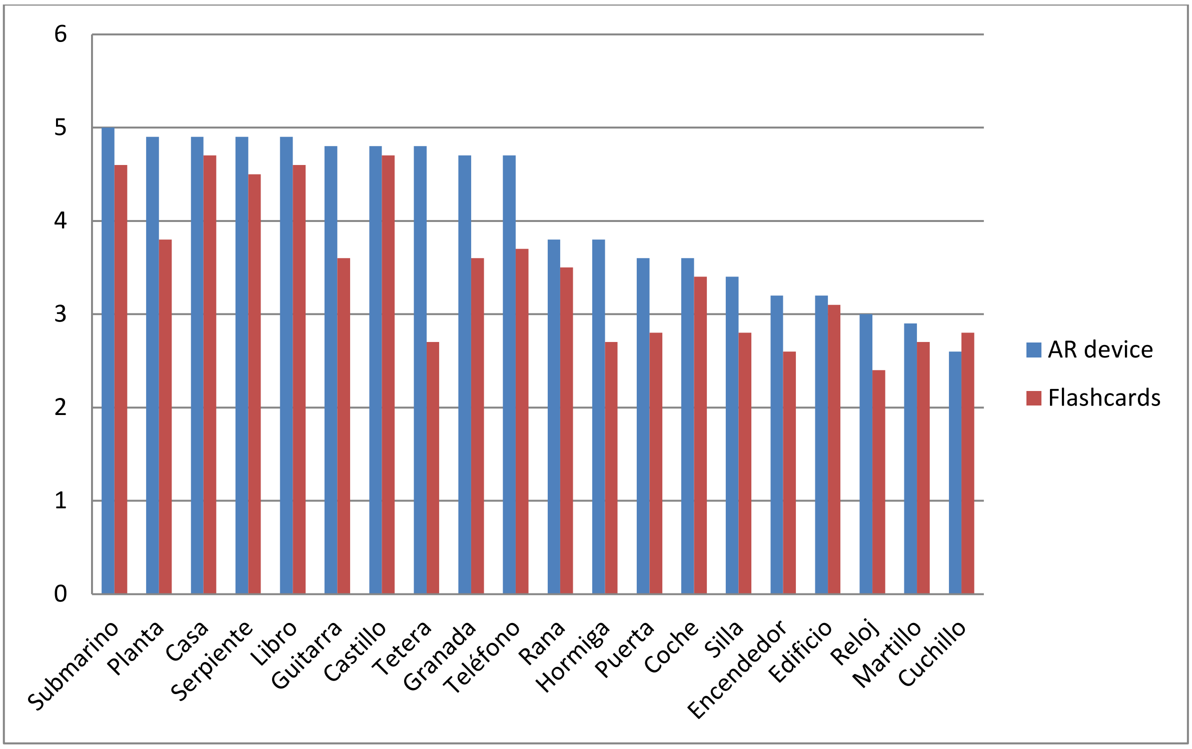



**Figure 15: Average score for each word one week after experiment (sorted)**

As we can see words that have similar spelling to their English counterparts score much higher. For example "Submarino" or "Guitarra" are pretty easy to remember because of their similarity to English words. On the other hand words such as "Cuchillo" or "Reloj" do not cause any association with their English meaning. The survey was constructed in such a way that it contains a mix of easy and hard words to remember. Using this information as an input we could also classify words on a scale describing how difficult they are to learn.

Another thing which should be discussed in the experiment results are open questions answers from the AR Language Learning Tool test group. Their content was as follows:

1. How would you describe the quality of experience compared to traditional learning methods (e.g. flashcards)?
2. Do you think that AR (Augmented Reality) can be a valid form of vocabulary learning? (even though this is an Yes OR No answer it stills remain here).
3. What are the benefits of using AR for language learning when compared with traditional methods
4. Other comments on the AR Language Learning Tool or experiment

For questions 1 and 2 in addition to open question there was also a 1 to 5 scale with corresponding meaning:

- 1 – very negative
- 2 – little negative
- 3 – neutral
- 4 – little positive
- 5 – very positive

The questions due to large amount of answers will be discussed in a summarized manner. Full answers to open questions can be found in Appendix under Item 4. For questions 1 and 2 there were also a scale from 1 to 5. I have created a histogram to better illustrate the results.

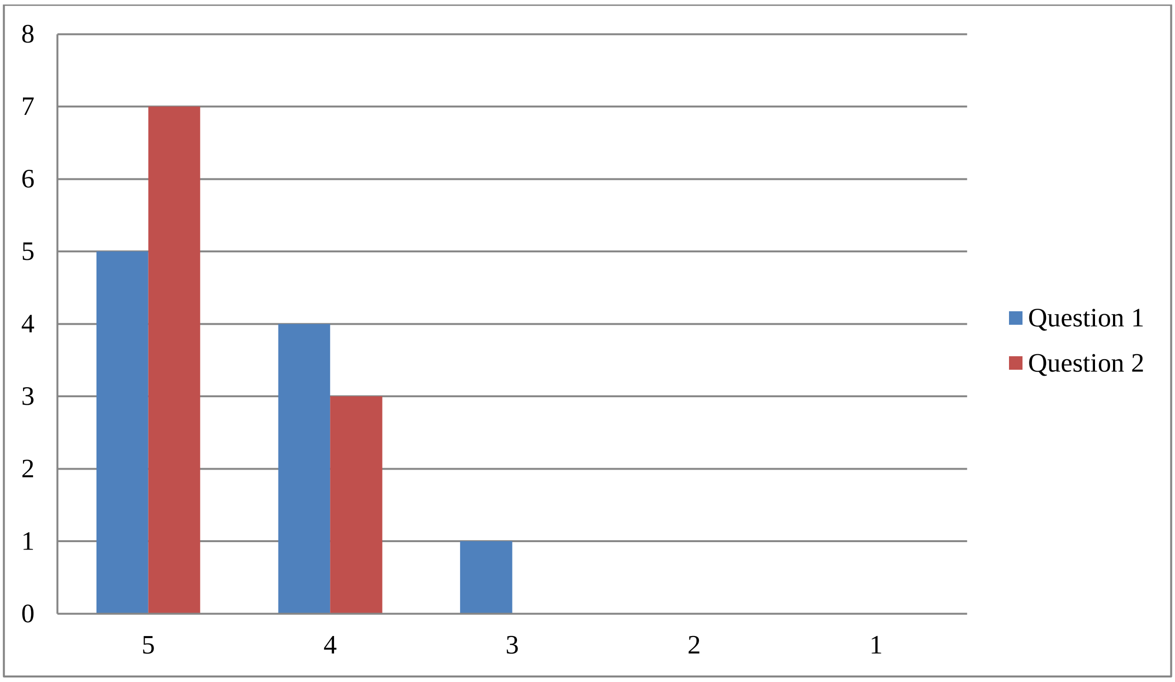



**Figure 16: Open questions histogram**

Almost all users were at least positive or very positive in their answers to question 1 and 2. One user was neutral in question 1; no users have been negative when it comes to both questions. Also question 2 has scored more points.

**Question 1 asked users about their quality of experience compared to traditional learning.**

Here people mentioned that it is interesting to see new technology and interact with it but some were also concerned with paying too much attention to animation and having fun instead of learning. Some people mentioned that it is easier to prepare than flashcards and you almost always have your phone with you. I think that downloading the language learning application from Google store is a lot easier than preparing flashcards by yourself. The tenth person was concerned with the overall quality of the AR Language Learning Tool which could allow for more interaction with user. A positive feedback was also that it worked intuitively. Users can interact with the device, interactively watch and hear the objects that they are learning; this stimulates imagination and facilitates remembering new words.

**Question 2 asked users if they find AR a valid form of vocabulary learning based on their experience with demo application.**

Here we had consensus between users that AR vocabulary learning is plausible with the provided device. Some of them answered laconically with just “yes” or “I think it can be” while others had more input to add. This also points out that the questions should have been better constructed (this is important and shall be elaborated in a deeper sense), to encourage more rich response. Users mentioned that 3D image; sound and interaction help to facilitate learning and not to get bored too quickly. Again some people were concerned that the demo AR device was not polished enough. This was expected because created the AR Language Learning Tool was just a demo, and there was no extra time for additional iterations in application development. Also AR especially in mobile form was mentioned as more convenient than standard notebook or flashcards.

**Question 3 asked about real benefits of using AR when compared with traditional learning methods.**

Here most people mentioned the benefit of using additional senses in their learning experience which facilitated easier remembering and was less boring. Also some people mentioned that it was more comfortable as they didn´t need to prepare any notes or flashcards and typically they had their phone with them.

**Question 4 was answered only by two participants it was provided to compensate for any feedback not accounted by previous questions.**

Both persons which answered this question (others have left this field blank) expressed concerns with application functionality. The first person wanted the 3D objects to be animated and provide additional interaction with user. The second person said that this could be much more advanced application with more functionality. Their concerns are valid and understandable but their implementation lies beyond scope of this master thesis. However it is good to see that the users are interested enough to express and wanting improvements.

# 6. CONCLUSIONS AND FUTURE WORK

## 6.1.CONCLUSIONS

Everything done in this master thesis was to create research questions in relation to the AR language learning interest. The learning device had to be created and developed as a standalone learning tool. I am quite happy with the work that was done and honestly feel that I can provide meaningful answers to my research questions.

**R.Q.1: Is AR valid option for language learning?**

All the data provided in here such as positive user feedback, implementation of working application, and better results in the AR Language Learning Tool group point me to a strong "YES" as an answer to this question. Every user of the mobile AR device was somehow intrigued by the possibilities it bring or just happy with comfort of learning s/he gets. With tools that are available for the developers today AR is not that hard to achieve for a competent team of developers and good polished applications can be developed in matter of months. Also the statistically significant difference in average recall rate in favour of mobile AR group points out that it is a good and valid method of learning.

**R.Q.2: Is the quality of experience higher than in traditional learning?**

Answer to this question is based mostly on feedback from open questions and my experience with the device. Users find the quality higher because of realistic 3D models and sound effects; the AR device provides them with virtual environment with which they can interact. When compared with traditional learning users don't get bored so fast and are happier that they don't have to tediously prepare by either taking notes or making flashcards. This all creates a higher quality of experience for them. For those interested in seeing the working device I provide a YouTube link: http://www.youtube.com/watch?v=j6SBKz2NS5Y&feature=youtu.be unfortunately because of the recording, overall device performance is slower and also I wasn't able to record sound.

**R.Q.3: Does the use of AR for language learning yield different results than traditional methods?**

After performing the statistical tests I can say with high confidence that recall rate is indeed higher in long term memory (LTM) for the user of mobile AR device than the

Flashcards group. I can suspect that the result would be the same when compared to other traditional learning methods. The main reason why AR device users have a higher score is in my opinion the use of more senses when learning and overall having more fun than learning your vocabulary as a tedious chore. The more senses we use and the more attention we can allocate via those senses when learning our score will improve.

**R.Q.4: Are there any benefits of using AR for language learning?**

This answer is based mostly on a group input and my interaction with AR. The most commonly mentioned benefit was the use of more senses; this is natural as we typically augment visual and sound effects of our surrounding. Another mentioned benefit was that you can interact with the AR Language Learning Tool by augmented buttons. In the demo this was simply used for changing words, playing sound and rotating objects but this could be taken to a whole new level where the user is really occupied with interaction. Many users mentioned also that this is something new to them and entertaining and if someone can have fun while learning s/he will most definitely do it more often that s/he would otherwise not. Benefits such as ease to use or convenience of having the AR device always with you are not exclusive to AR but certainly can be a part of the whole Language Learning Tool/experience. Finding many benefits with such ease means in my opinion that there is a real potential in AR and especially mobile AR when it comes to vocabulary learning or rather overall learning as it can be applied with ease to other areas of life.

## 6.2.FUTURE WORK

Another part of finishing a research is finding it weak spots that have not been covered but could be interesting to check out further. In my case some parts of the future work are easily identifiable while others are not. Also with the help of my opposition during master thesis defence some new future work came to light.

**More polished and advanced AR Language Learning Tool**

This point was mentioned by some of the users. There are many ways one can improve the presented mobile learning tool. One of the things to do, could be adding much more content such as adding more Spanish words or extending the software to support other languages. Another thing would be adding more interaction with the user in some entertaining ways. It could be a virtual game with just simple poking of objects which could trigger some interaction with AR. Next thing would be learning modes which there could be plenty where we could divide words into thematic subgroups or maybe group them by difficulty or level of exam on which they appear. Another thing to think about is identifying the user of the AR Language Learning Tool and allowing him/her to make his own changes in the setting and this could be synchronized between application instances by some external cloud service. Also adding some socializing forms to the AR Language Learning Tool like posting your learned words on Twitter or being able to share learning material on Facebook could be a meaningful addition for users.

**Repeating experiment for other language/ languages**

It would be interesting to see if the experiment results hold true for other languages or improve languages. This could provide more data to answer research questions and maybe tell the future developers of such Language Learning Device at which markets their software will give best results to its users. It would also be interesting to identify language differences or maybe people differences which cause different results in experiment.

**Repeating experiment with larger experiment groups**

The bigger the experiment groups are the more statistically significant data we get, and we can infer more accurately about the general population. For example test groups that are larger than $n > 30$ people are typically considered “big enough” to use normal distribution instead of student’s t distribution. Also larger groups make more impact when presenting data, and can be used to persuade let’s say a software company to invest their money into mobile AR vocabulary learning.

**Designing more sophisticated experiment running longer time and with more learning / measuring performance sessions.**

Another way of improving the experiment and gathering more interesting data would be to prolong the experiment period and add more learning material to the sessions. In that time users long term memory could be better tested after some longer period of time for example 2, 3 weeks. Also by adding additional learning materials we could test if there were any significant differences not just only in score but in learning capacity between both learning groups. There are also different things which we could test for in a longitudinal experiment. For example is there any difference between forgetting words in both test groups. How long learning sessions should be to be optimal or how many new words or sentences should there be in each learning session.

**Comparing AR Language Learning Tool with other types of learning methods.**

As it was pointed out during my master thesis opposition, physical flashcards are not the state of the art when it comes to learning methods. There are different types of learning techniques which provide interaction with more senses; a good example would be electronic flashcards which also can provide sound, image or video. There are many learning techniques so this could be taken in many different directions, but the main point would be to compare my AR Language Learning Tool with more modern learning techniques, to check if there would be any major differences in results.

**Exploring into negative aspects of using MAR.**

This was not considered much during the master thesis, but it is a valid topic to explore. One of the major downfalls of presented AR application was that it required a printed marker in order to gain orientation in space. This certain AR technique was used due to the ease of implementation, but as it was mentioned earlier there are different techniques to achieve AR, some of them don't require prepared environment to work properly. This is just one negative aspect, and with further research I think that more of them would come to surface. It is important to consider those negative aspects especially in longer term, as they may make this learning method impractical or not really usable in real world.

One thing that was brought up during my master thesis opposition was about storing the 3D models used in application. What would happen if the application had up to 10 000 3D models? I think that this problem is not exclusive to AR application, but exists in any application storing 3D models. In reality those models don't require much space and storing around 10 000 should be possible with space available on modern smarthpones.

# APPENDIX

**Item 1: VKS survey**

Name:......................
Age:……………………..
Date:……………………..

## Activity

After 15 minutes of learning, look at the following list of words and give each one a number rating from 1 to 5 based on how well you know the word.

Look at the VKS (Vocabulary Knowledge Scale) below:

1. **I don't remember having seen this word before.**
2. **I have seen this word before but I don't know what it means.**
3. **I have seen this word before and I think it means…(fill in English word)**
4. **I know this word: it means…(fill in English word)**
5. **I know this word and its spelling very well…(fill in English word)**

*(ref: Wesche M. & Paribakht T.S. (1996) "Assessing second language vocabulary knowledge: depth versus breadth", The Canadian Modern Language Review 53, 1:28)*

| Spanish word | 1 to 5 | English word |
|---|---|---|
| Tetera | | |
| Castillo | | |
| Coche | | |
| Guitarra | | |
| Edificio | | |
| Cuchillo | | |
| Hormiga | | |
| Casa | | |
| Serpiente | | |
| Encendedor | | |
| Granada | | |
| Silla | | |
| Rana | | |
| Teléfono | | |
| Reloj | | |
| Martillo | | |
| Submarino | | |
| Libro | | |
| Planta | | |

## Open Questions (only for persons that learned with AR application)

**1 – very negative** **2 – little negative** **3 – neutral**
**4 – little positive** **5 – very positive**

| Question | 1 to 5 | Place for your opinion/remarks |
|---|---|---|
| How would you describe the quality of experience compared to traditional learning methods (e.g. flashcards)? | | |
| Do you think that AR (Augmented Reality) can be a valid form of vocabulary learning? | | |
| What are the benefits of using AR for language learning when compared with traditional methods | N/A | |
| Other comments on application or experiment | N/A | |

## One week later

Fill this in 1 week later to test your recall rate.

| Słowo Hiszpańskie | 1 do 5 | Słowo Angielskie |
|---|---|---|
| Tetera | | |
| Castillo | | |
| Coche | | |
| Guitarra | | |
| Edificio | | |
| Cuchillo | | |
| Hormiga | | |
| Casa | | |
| Serpiente | | |
| Encendedor | | |
| Granada | | |
| Silla | | |
| Rana | | |
| Teléfono | | |
| Reloj | | |
| Martillo | | |
| Puerta | | |
| Submarino | | |
| Planta | | |

## Item 2: Detailed Application users scores

| | Application | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | | 2 | | 3 | | 4 | | 5 | | 6 | | 7 | | 8 | | 9 | | 10 | | | |
| | first | second | first | second | first | second | first | second | first | second | first | second | first | second | first | second | first | second | first | second | Avarge first | avarge second |
| **Tetera** | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 4 | 5 | 5 | 4 | 5 | 5 | 5 | 4,9 | 4,9 |
| **Castillo** | 5 | 5 | 5 | 4 | 5 | 5 | 4 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 4 | 5 | 4 | 5 | 5 | 4,9 | 4,7 |
| **Coche** | 5 | 5 | 4 | 4 | 5 | 5 | 4 | 5 | 5 | 5 | 1 | 3 | 2 | 0 | 1 | 0 | 4 | 4 | 5 | 5 | 3,6 | 3,6 |
| **Guitarra** | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 4 | 4 | 5 | 5 | 5 | 5 | 5 | 5 | 4,9 | 4,9 |
| **Edificio** | 5 | 5 | 4 | 4 | 3 | 3 | 3 | 3 | 5 | 5 | 1 | 1 | 2 | 2 | 5 | 2 | 4 | 4 | 2 | 3 | 3,4 | 3,2 |
| **Cuchillo** | 5 | 5 | 2 | 4 | 3 | 2 | 4 | 2 | 2 | 2 | 1 | 1 | 1 | 2 | 4 | 2 | 4 | 4 | 3 | 2 | 2,9 | 2,6 |
| **Hormiga** | 5 | 5 | 5 | 4 | 5 | 5 | 5 | 5 | 5 | 5 | 1 | 1 | 1 | 2 | 5 | 2 | 5 | 4 | 5 | 5 | 4,2 | 3,8 |
| **Casa** | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 4 | 3 | 5 | 5 | 6 | 5 | 5 | 5 | 5 | 5 | 5 | 4,8 |
| **Serpiente** | 5 | 5 | 5 | 5 | 5 | 4 | 5 | 5 | 5 | 5 | 5 | 5 | 4 | 4 | 6 | 5 | 5 | 5 | 5 | 4 | 5 | 4,7 |
| **Encendedor** | 5 | 5 | 5 | 5 | 4 | 3 | 4 | 1 | 2 | 2 | 1 | 1 | 2 | 1 | 3 | 4 | 5 | 5 | 4 | 3 | 3,5 | 3 |
| **Granada** | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 4 | 5 | 4 | 4 | 5 | 5 | 5 | 5 | 5 | 5 | 4,8 | 4,9 |
| **Silla** | 5 | 5 | 2 | 2 | 5 | 5 | 4 | 5 | 5 | 5 | 2 | 3 | 2 | 2 | 1 | 2 | 4 | 4 | 5 | 5 | 3,5 | 3,8 |
| **Rana** | 5 | 5 | 5 | 5 | 5 | 3 | 5 | 3 | 5 | 5 | 5 | 1 | 2 | 2 | 2 | 4 | 5 | 5 | 4 | 3 | 4,3 | 3,6 |
| **Teléfono** | 5 | 5 | 4 | 4 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 4 | 5 | 5 | 5 | 4 | 4 | 5 | 5 | 4,7 | 4,8 |
| **Reloj** | 5 | 5 | 4 | 4 | 5 | 5 | 4 | 5 | 5 | 2 | 1 | 1 | 2 | 2 | 1 | 1 | 2 | 2 | 5 | 5 | 3,4 | 3,2 |
| **Martillo** | 2 | 5 | 4 | 4 | 4 | 2 | 4 | 5 | 2 | 2 | 1 | 1 | 2 | 2 | 2 | 2 | 4 | 4 | 5 | 2 | 3 | 2,9 |
| **Puerta** | 5 | 5 | 4 | 4 | 5 | 4 | 5 | 4 | 5 | 5 | 2 | 1 | 4 | 1 | 1 | 2 | 4 | 4 | 4 | 4 | 3,9 | 3,4 |
| **Submarino** | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| **Libro** | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 4 | 5 | 4 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 4,8 |
| **Planta** | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 4 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 4,9 |
| | **97** | **100** | **88** | **88** | **94** | **86** | **91** | **88** | **91** | **87** | **64** | **61** | **66** | **61** | **77** | **70** | **89** | **88** | **92** | **86** | 84,9 | 81,5 |

## Item 3: Detailed Flashcard users scores

| | Flashcards | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **1** | | **2** | | **3** | | **4** | | **5** | | **6** | | **7** | | **8** | | **9** | | **10** | | | |
| | first | second | first | second | first | second | first | second | first | second | first | second | first | second | first | second | first | second | first | second | Avarge first | avarge second |
| **Tetera** | 5 | 5 | 5 | 5 | 4 | 4 | 1 | 1 | 4 | 2 | 5 | 5 | 4 | 3 | 4 | 4 | 5 | 5 | 4 | 4 | 4,1 | 3,8 |
| **Castillo** | 5 | 5 | 5 | 0 | 4 | 4 | 3 | 3 | 4 | 4 | 5 | 5 | 4 | 4 | 4 | 3 | 5 | 4 | 4 | 4 | 4,3 | 3,6 |
| **Coche** | 5 | 5 | 5 | 2 | 5 | 2 | 1 | 1 | 4 | 2 | 5 | 3 | 4 | 2 | 5 | 4 | 5 | 5 | 5 | 2 | 4,4 | 2,8 |
| **Guitarra** | 5 | 5 | 5 | 5 | 5 | 5 | 4 | 4 | 4 | 4 | 5 | 5 | 4 | 4 | 5 | 5 | 5 | 5 | 5 | 5 | 4,7 | 4,7 |
| **Edificio** | 5 | 5 | 5 | 2 | 2 | 2 | 1 | 1 | 2 | 2 | 4 | 4 | 5 | 3 | 4 | 3 | 5 | 2 | 3 | 2 | 3,6 | 2,6 |
| **Cuchillo** | 5 | 5 | 5 | 2 | 4 | 4 | 1 | 1 | 4 | 2 | 5 | 3 | 2 | 2 | 4 | 2 | 5 | 5 | 2 | 2 | 3,7 | 2,8 |
| **Hormiga** | 5 | 5 | 5 | 5 | 4 | 4 | 1 | 1 | 4 | 3 | 5 | 3 | 4 | 3 | 4 | 4 | 5 | 3 | 4 | 4 | 4,1 | 3,5 |
| **Casa** | 5 | 5 | 5 | 2 | 4 | 4 | 4 | 4 | 4 | 4 | 5 | 2 | 4 | 4 | 4 | 4 | 4 | 3 | 4 | 4 | 4,3 | 3,6 |
| **Serpiente** | 5 | 5 | 5 | 4 | 5 | 4 | 1 | 1 | 4 | 4 | 5 | 4 | 4 | 4 | 2 | 2 | 5 | 5 | 4 | 4 | 4 | 3,7 |
| **Encendedor** | 5 | 5 | 5 | 0 | 3 | 2 | 1 | 1 | 4 | 2 | 5 | 4 | 2 | 2 | 3 | 3 | 5 | 3 | 3 | 2 | 3,6 | 2,4 |
| **Granada** | 5 | 4 | 5 | 5 | 5 | 5 | 4 | 4 | 4 | 4 | 5 | 5 | 4 | 4 | 5 | 5 | 5 | 4 | 5 | 5 | 4,7 | 4,5 |
| **Silla** | 5 | 5 | 5 | 2 | 5 | 5 | 1 | 1 | 4 | 1 | 2 | 2 | 4 | 1 | 5 | 2 | 5 | 5 | 5 | 3 | 4,1 | 2,7 |
| **Rana** | 5 | 5 | 5 | 5 | 5 | 5 | 1 | 1 | 4 | 1 | 5 | 4 | 4 | 1 | 5 | 5 | 4 | 2 | 5 | 5 | 4,3 | 3,4 |
| **Teléfono** | 5 | 5 | 5 | 5 | 5 | 5 | 4 | 4 | 4 | 4 | 5 | 5 | 4 | 4 | 5 | 5 | 5 | 5 | 5 | 5 | 4,7 | 4,7 |
| **Reloj** | 5 | 5 | 5 | 4 | 2 | 2 | 1 | 1 | 2 | 3 | 5 | 4 | 4 | 3 | 2 | 2 | 5 | 5 | 2 | 2 | 3,3 | 3,1 |
| **Martillo** | 5 | 2 | 5 | 2 | 2 | 4 | 1 | 1 | 4 | 2 | 4 | 3 | 4 | 4 | 3 | 3 | 5 | 2 | 2 | 4 | 3,5 | 2,7 |
| **Puerta** | 5 | 5 | 5 | 2 | 5 | 2 | 1 | 1 | 4 | 3 | 3 | 2 | 4 | 3 | 5 | 2 | 5 | 5 | 3 | 3 | 4 | 2,8 |
| **Submarino** | 5 | 5 | 5 | 5 | 5 | 5 | 3 | 3 | 4 | 4 | 5 | 5 | 4 | 4 | 5 | 5 | 5 | 5 | 5 | 5 | 4,6 | 4,6 |
| **Libro** | 5 | 3 | 5 | 2 | 4 | 4 | 2 | 2 | 4 | 4 | 5 | 2 | 4 | 4 | 4 | 2 | 2 | 2 | 4 | 2 | 3,9 | 2,7 |
| **Planta** | 5 | 5 | 5 | 5 | 5 | 5 | 3 | 3 | 4 | 4 | 5 | 5 | 4 | 4 | 5 | 5 | 5 | 5 | 5 | 5 | 4,6 | 4,6 |
| | **100** | **94** | **100** | **64** | **83** | **77** | **39** | **39** | **76** | **59** | **93** | **75** | **77** | **63** | **83** | **70** | **95** | **80** | **79** | **72** | 82,5 | 69,3 |

### Item 4: Application group open questions answers

| Person | Question 1 | Question 2 | Question 3 | Question 4 |
|---|---|---|---|---|
| 1 | Flashcards are easy to lose, AR additionally uses image and sound which is beneficial | yes | More senses are in use, you can interact with the object or whole environment | |
| 2 | Very use full but I paid too much attention to the pictures/animations instead of learning words | Yes you can learn everywhere where you have your phone and small marker also the program uses different types of remembering (sight, hearing) | Great addition is the sound of speaker and portability | |
| 3 | | | | |
| 4 | | Availability of 3D image and sound really facilitates learning | | |
| 5 | Great fun | While you learn it isn't so tiresome(boring) but you remember the picture more than word | Easy to learn and remember, I never had willingness to do flashcards ( make them) | |
| 6 | Pretty impressive because it is a new method and works on your imagination | I think that It can be | Works on imagination everything is on phone, you don't have to write and carry additional things – comfort. | It would be nice for the objects to be animated, and have some kind of interaction with user |
| 7 | Lacks testing mode(i.e. just the picture without meaning which appears after clicking „check" button).That would be useful in checking which words are already remembered | Useful yes but in demo application is not polished enough to be used in long term time | Using AR to learn language is a new thing and because of that it can attract new persons, which normally wouldn't be interested in it. | |
| 8 | No need to prepare materials application can use random objects to increase remembering rate | Simultaneous learning of spelling and pronunciation seeing people can remember by sight | | This could be used in much more advanced learning program with many additional futures( optimal number of words per day, increased rate of appearing in words we have trouble with) |
| 9 | Today it maybe more interesting to use new technologies especially something you can have in phone to learn rather than writing words on flashcards or notebook | Augmented Reality is a good way to entertain user but when this interest disappears it still seems more convenient to use than notebook or flashcards | Most noticeably the use of multiple senses and possible interaction with user | |
| 10 | If the application was more polished and augmented reality allows for more interaction with user it can be a new way of learning (new quality) | Just in this application I can see how It can be used and there are probably many more possibilities. It certainly is viable | | |

**Item 5: Overview of the tools for achieving AR on Android devices**

There are many tools available which are commercial and of free use, some of them are still developed while others seem to have died out. Some of those are student's projects related to their interest, classes or are master thesis projects. In most cases those tools are related in relation one to one to previously mentioned technologies, in some cases tool combines or allows to use more than one technique. Below a short description is provided to more popular solutions.

1. ANDROID-AUGMENT-REALITY-FRAMEWORK

This is a project available on Google code (http://code.google.com/p/android-augment-reality-framework/), in introduction we can read that it is loosely based on Mixare (another AR tool). Code is maintained by two people who are responsible for the development. Project started in January 2011 and latest revisions are from January 2012. Based on Wiki site of project we can get view of how the application is designed and which technique it uses.

This framework is an example of using hybrid based tracking to achieve AR. It uses GPS to find out user's coordinates in word, and accelerometer with compass to find out device orientation. Based on this information on location of marker which is to be displayed framework actually calculates what should be displayed in device field of view.

One of the application functionality which deserves mentioning is support for easy importing of points of interest from Twitter and Wikipedia by extending TwitterDataSource.java and WikipediaDataSource.java classes.

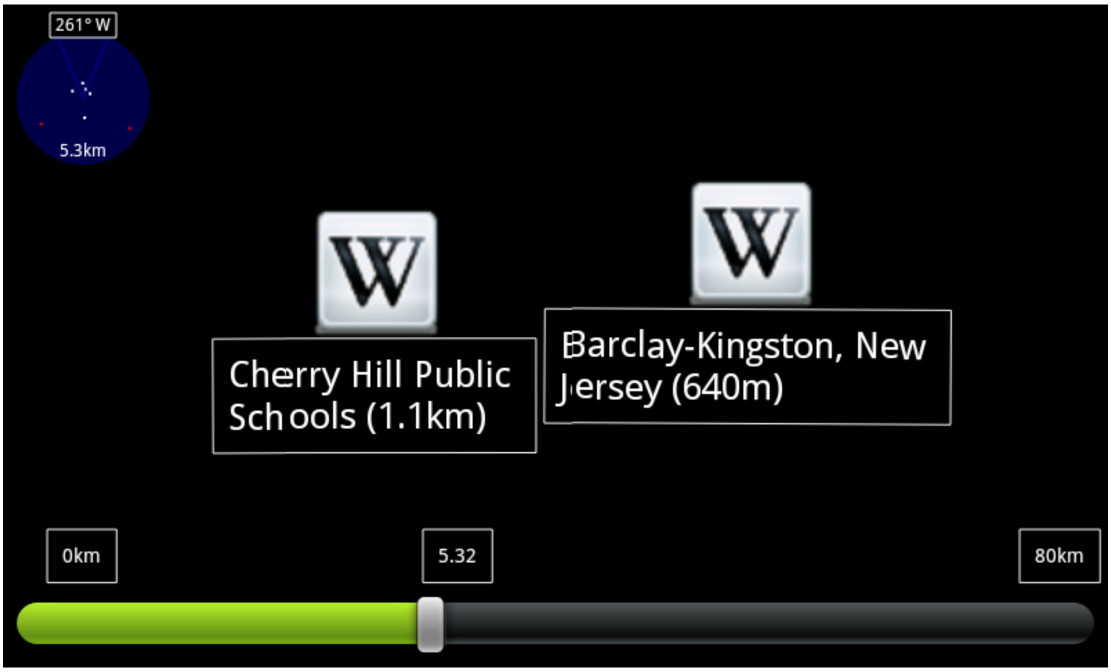



**Figure 1: android-augment-reality-framework Source: http://code.google.com/p/android-augment-reality-framework/**

## 2. SOMAVIEW - DISCOVER YOUR VIRTUAL NEIGHBORHOOD!

SomaView (http://www.chrismc.de/development/somaview/) is a commercial example of hybrid based tracking. It provides similar functionality to previously mentioned android-augment-reality-framework, but has much more support and development. Basically it allows you to find points of interest in your neighbourhood using AR. Application is currently unavailable on Android Market and last entries on its webpage are from June 2010 as of now project seems to be dead. Interesting functionality in SomaView was that it supported many backend as source of information.

## 3. WIKITUDE

Wikitude (http://www.wikitude.com/en/) was first AR browser released on Android platform; nowadays it supports also Blackberry, Bada, Windows Phone and iOS. It started in October 2008 as freeware and is another great example of hybrid based tracking. In this case we have a full application that is currently available on Android Market.

Wikitude's strong points and also what makes it unique is two business models it incorporates. First one is to place user generated AR content into their Wikitude browser which is freely available on android market. This way they present their application as a viable marketplace or rather advertisement source. For example hotel owners can place markers of their hotels into the application and later on users searching for place to sleep can find those hotels in AR.

Second business model of Wikitude is its SDK, it was later on decided that software used in Wikitude Browser could be re used as framework for designing AR applications. SDK is currently available for Android and iOS it allows for easy integration and development of AR enabled applications. It is also developed according to latest standards as Wikitude is also a member of Open Geospatial Consortium.

Wikitude SDK is a commercial solution but is also available as a trial version with some limitations, it was considered in application development but due to those limitations such as:

- Watermark in cam view
- Starting animation
- Wikitude logo in cam view

I've decided not to use it in favour to fully free solutions. Nevertheless it is one of most famous AR applications available on Android Market.

4. LAYAR

Layar (http://www.layar.com/) is a Dutch company which in 2009 released application with the same name. Layar is AR browser similar to Wikitude, they offer basically same functionality along with browser for displaying AR layers and SDK for developers who want to incorporate or introduce AR into their application.

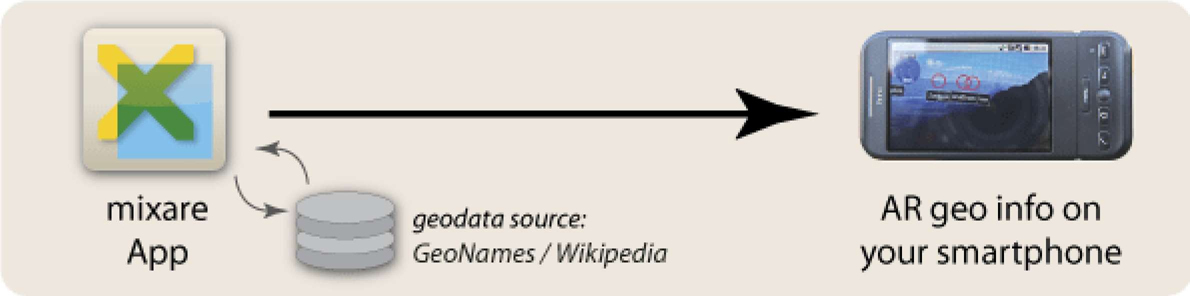
Both Layar and Wikitude are often mentioned as two major rivals in AR battle on mobile devices, and there is no clear winner yet.

5. MIXARE

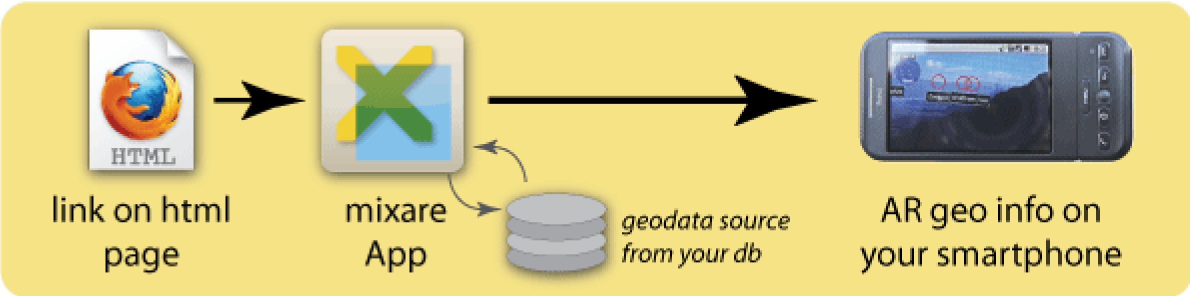
As we still stay in hybrid based tracking Mixare (http://www.mixare.org/) is a freeware application published under GPLv3. It is available on Android an iOS and allows for augmenting of real world. What differs this solution from others is that it is entirely free to use. According with Mixare homepage there are 4 different ways to use it[2]:

1. As an autonomous application, this (for the moment) displays Wikipedia POIs of the surroundings.

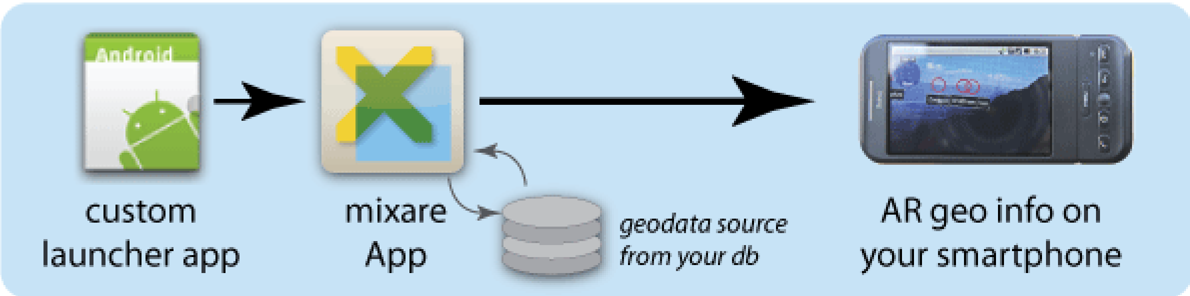
[2] Taken from http://www.mixare.org/usage/ under GPLv3




2. By a link on an HTML site, whereby the data source is transferred to the application. (Info)




3. Access by an own launcher-app, the data source is transferred to the application. (Info)




4. Mixare is freely expandable and can even be modified into an individual application (GPLv3).

## 6. LOOK!

Look (http://sourceforge.net/projects/lookar/) is another example of hybrid based tracking augmented reality. What makes it special is that it is three student's master thesis project. In the about section we can read:

*"Look! and adjunct applications have been developed as **Thesis** (Computer Systems) for the Faculty of Informatics, University Complutense of Madrid during the academic year 2010/2011."*

As the implementation of hybrid based tracking technique is fairly simple compared to others there are many tools using it. There are also simple tutorials describing how to implement hybrid based tracking. This project is a good example that you don't need whole company to develop AR software. In Look we programmatically add POI defining their GPS position, later on they can be displayed and programmed for events on touching. All information regarding this project is in Spanish and there is no English translation. Based on translation of information and lack of updates since June 2011 I can say that this project is finished and won't be further developed.

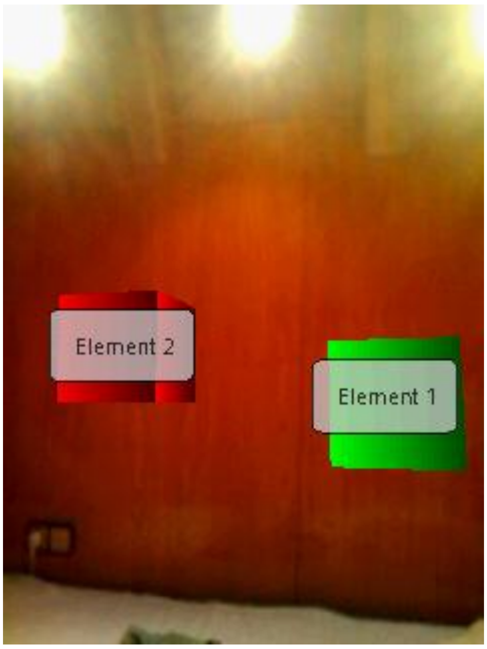



**Figure 2: Example of POI! in Look application**
**Source: http://www.lookar.net/wp-content/uploads/2011/07/tutocapt3.png**

## 7. ARTOOLKIT AND ITS ANDORID PORTS

ARToolKit (http://sourceforge.net/projects/artoolkit/) started out as a library for augmented conferencing system and was developed by Hirokazu Kato and Mark Billinghurst

(Kato and Billinghurst, 1999). Since then it has become one of the biggest AR libraries available with ports and forks to many different platforms.

When it comes to Android OS there are two ports of ARToolKit available one of them is AndAR - Android Augmented Reality, and the second one is NyARToolkit for Android.

#### 10.2.7.1. ANDAR

AndAR (http://code.google.com/p/andar/) is a one man project run by user under nickname tdomhan (tdomhan@gmail.com), a simple project check on code.google or Google search reveals that he is an eager engineer related to many different projects. Commits into this project started on December 5 2009, and last commit is from November 29 2010. Right now project seems to be dead. His framework offers pure Java API and is object oriented there is no native C++ code in it. Framework provides functionality of marker tracking based on ARToolKit and provides some example projects, such as Pong AR, and simple displaying of augmented objects on top of markers.

#### 10.2.7.2. NYARTOOLKIT FOR ANDROID

NyARToolkit (http://sourceforge.jp/projects/nyartoolkit-and/) for Android is another framework that seems to be dead now. There is still some users' activity on Sourceforge project page as last update comes from February 27 2012 but is just a webpage update. Last code updates come from June 28 2010 and there does not seem to be any more activity regarding code. This library also supports only marker based tracking as this was ARToolKit functionality and porting projects rarely extend beyond ported software capabilities (it is not strict port in that case). There are many examples of using this library available on YouTube for interested to watch. As the project was started and maintained in Japanese community, project's home page is in Japanese and provided marker templates are also based on Japanese words.

### 8. METAIO MOBILE SDK

Metaio's (http://www.metaio.com/software/mobile-sdk/) mobile SDK is another industry leading solution for implementing AR into mobile applications. Its future set contains marker or markless tracking, POI's tracking, support for QR code and barcode reading, built in 3D renderer, optimizations for mobile chips, and much more. On their webpage we can read that their SDK was used in more than 70 mobile applications across iOS and Android platform. They also mention 10 years of experience in the field and continuous integration of latest technology and advancements in this area. One of their unique futures allows for simple deployment of applications without the need to upload and encrypt files. In addition to their own 3D rendering engine they also provide integration with Unity 3D cross platform game engine.

9. VUFORIA™

Vuforia (https://developer.qualcomm.com/develop/mobile-technologies/augmented-reality) is a project developed by Qualcomm Company, who is as well a famous chipset/mobile CPU provider also in field of mobile phones. What is interesting or maybe more tempting is that you can use Vuforia without any royalty payments even for commercial projects, that is why many indie software companies prefer to use this solution. But in terms of AR this framework is also top notch and provides some unique functionality on both supported platforms which are Android OS and iOS.

Based on ability to use this framework for free and without any restrictions (no watermarks or any other disadvantages), and also very good documentation and simple to use API. It was decided that Vuforia will be used in the implementation of the language learning application. Some additional functionality like virtual buttons is another great benefit in using this tool.

Vuforia allows for standard 2D object tracking, in which object doesn't necessarily need to be a black square with shape in it, we can also use any image we want provided it is "enough" feature rich for software to extract some characteristic information. Standard fiducial marker tracking is also possible but less favoured in this framework. In addition to this tracking we can use multi tracking which is marker tracking of simple 3D objects such as cube. In this case we need to supply marker tracking information for each wall of the object. Another great functionality is virtual buttons which allows defining part of tracked object space to be a button which interacts with user on occlusion events.

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