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ENHANCING LEARNING EXPERIENCE WITH AUGMENTED MIND MAPS

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Abstract

For many years, people have developed different tools and techniques to help them with learning and knowledge retention. Note-taking is one of the traditional techniques for knowledge acquisition and retention, being used for centuries through different means. It ranges from wood chirps and stones to carve on rocks centuries ago, to state-of-the-art devices we have in the modern world. Though note-taking in the past was traditionally linear in nature, evolution in this field based on research developed new forms of note-taking techniques. Mind mapping, where in a central idea is drawn and branched out to linked concepts, has been a promising technique to enhance the learning experience of students and is gaining momentum in educational settings.

Mind mapping was traditionally physical in nature this is pen and paper based, however the advent of technology paved the way for digital mind mapping solutions. Both have their fair share of advantages, however, a gap still exists in both techniques, and it is considered beneficial to combine the benefits of physical and digital worlds together to enhance the learning experience.

This thesis aims to study the effectiveness of mind mapping over traditional note-taking technique and explore the benefits offered by physical and digital mind maps based on literature review and available surveys. It further analyses available tools in the market which could be used to develop a solution that intends to bridge the gap between physical and digital mind maps.

The proposed solution aims to exploit the capabilities of Augmented Reality to combine real and virtual worlds to bring the best out of mind maps. Keeping this in mind, a prototype of augmented reality based mobile application is also developed as part of this thesis. The application enables users to enrich physical mind maps with digital information - text, images and hyperlinks to enhance the learning experience of the user.

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Contents

List of Abbreviations

BPMN	Business Process Model and Notation
AR	Augmented Reality
MM	Mind Map
OS	Operating System
DSRM	Design Science Research Methodology
3D	Three Dimensions
EFL	English as a Foreign Language
SDK	Software Development Kit
PCs	Personal computer
UI	User Interface
2D	Two Dimensions
SLAM	Simultaneous Localisation and Mapping
GPS	Global Positioning System
IMU	Inertial Measurement Unit
IDE	Integrated Development Environment
CPU	Central Processing Unit
APK	Android Application Package
GPU	Graphics Processing Unit
SVG	Scalable Vector Graphics
PSD	Photoshop Document

1 Introduction

For a long time, tools have been developed to help us with learning and knowledge reflection, that ranges from stones for carving on rocks in ancient times to state of the art digital platforms we see nowadays. There are several learning techniques adopted by teachers in school for improving learning experience and growth of students and on the other hand different forms of note-taking style and techniques are at disposal of students to organise and structure the received information for retention and retrieval in future, especially while preparing for examination. This storage and retrieval of information could be via physical mediums such as pen and paper notes or could be digitally stored notes on a laptop or even a mix of both.

In schools, it is observed that mind mapping is one of the techniques used by students to learn to structure and organise their thoughts and collect information received during learning hours for referencing in the future, for instance, while preparing for exams [1]. Though with advancement of technology more students are inclined towards taking notes via digital medium like tablet and laptops, researchers [2] argue that there is still significant use of pen and paper for manual note-taking, as it enhances the quality of learning when students paraphrase or summarise the information in their own words without any distractions from digital platforms, for instance a missed call pop-up on a laptop connected to one's phone.

Use of pen and paper not only makes us smarter, but the physical space can offer much more possibilities. In the educational field, solutions have been re-

searched for learning words with use of tangible letters [3], the perception of time via Time Blocks [4] and even haptic feedback during different brainstorming exercises. Though, significant work has been performed in the fields of tangible user interfaces and data physicalisation, there is a gap in understanding the design space for solutions that support scribbling behaviour during daily activities in education across the reality-vitality continuum [5], which should be addressed, so students can be assisted with tools that blend reality of physical mind maps with the virtual world (Augmented reality). This will provide enhanced learning experiences for students with a more interactive platform to store and retrieve information for useful purpose.

1.1 Problem Statement

Mind maps are one of the most used note-taking techniques to learn and remember subjects of interest in individuals. While, Physical Mind maps which are traditionally taken on paper are easier to make, provide great flexibility to work together, they lack rich media integration like addition of images and audio which could enrich the information and make them more interesting for users as is the case with digital mind maps. Although there are tools available in the market for digital mind maps, however, they tend to isolate the use of physical mind maps and thus do not bring the advantages of two approaches together.

1.2 Research Questions

- What differences exist between physical and digital mind mapping tools and techniques, and what is their impact on how people learn?
- How can augment reality be used to integrate Physical Mind maps with digital media to enrich information and make it more interactive?
- What tools are available in the market that can be used to implement a user-friendly Augmented Reality-based mind mapping application?
- How to implement a solution that allows integration of advantages offered by digital and physical mind maps?

1.3 Objectives

To tackle the research questions defined in this thesis, the following objectives must be met to produce relevant findings and solutions.

- Do a literature review on learning techniques, note-taking, and mind mapping.
- Perform a comparative analysis between physical and digital mind maps.
- Analyse which tools exists in the market to implement Augmented reality based mind maps.
- Propose how an augmented reality application that bridges the gap between physical and digital mind mapping would look like.

1.4 Motivation

Multiple research in the past has shown that paraphrasing and summarising what you read in your own words is highly effective in helping you to retain information. This can be achieved by different note-taking techniques, for instance Linear, spider gram, mind maps etc. Also, whether someone takes notes on physical medium (pen and paper) or digital medium (laptop, tablet etc.) could affect the information gathering, interconnection of gathered data and ease of retrieval in future.

The motivation of this study is to understand and evaluate different learning and note-taking techniques being used by students for their daily classwork and homework via online or offline mode and to provide them with useful Augmented reality based user interface to add information over existing physical mind maps that could enhance their learning experience by bridging the gap between physical and digital world. This would not only make learning and note-taking more interactive and fun for students, but could also enhance the way information can be structured and interlinked for different concepts, and later retrieved.

1.5 Benefits and Solution

The purpose of this master's thesis is to explore the usefulness of different learning techniques used by students, with specific focus on mind mapping techniques. The collected information will be used for analysing and evaluating mind mapping techniques based on physical and digital mediums. This will further be used for combining the advantages of both mind mapping techniques to enrich information

of physical mind maps with digital content to make it more fun and interactive for students, which will help in enhancing their learning experience.

As a third dimension can give better understanding of a concept, this thesis will explore the inclusion of Augmented reality with physical mind maps, which is considered as less distracting than regular digital mind mapping tools. This will involve gathering different user requirements related to interactive mind maps and come up with a design of a user interface and a list of expected functionalities to be provided by the proposed application.

This study will collect information related to tools available in market that could be used for implementation of an augmented reality based mind mapping application that could integrate the benefits of physical and digital mind maps, and a prototype will be developed.

1.6 Contributions

- Produced findings of comparative analysis between Physical and Digital Mind maps
- Proposed solution about how Augmented reality can be used to enhance Physical Mind maps with digital content
- Conceptual Augmented reality application design, listing possible functionalities, user interface and use cases.

1.7 Methodology

This thesis adopts Design Science Research Methodology (DSRM) which is one of the widely used research methodologies for Information systems [6] and proved to have significant economical and societal impacts [7].

Below, the process model shows different steps of DSR methodology.

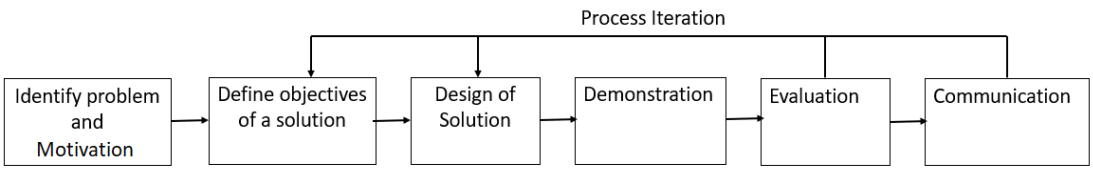


Figure 1.1: DSR Methodology Process Model (adapted from [6])

A brief description of how outlined steps of DSR methodology are followed for work carried out in this thesis is as mentioned below.

Identify Problem and Motivation The problem is already identified in chapter 1 of the thesis, which is further narrowed down to research questions that need to be tackled with this study. This chapter also showcase the motivation behind this study, which is to enhance the learning experience.

Define objectives of a solution The objectives of this study are defined based on the research questions identified in the chapter 1 and on the literature review for background of related work. Taking into account mentioned objectives of the study, a solution is proposed and implemented.

Design of Solution The design of the solution presented in this thesis is based on the identified problem we are trying to solve, together with the defined objectives. These were discussed during status meetings and iterated to improve the final design of the solution.

Demonstration Demonstration of the work carried out is shown through use of simple use cases and a prototype solution. The prototype was discussed in meetings with stakeholders and necessary suggestions were implemented to improvise the prototype.

Evaluation An evaluation of the proposed solution was done internally with this thesis promoters to get their opinion on the proposed solution and prototype.

Communication Communication part of this thesis work is limited to regular discussion and meetings with the promoters and a presentation for defence of the thesis. This work is not published in any journals, but will be available with in the VUB thesis archives for the WISE department.

1.8 Structure of Thesis

This thesis is structured as follows

Chapter 2 Background and Related Work This chapter is intended for literature review of related work done in the past, together with relevant concepts and terminologies being discussed to provide general understanding for the reader. This section will form the basis of the proposed solution presented in the thesis.

Chapter 3 Analysis and Findings This chapter provide the analysis done on different note-taking techniques with focus on mind maps and provides pros and cons of different techniques.

Chapter 4 Solution This chapter of the study focuses on the solution being proposed based on defined problem and research questions. It also describes in detail the process model of the solution and what functionalities are expected from the application being implemented.

Chapter 5 Implementation This chapter explains how the application is implemented based on choices made for underlying technology and processes. This part also describes the issues and challenges faced during implementation of the proposed solution.

Chapter 6 Use cases and Prototype In this chapter, basic use cases for the application are defined together with a demonstration of a prototype.

Chapter 7 Future Work This chapter provides a brief overview of possible improvements and additions for the future.

Chapter 8 Conclusion This chapter is to conclude the findings of the work carried out during this thesis.

2
Background and Related Work

As mentioned in the previous chapters, one of the objectives of this research is to study different note-taking techniques with focus on mind maps and benefits that augmented reality can bring to the learning experience with augmented mind maps. Thus, this chapter starts with briefly discussing different note-taking approaches and then moves on towards extended details for mind mapping techniques. Further, context related to what is augmented reality and its different types is outlined. The later part of this chapter focuses on an overview of current technologies and tools that allow the development of augmented reality based mobile applications, and an overview of already existing applications is discussed.

2.1 Note Taking

Note taking is one of the most widespread learning techniques used by individuals to record information gathered through different transient sources, like lectures, oral discussions and meetings. It helps to free the mind of a learner from recalling everything later [8]. This technique is not something new but existed from ancient times, which is evident from 'hypomnema', a technique developed by ancient Greeks which meant to take personal records on topics of interest. Later during the Renaissance and early modern periods, note-taking practices were learnt by students in various academic settings and their noted work served as reference for future studies to build on existing knowledge[9]. Traditionally notes were mostly handwritten which we see also nowadays but with the advent of technology and

note-taking software a shift is observed in behaviour of students and professionals towards digital note-taking practices.

Note-taking is considered as one of the most important skills for students ranging from primary to college level. The main purpose of note-taking for students is to capture the information being delivered during lectures which could help them later while referencing to learn the delivered concepts, prepare for examinations or sharing information with classmates or interested learners. Various studies and research [10] [2] [11] were done in past which showcased that note-taking enable students to be more engaged in lecture and allows them to better understand the concepts. Even when students do not refer to notes taken in class while preparing for tests have shown better performance than their counterparts who did not take any notes while learning. The difference becomes more evident when notes are handwritten and paraphrased, then transcribed or typed.

2.1.1 Note-taking Versus Note Making

Note-taking and Note making does not seem to be different terms to an individual in general, however as per Raman (2010) there exists a difference in terms of how the information for which notes are drawn is being provided, i.e. verbally or in written form. According to Clara (1996), note-taking is a sort of passive approach which is used during lectures or meetings which focuses on copying of words delivered verbally by the presenter without any self thought process of recipient being triggered. Whereas, note making is more of an active process which comprises reading, evaluating and summarising the source of information provided in textual form.

Note-taking versus Note-making	
Note-taking	**Note-making**
Brings no obvious improvement towards the study skills.	Making notes improve the skills in study.
Only jotting down points. No interpretation is involved.	Help students to see each point clearly along with its connection with each other.
Taking points from one source at a time.	Involve taking points from different sources.
Less understanding process is involved; the aim is to take notes.	Aimed at making notes that help students to understand the topic in a better way.
Points given by the source/lecture are taking straightly.	Making notes involve summarising all the information within the points studied.
Overall structure cannot be shown as it is still in complex form.	Shows the overall structure of the specific subject.

Table 2.1: Note-taking vs Note making [12]

2.1.2 Note-taking Methods

Regardless of the medium being used i.e. Physical or Digital, note-taking can be classified into two methods, Linear and Non-Linear.

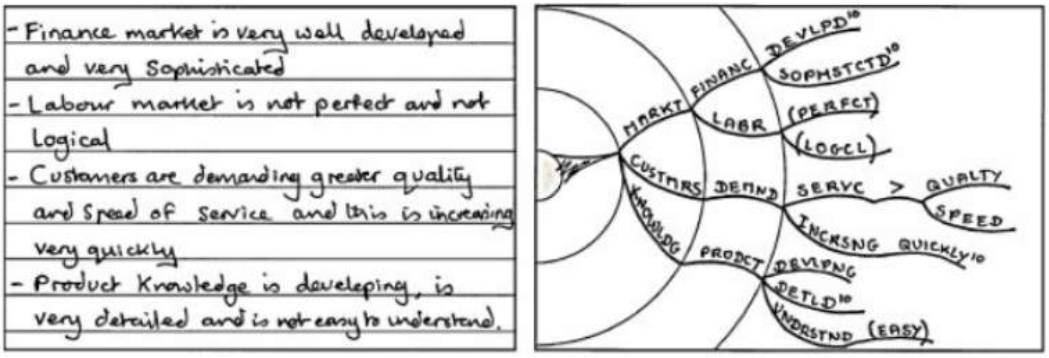


Figure 2.1: Example of Linear Vs Non-linear note-taking approach [13]

- **Linear note-taking** method is the approach of writing the information in the same sequence as it is being received by the learner. This method is commonly used in academic settings, where students tend to write notes while attending lectures.

  Most common Linear note-taking techniques are Outlining and Sentence methods. the **Outlining approach** proceeds with gathering information in a structured way with use of headings, subheadings, and bullet points. This helps to digest a lot of information in a shorter period of time [8].

  The information gathered via this approach can be done physically (pen and paper) or digitally (laptop, tablet etc.). Though notes taken physically are easier to make, they however lack the flexibility of addition of concepts later to structure as there is a lack of physical space between already written points; this is much easier to manage in digital form. On the other hand, digital notes do need some technical skills.

  The **Sentencing approach** of Linear note-taking method is about writing down the topics of interest in simple sentences. This approach works better in cases where a lot of information is being covered by the presenter. The recipient writes each new thought a concept in a separate line with single or multiple sentences, and each concept can be numbered or marked in bullet format to identify the start of a new concept.

  Though linear note-taking is widely used by students in academic environments, for example while attending lectures and presentations, these have

certain challenges that affect the learning experience, as described below [14].

- Linear notes tend to be more monotonous, thus making them less efficient and even boring for certain students, which makes it difficult to be memorised.
- While taking linear notes when the page is filled or structure is drawn in numbered/bullet points, its very hard to modify the content i.e. to add/remove pieces of information as that would mean squeezing the information in less space.
- While information needs to be retrieved from linear notes in the future, it is also not easy to identify the concept directly as students have to re-read a lot of content to find back topics of interest.
- As this approach is based on transcribing the information being received by the learner, without their own thoughts the understanding gained is also adversely affected.
- Few of these challenges could be overcome if note-taking is done via a digital medium like a laptop, however researches in the past have shown that use of digital software incline students to type word-for-word the information being received, thus making it less efficient than handwritten linear notes.

- **Non-Linear note-taking** allows to record the information in a semi-structured but organised graphical format. This is not similar to recording the information in the same sequence it is being received as was the case in linear method and is proved to provide a more efficient learning experience for individuals [13] as it is based on re-framing of collected information, which also adds own thought process of individuals and thus proves more engaging and efficient. The most common non-linear note-taking approaches are Charting, Cornell notes and Mapping.

  Charting works best for subjects where information can be categorised, for example to show similarities and differences. This allows a better organisation of information and helps students who learn better by understanding patterns.

  Cornell Notes This method is commonly used by university students today where in a page is divided into 3 parts, left part is to write down cues or

keywords related to topic, right part allows to record information as notes related to mentioned cues/keywords and a section down the page summarising the information. Though this approach proved useful to better understand the concepts and readable notes, studies [15] [16] in past did not find relevant increase in student performance.

Mapping uses tree like structures to interlink information related to various concepts. Ideas are written as tree nodes and are interconnected via links between them. The approach here is to have the goal as the central node and then branching it out with different but related ideas to the goal. This technique of note-taking is considered as core practice behind different accelerated learning methods[17].

2.1.3 Handwritten versus computer-based note-taking

Although a study has shown that taking notes by hand may improve short term memorisation and allows synthesising better, other factors must be taken into consideration when choosing between paper or digital note-taking. This section compares handwritten versus computer-based note-taking.

The advantages of handwritten note-taking:

- Memorisation: As mentioned above, information can be better memorised.
- Relevancy: As taking notes by hand ordinarily does not allow being fast enough to record everything, handwritten notes are usually more selective and thus more synthesised.
- Flexibility: Handwriting usually brings more flexibility, especially for complex schema, formulas, or charts.
- Fewer distracting: For some students, taking notes by hand can be less destructive than on a computer with an internet connection.

The advantages of computer-based note-taking:

- Rapidity: For many students, it is faster to type and to structure text on a computer than with a pen.
- Modifiability: One major advantage of computer-based note-taking is that it allows editing, restructuring, and reorganising notes easily afterwards.

- Searchability: It is unquestionably faster to search in digital notes.
- Space and order: All the notes can fit on a laptop, while handwritten note-taking produces several stacks of paper that have to be stored and carried for each lesson.
- Shareability: Digital notes can be shared easily with others.

Given the advantages of the two approaches, handwritten note-taking may seem more efficient for courses which do not require reworking the notes later and which contain few cross-references. However, computer-based note-taking has many advantages that can be more beneficial in the long term and for courses that require more work at home.

2.2 Mind mapping

2.2.1 Definition of mind mapping

Mind mapping, also known as visual mapping, visual thinking and spider diagrams is a graphical tool that consists of a central idea as a primary node and then secondary ideas that branch out of the central idea, which are linked together[18].

According to Buzan (1994), mind map is an expression of radiant thinking, thus serving as a natural function of human brain. It is a powerful graphic technique which helps to unlock the potential of brain [18].

As mind maps are analogous to natural structure of brain, it helps users to visualise, understand and remember information in an efficient manner. Mind maps are created similarly to functionality of the brain. Below is a depiction of a brain activity occurring in human while decision-making in contrast with how mind mapping works [19].

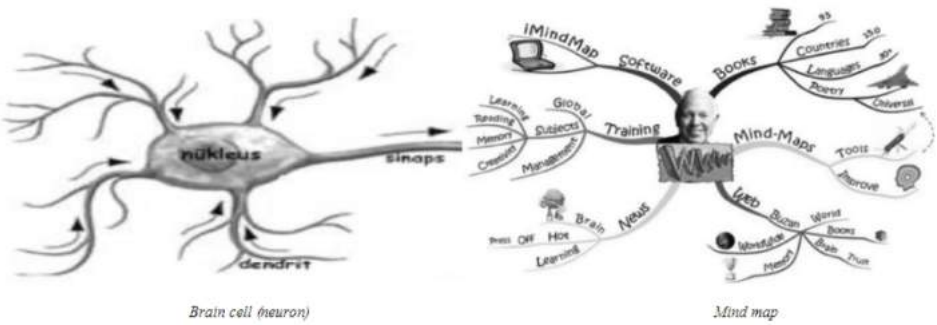


Figure 2.2: Brain functionality in similarity with Mind map [19]

Mind mapping technique simulates both hemispheres (left/right) of brain, where in left side is used for logical thinking and right side serves creativity, thus making it more engaging and efficient for user [18].

2.2.2 History of mind maps

History of mind map usage is from centuries, where in thinkers like Leonardo Da Vinci used pictures and symbols to express his thoughts on paper. These pictorial representations helped him to explore various fields like arts, machines, and biology. Also, Richard Feynman who won Nobel Prize in field of physics used to keep all his theories of quantum and electrodynamics into visual and diagrammatic forms.

British psychologist Tony Buzan developed mind maps in the late 60s to provide an alternative to traditional note-taking methods. He made use of different mind mapping aspects, which could help people to create their own non-linear note-taking approach. These aspects included use of landscape paper, symbols, colours, and branches around the central image.

Though mind mapping techniques were previously done mostly on physical medium like pen and paper, with advent of technology various tools and software now exists in market such as MindMeister, Mind Node etc. which allows users to create and share mind maps digitally.

This shows that mind maps were used from centuries, which was simpler than the evolved version of mind maps we use today, but this indicates their efficiency in different fields.

2.2.3 Types of mind maps

As mentioned by Buzan (2006), mind maps are mainly classifies into below categories.

Dyadic mind maps, which are drawn by making two radiant branches in the centre.

Poly Categoric mind maps, usually contains three to seven branches based on the fact that average mind have limitation of keeping seven pieces of information in short term memory. These kinds of mind maps boosts the mental capabilities for categorisation and classification.

Group mind maps, As the name suggests, are based on collective input from individuals. This serves as a reflection of group consensus on the topic being brainstormed and subsequently becomes group record or memory. This also helps in increasing the efficiency as multiple brains are involved and thus producing mutually agreed design.

Computerised mind maps, as compared to traditional mind mapping which is done on paper these mind maps are digital, which means they are taken over computers like laptop, tablets digital boards etc. There are multiple software available in market such as iMindmap, MindMeister etc. which allows users to create individual or collaborative mind maps.

2.2.4 How to make mind maps

While creating mind maps several aspects needs to be considered, which includes most importantly the central idea/image followed by branches, keywords, colours etc. Buzan (2006) described these aspects as following.

- The most important aspect is to narrow down on the centralidea, i.e. to focus on what is the core question or problem being targeted.
- As mind mapping approach suggests to use landscape mode instead of traditional portrait mode of note-taking, page should be turned accordingly to landscape format. This allows to have the core concept being centralised on page and also helps to eradicate the physical space constrained when further branching of ideas happen from core concept on paper.
- To represent the goal or core concept, draw an image in the centre of paper.

- Colours should be used for emphasis, structure and creativity. This will help to simulate visual flow and efficient memorisation.
- Next, draw thick lines branching out from the main idea or central image.
- Use of curved lines is encouraged while joining different concepts on paper as it is proven that curved lines are more visually appealing to eyes than straight lines and thus helps in information retention in memory.
- For each branch, write one key word to associate it with a topic.
- It is also suggested to add few empty branches on mind map, as these empty branches will prompt brain to think more to fill them and thus simulating more thoughts to enrich information.
- Proceed to create second and third level branches for associated concepts or thoughts. This will result in a tree like structure where in core concept branch out to second level nodes which will be spread over to third level and so on.

2.2.5 Advantages and disadvantages of mind maps

Advantages of mind maps

Analysis of data collected in multiple studies [20] [18] [21] below are few benefits offered by mind maps

- Mind mapping is one of the easiest techniques to engage one's mind and bring out thoughts about a topic of interest.
- As it taps the creativity of individuals involved in creating mind maps by encouraging to add colours, lines, pictures and symbols etc., people feel more engaged and thus end result which is considered self produced gives happiness and sense of accomplishment to creator [22].
- As mind mapping is more engaging, it is perceived as fun and interesting by students and thus helps to motivate them to learn.
- According to Byrnes (2010), Structure of mind mapping is analogous to how our brain functions and this characteristic helps in enhancing learning capability and information retention by 95% as compared to traditional note-taking [23].

- Mind mapping is based on concept of creating nodes and branches of keywords and related concepts thus it also saves time in comparison to traditional note-taking technique where in individuals have to take lengthy notes and worry about grammar and punctuation marks for better quality notes, which is avoided while using mind maps [23].
- As mind maps are like tree structures where concepts or keywords are interlinked as branches at different level, it provides more clarity and on topics of interest. This also helps in visualisation of closely linked concepts and better memorisation.
- Mind mapping provides meaningful learning than basic memorisation of facts via traditional note-taking technique.
- Mind mapping is useful for individuals as well as groups for brainstorming, as it helps to exchange ideas between people and come up with agreed and structured information in form of interlinked nodes with relevant concepts and facts [22].

Disadvantages of mind maps

Nothing in the world is perfect, and the same applies to mind mapping technique as well. Though it has multiple advantages, it also has few drawbacks, as listed below.

- Mind maps are mostly personalised notes of an individual and thus for a mind map which is very useful for one's own usage might be difficult to understand for other user.
- As students are mostly taught with traditional note-taking techniques in their early age, it is tough for both teachers and students to adopt mind mapping technique at later stage due to simple human psychological barrier to change the way things are already being done. This means they need both willingness and time to get used to it [18].
- As mind mapping is mostly done on paper, the size of paper limits the size of mind map being created.
- According to Menn (2013), mind maps which have more than two branches tends to be increase complexity of mind maps and thus its effectiveness [24].
- Mind maps are normally self-explanatory, but readers who did not actively participated while mind map is created might face challenges to understand the information being conveyed through mind map.

Though mind maps have some drawbacks, advantages they provide still outweigh the disadvantages as relevant from several studies in the past, which shows that mind mapping technique is better than traditional note-taking techniques.

2.2.6 Applications of mind maps in teaching

Creating a favourable environment for students to engage them in learning is not always easy. Due to engaging nature of mind maps, their usage in academic settings have grown recently [25]. As mind maps have a visual appeal, it promotes better understanding for students. Based on analysis from studies[26] [25] [27] [18], below are few areas where use of mind maps can help teachers and enhance learning experience of students.

- Teachers can make use of mind maps to prepare their lecture notes, as it requires less note-taking compared to traditional technique and allows both teacher and students to have an overview of the whole subject at a glance.
- Teaching requires a well-organised planning and according to Buzan (1994), mind maps can be used to provide overview of whole year study program with divisions and lessons to be covered.
- Mind mapping can be used to introduce new concepts as they are perceived more interesting by students and help to retain information for longer period.
- Mind maps can be used by students for brainstorming and project planning.
- Mind mapping can also be used as an evaluation tool by teachers, as students can present what they learnt with help of mind maps and teachers can quickly assess the information at a glance to evaluate students.

What can be taught through mind maps?

- Speaking

  Communication is considered as one of the most important language skills, as it enables us to express our feelings, thoughts, and opinions. Teachers use multiple techniques to enhance speaking skills of students, and mind mapping is one of those techniques. One of the most challenging tasks for students when asked to speak about a specific topic is lack of what all to speak and in what sequence. This can be overcome with the help of mind maps, where in students can put the central idea on paper and then brainstorm what all

to speak about it. This could be an individual task or group brainstorming to agree on specific things to speak about [18].

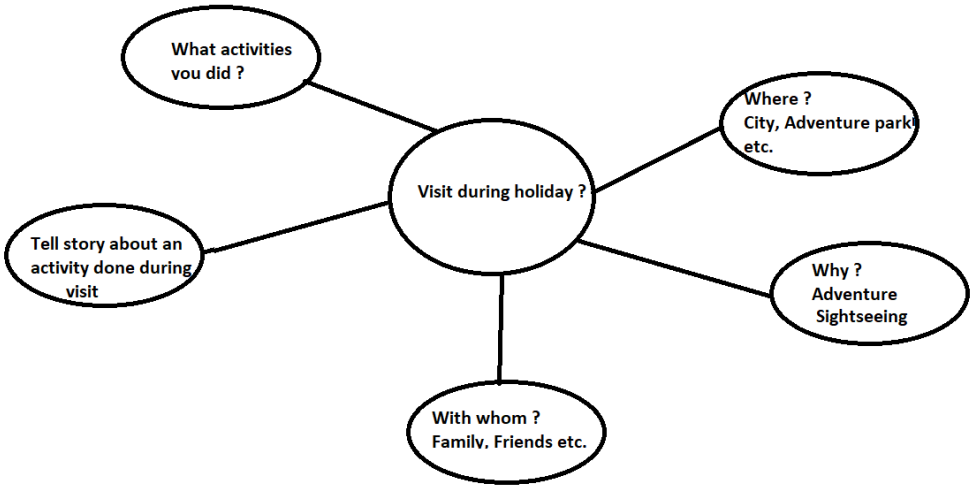


Figure 2.3: Example of mind map used to brainstorm for speaking task

The above figure shows an example where in students were given a task to speak about their visit during the holidays. Students may start with Visit as the central idea of mind maps and explore different related thoughts like What they visited, Where it was, What activities they performed during the visit and can do a story telling about one of the activities they did during the holiday. Such a mind map can be prepared by teachers or brainstormed between students to organise what they will speak about. This way mind maps can be used to enhance communication skills.

- Listening

First language skill any human encounter in his life is listening. Thus, it is the most vital skill to improve overall learning experience.

As stated by Guinan (2015) mind maps can be used to enhance listening skills as following.

Mind maps can be used as general predictions before listening of content. In this approach students are provided with a central idea and coloured branches with related keywords and students can append it with their own ideas and branches.

Mind maps can also be provided to predict the language, with a central idea and branches for parts of speech. Students can then append the mind

maps with noun, verbs and adjectives etc. which they expect to hear during speech.

While listening, students can be given a pre-filled mind map with central idea and branches. The students are then expected to listen and add relevant branches and keywords to mind maps.

A study done by [28] also showed that mind mapping is a promising approach to improve listening comprehension and vocabulary for students.

- Reading

  Most students are reluctant to reading long texts as it is perceived as time-consuming and even boring by some of them. Another reason for this reluctance is also lack of vocabulary [18]. As mind maps have visual appeal due to use of colours, pictures, inter-related branches etc., it helps students to make connection and associations thus making reading more interesting. Students may also be provided with a task to summarise the text they read with help of mind maps, as this will help teachers to grasp what the student learnt at a glance.

- Writing

  Writing is considered as one of most challenging skills and have always posed challenges to students at different levels. The difficulty in writing can be contributed to the fact that students need to think of ideas and connect those ideas into a meaningful structure to produce quality text.

  As mentioned by Hdii (2015) [29] mind maps can be used in pre-writing stage as it provides an efficient way to brainstorm and plan what all ideas should be considered while writing the final text. The mind map created in pre-writing stage can then be used as a framework for writing the whole text. One of the examples for use of mind maps in writing is the brainstorming done to structure a thesis for writing. Below figure shows a high level overview of sections that needs to be considered while writing the final text.

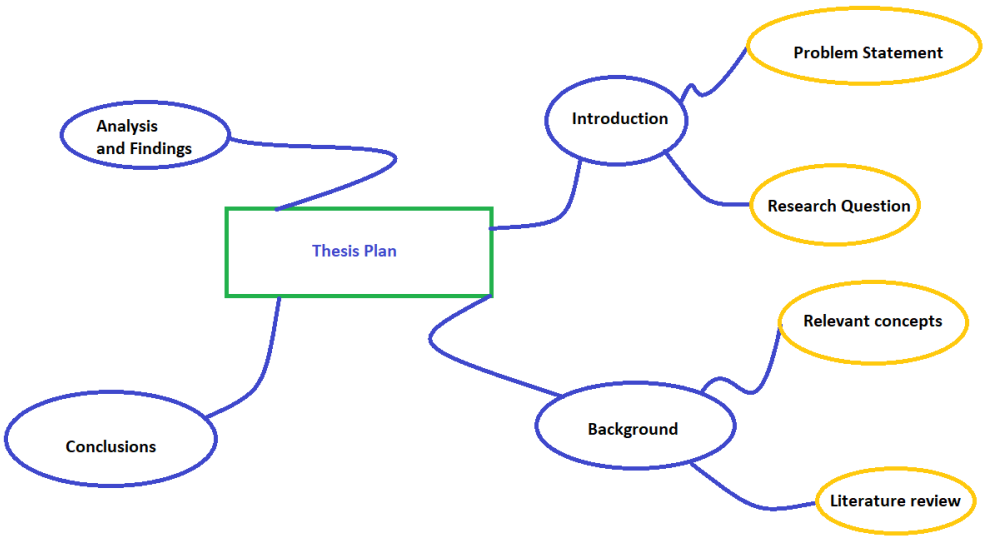


Figure 2.4: Brainstorming about thesis structure for writing

- Grammar

  Grammar is considered very important in language skills as it is an essential part of all four language skills i.e. listening, reading, writing and speaking. Limited knowledge of grammar severely impact individual's ability to learn and communicate. Student faces different challenges while learning grammar and several researches are done in past to find out efficient ways to teach grammar to students. Many methods are proposed by researchers, including use of mind maps. Mind maps can be used at different stages of grammar teaching and learning, for instance while preparing for lecture, revision and also evaluation.

  Below figure demonstrate an example of a mind map used to teach students about different articles in grammar. As compared to linear texts, mind maps provide better visualisation of concepts and their interrelations and thus are considered more efficient.

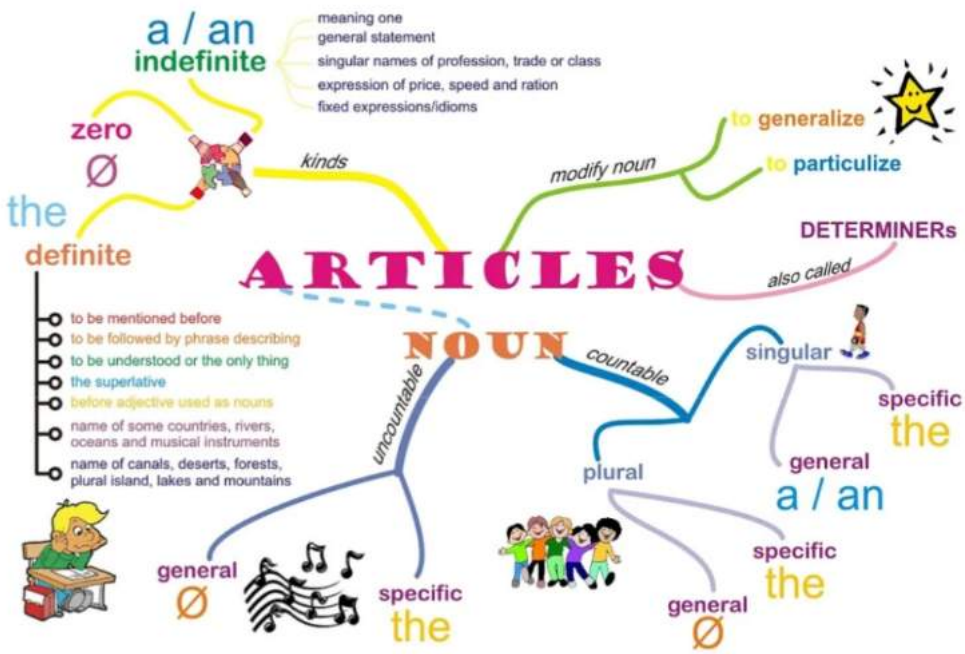


Figure 2.5: Mind map for teaching articles [30]

2.2.7 Mind mapping tools

With advancement of technology in the 1990s multiple organisations started development of software that allowed user to create digital mind maps. Such tools make it easier to visualise and work through an idea or strategy, and to allow a user to map his thoughts in an organised structure. There are several tools available in market which facilitates creation of digital mind maps. A few of the most popular and used tools based on studies [31] [32] [33] are briefly discussed below.

iMindMap is a mind mapping software developed by Buzan organisation linked to Tony Buzan who developed the mind mapping techniques. This tool was developed to mimic the process of hand drawn maps. It boosts a simple yet well-designed interface that allows to place the central idea in the middle of the screen and add topics/ideas around it. It also has an option to switch to hand-drawn branch mode, which allows the user to be more creative and give a personal touch to the mind map. It has a powerful search functionality which could find relevant words across single or multiple mind maps and also allows export of mind maps in different formats like image, document or PDF [33].

MindMeister is a web based mind mapping tool that can be used to create intuitive mind maps with real time collaboration. It can be used for in class learning as well as virtual classrooms. The platform offers templates and various editing tools to create mind maps but also have functionalities like chat with group, see contributions of an individual and vote on ideas. A library of images is also available which can be used to enrich information and users are free to add video and audio to their mind maps to make it more interesting. Created mind maps can be shared via email or link, so others can view or edit [34].

Lucidchart is a diagramming tool which can be utilised for creation of visual maps, including mind maps. It facilitates user for creation of mind map by providing features like drag and drop of shapes on maps, automated layouts, co-authoring via collaboration and a chat box for messaging between group. Though this provides an array of functionality, one of the major set back is that it can not be used offline and thus data is saved on a distant server instead of user's local storage [35].

XMind is a mind mapping software that allows users to generate ideas, goals and tasks. It comes with set of interesting features like pre-defined mind map templates, shapes etc. It also boosts a Zen mode to help focus on a single mind map, and addition of mathematical equations is also possible. User have possibility to password protect their mind maps and share it across. One of the disadvantages reported by users is that it is quite slow when loading larger mind maps [35].

2.3 Augmented Reality

Augmented reality is a promising technology that allows superimposing digital information on real world objects or space to enhance user experience. It can be considered as an advancement of Virtual reality, which creates an immersive but digital world for the user that encapsulates the user from real world [36]. Users can experience the world through handheld devices like mobile phones or head mounted displays, which are either see-through or capable of overlaying virtual objects over real surroundings. Augmented reality enhances user experience by combining real and digital world, unlike other interfaces that tend to draw user far from real world and focus on information on screen [37].

Augmented reality can also be defined on three characteristics [38]:

- AR combines real world environment with computer graphics
- It allows real time interaction with surroundings of user
- It is three-dimensional

2.3.1 Evolution of AR development

Augmented reality though gained its fair share of popularity in recent decade, but the idea of its existence could be traced back as far as 1901, when author Frank Baum first came up with the concept of electronic glasses that could overlay data over real life. However, it was only around the late 50s when Morton Heiling patented Sensorama, a simulator that was capable of incorporating visual, sound, and smell effects to enhance the cinematic experience for viewers. This simulator was not computer controlled, but was considered as the first genuine attempt to provide enhanced experience with additional data [39].

In 1966, Ivan Sutherland invented a head mounted display, which helped him to create the first augmented reality system with a see through display. Later, in 1975 L.B. Rosenberg developed Virtual Fixture, which is considered as the first functioning AR system that was capable of demonstrating human performance.

Figure 2.6: Sutherland's hand mounted display [39]

In following years, more advancements were seen in field of Virtual and Augmented reality application and interfaces. Myron Krueger designed Videoplace in 1975, which was the first display that allowed users to interact with virtual objects in real-time [40]. Followed by use of the term "Augmented Reality" by Tom Caudell, a researcher from Boeing, to describe a computer based display used by electricians that combined virtual objects with real world [41]. In 2000, Hirokazu Kato from Japan developed ARToolKit, a software that allows to capture real world actions and connect it with virtual object communication [42].

In 2009, Esquire Magazine utilised the potential of augmented reality in print media. Where in magazine issue had barcode which can be scanned by users to view AR content [43].

Figure 2.7: Esquire magazine's AR based bar code [44]

Google launched its augmented reality glasses, Google Glass, in 2014. These can be worn by users like a normal eyeglass and allows users to immerse themselves

in action. It can be used to access number of applications like Google Maps, Gmail etc [45].

Figure 2.8: Google Glass [46]

Though several advancements were made in augmented reality in a couple of previous decades, however, the real inclusion in life of normal people is considered to be the launch of "Pokémon Go" which ignited a global craze. This game allowed users to interact with virtual characters and try to catch and fight with them in real life locations like park, building etc [43].

Figure 2.9: Pokémon Go [47]

In 2022, exploiting the potential of augmented reality, French National Sea Center Nausicaá the largest aquarium of Europe teamed with SAOLA Studio to provide one if its kind of experience to visitors, where in they can interact with

virtually placed endangered sea creatures together with physical animals present in the aquarium. This project was developed to raise awareness for endangered species in a fun and interactive way to sensitise visitors with the effect of human activities on ocean life [48].

Figure 2.10: Augmented experience at French National Sea Centre Nausicaá[48]

2.3.2 Types of Augmented Reality

Based on their functionality, AR applications can be divided into two broader categories, Trigger based and View based. Where in trigger based augmentation is initiated by stimuli which could be a marker, location or a combination of other characteristics. On the other hand, view based category include digitised augmentation irrespective of what is in the view or augmentation of a static view. These two categories are subdivided into 6 types as shown in below table [49].

A list of augmented reality categories and types.			
Category	**Type**	**Examples**	**Characteristics**
Triggered	Marker-based: Paper/Object	String and Blippar	Paper marker activates stimulation
		Aurasma	Most objects can be made into markers.
	Location-based	Yelp, PAJ and Instagram	Overlay of digital information on a map or live camera view. GPS may activate stimuli.
	Dynamic Augmentation	Video Painter	Meaningful, interactive augmentation with possible object recognition and/or motion tracking.
	Complex Augmentation	Google Glass	Augment dynamic view and pull internet information based on location, markers, or object recognition.
View-Based	Indirect Augmentation	Wall Painter	Image of the real world augmented intelligently.
	Non-specific Digital Augmentation	Swat the Fly and Bubbles	18.Augmentation of any camera view regardless of location.

Table 2.2: Summary of augmented reality categories and types. [49]

As this thesis utilises Marker based augmented reality, it is discussed briefly as below.

Marker based augmentation is a trigger based approach, where in a static im-

age is used as stimuli to trigger augmentation. Use can scan the image through AR enabled application which triggers additional pre-defined content like video, animation etc. to appear on top of marker. Information for marker could be stored in local or cloud based database, however depending on where data is stored the performance varies and detecting marker through distant servers could impact performance of the application. It is also important that the markers are unique, specially when database of markers is stored in cloud, as there could be other projects or applications that might be using similar image as different marker [50].

For augmented reality application it is important that the markers can be detected in large field of view i.e. even when there could be slight distortions. Also, the markers should not be overpopulated with information, as it makes it difficult to extract information from distant view. Markers must have some distinct points, at least four, to allow calculation by camera involved in detection of markers. Such markers have quadrilateral outline and corner points (4) are used for 3D pose calculation [51].

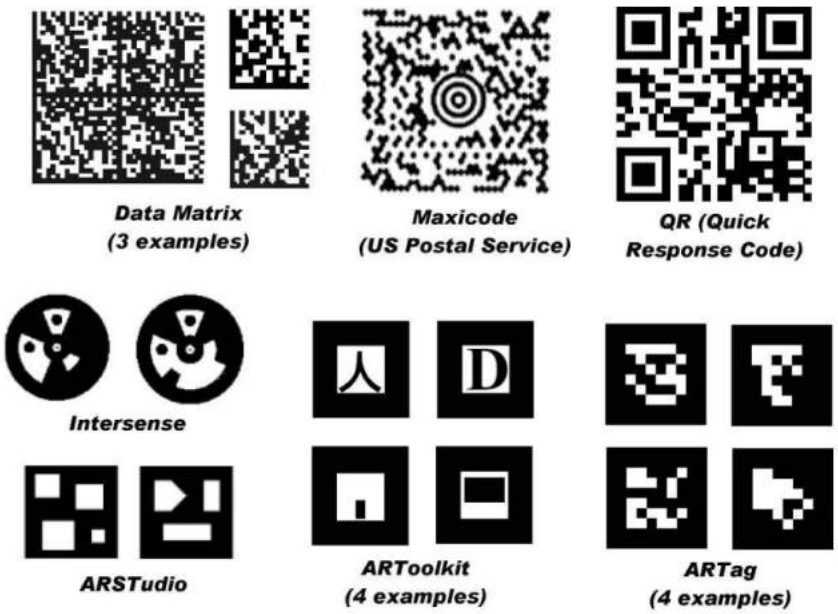


Figure 2.11: AR markers [51]

Whereas DataMatrix, Maxicode and QR are suitable for encoding information under controlled environments, they have limited field of view as distant captures could have issue due to distortions. On the other hand, ARToolkit use bitonal markers with black borders and pattern in interior which improves marker detec-

tion based on threshold values, but illuminating conditions could impact marker detection. Further, ARTag also used bitonal markers but instead of threshold detection approach of ARToolkit, it used edge detection technique to overcome the issue of detection under different illumination conditions. This also gives ARTag possibility to detect markers with slightly broken sides and missing corners, making it more robust [51].

3
Analysis and Findings

This section outlines and discuss the findings made during literature review done for this thesis. Firstly, comparison of traditional note-taking techniques and mind mapping is done to get more insight on advantages of mind mapping. Further, pros and cons of physical and digital mind maps are discussed. Also, different studies done in past on usefulness of physical vs digital mind maps is presented. The last part of this section explores the advantages and limitations of Augmented reality in mind mapping and how it can improve learning experience [20] [52].

3.1 Mind mapping Versus Traditional technique

As already outlined in this thesis, note-taking is considered as vital learning strategy and have shown positive impact on students learning performance. One of the major factor behind its usefulness is engaging nature of note-taking techniques which helps students to understand and recall relevant concepts. Multiple researches done in past compared traditional note-taking with mind mapping and their usefulness in different fields ranging from education at primary level to executive education [53].

Based on literature review and past researches 5 mind mapping benefits over traditional note-taking are discussed below.

Mind mapping enables meaningful learning

Researchers mentioned that learning can be defined in three levels[54]:

The first level is termed as Non-learning, which is defined as a state where there is no value addition to the student's knowledge before and after being taught a new concept. The next level is Rote learning, where in student build up knowledge but is not able to connect it to what is already known about the subject. Then comes Meaningful learning, which allows students to build up knowledge as well connect it to existing knowledge.

As mind mapping is based on building up on a central idea with connected keywords and branches, it enables students to be more engaged and allow them to connect new learned knowledge to existing one. Thus, it improves understanding, retention and recall of information and provides meaningful learning experience.

Research [55] done on Bachelor of science students to study effectiveness of mind mapping technique as compared to traditional note-taking showed that mind mapping enabled a meaningful learning experience for students and helped them to understand the subject better.

For this study, students were divided into two groups and were taught about theories of growth and development of children, where in first group was taught with use of black board and mind maps and other group was taught using traditional technique with black board. After a lecture of 45 minutes, acquired knowledge was assessed via multiple choice questionnaire.

Below table shows the mean score students achieved in their evaluation, where in students taught with traditional method scored 6.4, students taught through mind mapping technique clearly outperformed with average score of 8.4.

Group		**N**	**Mean**	**SD**
Knowledge	Mind map	15	8.4	1.183
	Traditional	15	6.4	2.197

Table 3.1: Effectiveness of mind mapping Vs traditional approach on learning (Edited from [55])

Further study done on nursing students for effectiveness of mind maps of learn-

ing showed that it was considered beneficial by nursing students to use mind maps to better understand the subject i.e., critical thinking for decision-making and improved their understanding of complex process [56].

Question	**Strongly Agree**	**Agree**	**Strongly Disagree**	**Disagree**
Mind mapping is useful to describe the concept of critical thinking	63.3%	33.3%	0%	3.3%
Mind mapping assisted me with communication on the subject of critical thinking	56.6%	36.3%	0%	6.6%
Mind mapping provided me with a wider perspective on critical thinking?	63.3%	33.3%	0%	6.6%
Mind mapping helped me put my ideas in some type of order.	76.6%	20%	0%	3.3%
Mind mapping is a useful learning strategy.	56.6%	40%	0%	3.3%

Table 3.2: Effectiveness of mind mapping for medical students [56]

Improves memorisation and retention of information

Mind maps have better visual appeal because they use concepts and interrelations which is analogous to how our brain functions, it enables for better memorisation, retention, and recall of information. This is evident from following researches done in the past.

Research discussed in previous section also supports this benefit, where in overall performance of students in evaluation was better when being taught by mind maps.

Efficacy of mind map technique was also explored in a study done in University of London[57], where in students were presented with a 600-word text and were then divided into two groups, where in first group was asked to apply their own study techniques and second group trained in mind mapping was asked to apply mind map technique. Based on results of the study, researchers found that mind mapping improved the retention of information by 10-15%. Though they also pointed out here that a better result can be obtained if motivation of students can be increased to use mind maps than traditional technique, as not all students were very comfortable with use of mind maps because of their experiences where in teaching was mostly done with traditional techniques.

Also, a qualitative study done by researchers from University of Ankara showcases the benefits of mind mapping in relation to memorisation and better retention of information [19]. Below table shows a summary of cognitive theme of study where in sample students were asked about what benefits they perceive while using mind maps. Out of 31 students who participated in survey put permanent learning through mind map on top place which was supported by 28 students, followed by use of right and left lobe of brain while using mind maps and improved remembrance.

Themes	Codes	No.	Sample Expressions
Cognitive	Ensures permanent learning.	28	"Page layout and colourful pens that we use ensures to be permanent."
	Ensures the usage of right and left lobes of brain actively.	17	"Mind map is a method in which we imprint information by using the right and left lobes of our brain in opposition to memorising."
	Facilitates remembrance	17	"Mind map is giving you a key while recalling. It enables you to open the door."
	Ensures envision of what was learned	16	"Studying by preparing mind map enables to prevent us from note extracting of 15-20 pages in vain." "Since we codify each information in a way that it will be kept in our mind, it becomes personal, and it becomes easy to remember."

Table 3.3: Cognitive benefits of mind maps [19]

Same study also put forward question to students to know about the purpose for which they deemed mind mapping as a better option and response from students after qualitative analysis was categorised as below. Interpretation of what was learned topped the findings, as students perceived it easier to remember and recall complex topics while using mind maps.

Themes	Codes	No.	Sample Expressions
Learning	Interpreting what was learned.	28	"I use it for envisaging the concepts, which is hard to keep in mind."
	Reinforcing what was learned and increasing the permanence	19	"Since we express mind map via symbols and pictures, we learn hard subjects in a permanent and funny way by using both right and left lobes of our brain."
	Preparing for exam	4	"I use mind map at subjects which I find them hard to remember while I prepare for exam"
	Concertising the abstract subjects	3	

Table 3.4: Purpose for mind map usage [19]

More engaging than traditional note-taking As mind mapping technique is an active learning approach, it enables students as well as teachers to be more engaged in content being studied. Learners are expected to be more engaged as they have to brainstorm the ideas and their relations.

Researchers pointed out that mind mapping is more engaging because it activates both sides of the brain. Where in traditional note-taking utilises the left part of brain which is for analytical thinking, mind mapping on the other hand also activates the right part which is closely associated with visuals, non-verbal thinking [58].

Another study done by researchers from University of Anakara, where in students were asked about benefits of using mind maps also showed that mind mapping improves engagement and is termed as fun activity compared to traditional note-taking. Below figure taken from the findings of the study shows different cognitive, affective and individual features which were perceived as usefulness of mind maps [19].

Themes	Codes	Sample Expressions
Cognitive	Ensures the usage of right and left lobes of brain actively	"Mind map is a method in which we imprint information by using the right and left lobes of our brain in opposition to memorising." "Since we codify each information in a way that it will be kept in our mind, it becomes personal, and it becomes easy to remember."
Effective	It is a funny activity.	"Mind maps are like traffic rules. We understand what it is when we see it."
	Increases interest, attention, and motivation.	"It is a funny job to study with colours and visuals, and so learning becomes funny in a way."
Individual features,	It is personal.	"It is funny because we use visual elements more than writings, and we express the information we have learned with personal pictures and writings "While it was boring to take notes before, thanks to mind map it became funnier, and it ensured my brain to operate multifaceted."

Table 3.5: Engagement with use of mind map [19]

Triggers creativity and enhances productivity

As demonstrated previously in this section, mind mapping enhances the engagement of students and as it uses visual cues it triggers the right lobe of brain which is responsible for our creativity and non-verbal thinking. Combined with ease of use, meaningful learning and brainstorming nature, it also improves the productivity. This is evident from past surveys or researches done in this field as following.

Researchers in their study mentioned that mind mapping improves creativity of individuals because it puts focus on brainstorming and radiant thinking, which is not the case when using traditional note-taking technique [58]. The same study also pointed out that as mind mapping uses keywords, symbols, and associations, the note-taking is faster than compared to traditional lengthy note lines. This saves time while taking notes but also to retrieve information later cause instead of lengthy multipage notes, one can refer to a mind map just on a single or even part of a page.

One of the bi-yearly surveys done by mind mapping blog of Chuck Frey to study the usefulness of mind mapping for professionals also found that respondents agreed that their productivity increased by 20-30% while using mind maps. This finding was also consistent for 3 consecutive bi-yearly surveys. The largest proportion of respondents in the study mentioned that mind maps increased their creativity by as much as 30% [59].

This is also backed by a study done on nursing students in Farmingdale state college, New York, where in 56.6% of respondents strongly agreed that mind mapping enhanced their creativity, followed by 36.4% who agreed. Merely 6.6% of respondents mentioned that they do not agree with it [56].

Also, study done by researchers from University of Ankara shows that most of the respondents agreed that mind mapping increased their creativity, imagination and visual perception [19].

Improves writing skills One of the most challenging tasks for students is to improve their writing skills. It is not only about what should be written about a subject, but also the organisation of information being written to produce quality notes. Mind mapping helps to organise thoughts around a topic and thus improves the writing skills. This is evident from multiple studies as following.

Study was conducted on 86 freshman EFL student, where in they were divided into two groups. The first group was taught with traditional technique for writing

and the other was trained for mind map usage while writing for a task. Students were assessed twice, once before learning usage of mind map and later by incorporating it in a writing task. There was no significant difference seen in median score of students from both groups in pretest, however a significant improvement was noticed in post test for students utilising mind maps. The median score increased to 60% as compared to pre-test where they scored 24%. This gain was much higher when compared to students taught with traditional writing technique[60].

Another study done on nursing student found that 76.6% of respondents strongly agreed that mind mapping helps to put ideas in some order, and it provides a wider perspective around the subject, which was supported by 63.3% of respondents.

Also, a study conducted on primary school students from Qatar, where in students were assessed on four skills of writing i.e. grammar, punctuation, spelling, and content. For the study, students were divided into two groups of 24 students. One group was provided instructions for traditional writing and the other with mind maps. A pre-test and post test was conducted to assess the skills. Significant progress was seen in the group which utilised mind mapping technique as evident from increased mean score in post-test, show in below figure based on data taken from study [61].

Skill	**test**	**Mean**	**N**
Total	**post**	**11.542**	**24**
	pre	7.8750	24
Grammar	**post**	**2.0208**	**24**
	pre	1.0208	24
Spelling	**post**	**2.0203**	**24**
	pre	1.4375	24
Punctuation	**post**	**1.3958**	**24**
	pre	1.1042	24
Content	**post**	**6.1041**	**24**
	pre	4.3125	24

Table 3.6: Improvement in writing skills with use of mind maps [61]

3.2 Physical Versus Digital mind mapping

During previous sections of this thesis, we already demonstrated several benefits of mind maps over traditional techniques. Mind maps, which have their history ranging from 1960 when Tony Buzan developed this technique. However, with advent of technology during the 1990s, companies started working on software capable to create digital mind maps [62]. This also started a long ongoing debate on which medium can be considered as more beneficial for enhancing over all learning experience of students. Multiple researches and surveys were done in past around this topic.

A study done on pre-service science teachers by a Turkish university on perception and usefulness of physical and digital mind maps showed that most teachers agreed that mind mapping is better when compared to traditional technique. However, there was a division between teachers about who is the clear winner between digital or paper based mind maps, as both had their fair share of advantages over each other. Respondents mentioned on one hand that while preparing physical mind maps limitations were observed that includes lack of possibility to add photos and videos, correction of mistakes taking considerable time thus reducing productivity and very limited visual elements available that can be added to paper based mind maps. However, respondents also pointed out some advantages like less distraction, improved engagement, psycho-motor skills improvement and experience of learning by doing, which are less impacting when using digital mind maps [21].

Based on data collected from studies [62] [21] [63] [64] done in the past, a comparative analysis of paper based and digital mind maps is shown below.

Advantages of Paper based mind maps over Digital mind map	**Advantages of Digital mind maps over paper based mind maps**
Low cost, as basic requirement is to have a pen and paper. Could be supplemented with coloured pens as well for better visual appeal, but still low cost. However, digital mind map includes cost for the software which could be free sometimes but still an electronic device like laptop/tablet is required to draw digital mind maps.	The information that a digital mind map could contain is significantly much higher than paper based mind maps. User can use hyperlinks, photos, audio etc. to enrich information which is not possible in case of paper based mind maps.
As it is done on paper, the user is free to use whatever format or layout that seems fit for purpose. Whereas, limitations are present in digital mind mapping software, as different software restrict users to use specific formats.	Editing of information once a mind map is created is easy in case of digital mind maps. Whereas in case of paper based mind maps it can be achieved by crossing out already written information or overwriting, both cases will make the mind map look less visually appealing and thus less effective.
No constraint on when/where it can be created, as it is easy to carry pen and paper or even buy it on the go, if required. However, in case of digital maps, user should have compatible device as well as software. Needless to say, that just to create a mind map on the go, people will not invest money to buy a temporary device.	Searching for specific information from created mind map is much easier in case of digital mind maps.

Mind maps are considered unique creation of user, as all the elements in mind maps are hand drawn and in user's own format or style. This is not always the case in digital mind maps as different elements are unique to the user and some are based on supported styles of software.	If we have multiple mind maps, it is much faster to search for a specific mind map or even filter information based on specific keywords. Tags can also be used to categorise mind maps which might have interlinkage. This makes digital mind maps more efficient and productive.
Adopting paper based mind mapping have a very low learning curve as compared to digital mind mapping, where in user have to be technically sound or should spend considerable time to first get familiar with technology and use of electronic devices before even starting to learn to create digital mind maps.	It is possible to create templates in case of digital mind maps and user can use one of pre-defined templates to start working on mind map creation. It could save considerable time and user will focus more on content than design.
In classroom setting, creating paper based mind maps is perceived more engaging for students and thus considered more beneficial in terms of memorisation, retention and recall of information as compared to digital mind maps.	It allows collaboration in real-time between users present in different geographies. This is not possible in case of paper based mind maps, where in users are supposed to be physically present at the same place.
While creating hand drawn mind maps, chances of distraction are much less than digital mind maps, where in user might easily get tempted to start multitasking on a laptop/tablet without even knowing.	Digital mind mapping software does not have any size limitation on mind mapping, as compared to paper based mind maps restricted with size of paper being used.

Table 3.7: Advantages of Paper based mind maps over Digital mind map and Digital mind maps over paper based mind maps

Though both techniques have their fair share of advantages, but the debate

of which one is best in isolation could be never ending. One of techniques could be better in specific setting than other one, for instance, physical mind mapping could yield better performance in classroom setting but for collaboration over distance digital mind map can come to rescue. However, a gap still exists in both techniques. It would be more beneficial to have a solution that could integrate advantages of both techniques.

3.3 Augmented reality to enhance learning experience of mind maps

As already discussed in previous sections of this thesis, there is no doubt that inclusion of advantages of digital mind map technique can further improve usefulness of physical mind maps. However, the question that remains to be explored is how to bring the physical and digital world together ?

Real and Virtual world paradigm is well-defined by Milgram Reality-Virtuality Continuum as shown in below figure. It ranges from a complete real environment (reality) that can be viewed in real world to a completely virtual environment (virtuality). Between these two extremes lies the space of mixed reality, where both worlds blend in. This is further divided into two parts, augmented reality and augmented virtuality, based on proportion of real world to digital (virtual) information. Where in augmented reality have small amount of virtual data superimposed on real world, augmented virtuality have fewer elements from real world and more digital data [65].

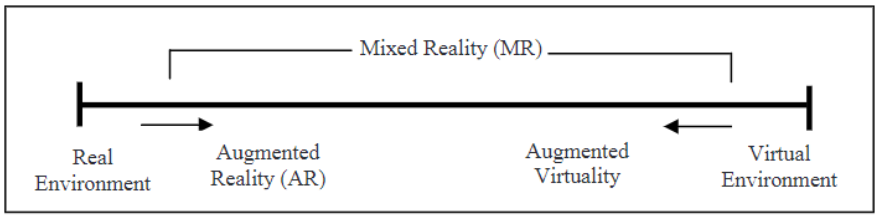


Figure 3.1: Milgram reality-virtuality continuum [65]

Augmented reality has been an interesting area of research to explore its advantages in learning and teaching processes around the world. It gathered this attention from research community because it is considered that learning experience provided by AR is unique and can not be achieved through other technologies.

AR takes interactivity with learner to a new level with utilisation of three dimensions and combining virtual and real world of user[66].

Below figure evidences the growing interest of researchers to explore Augmented reality in education between 1998 – 2020. It is clearly visible that the number of studies for effectiveness of AR in education jumped significantly, specially in last decade, which could be attributed to advancements in mobile technologies (smartphones and tablets) which allowed widespread reach of AR application to public [67]. As the study [66] from which data is taken was submitted in Feb 2020, data for 2020 is only for first two months and thus should not be considered as a severe drop.

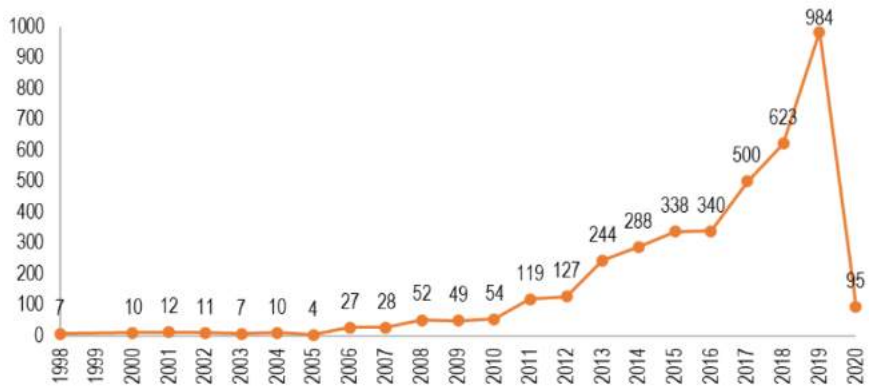


Figure 3.2: AR studies in field of education between 1998 – 2020 (February)[66]

Based on analysis of studies done in past on effectiveness of Augmented reality in education, this thesis outlines below benefits of AR that could be exploited to combine the advantages of physical and digital mind maps to enhance learning experience of students.

Inclusion of third dimension perspective improves understanding of concepts, even complex ones

Around the world, teachers, and students are still used to learn though two-dimensional mediums like text/images printed on textbooks, articles, or even e-learning sources. AR allows addition of third dimension, as it is capable of registering real and virtual world objects in 3D and thus allows user to visualise the learning content in 3D perspective. This enables students to visualise the phenomenon or concepts that are difficult or sometimes even impossible to be viewed in real life scenario, thus improves understanding of students [65].

A study done by Yeom in 2011 on medical students to study effectiveness of teaching anatomy through use of AR enabled 3D anatomy images and haptic feedback showed improvement in understanding of concept and resulted in better test performance of students [68].

Another study done by Cerqueira and Kirner in 2012 on mathematics students was done to study usefulness of AR to teach geometrical concepts through head mounted displays demonstrated that students were able to understand complex concepts in 3D space, when compared to traditional 2D learning experience [69].

Also, Lindgren and Moshell in 2011 too conducted a study to compare learning experience of astronomy through PC (Personal computer) and augmented reality based application. The study did not provide any significant quantitative differences, but qualitative analysis showcased that students conceptualised the content in different ways. Group which learnt through PC were more focused on surface details of planet i.e. visual look of planets, where the other group was focused on dynamics i.e. movement of planets. It should that there is a cognitive difference on students experience in case of AR applications [70].

Increases motivation

Due to engaging and immersive experience delivered by AR systems, it is considered fun and interesting by learners and thus motivates user.

A study done on fourth grade students from a school in Taiwan on 57 students showcased that the group for which teachers employed AR based learning, outperformed their counterparts with a significant difference in mean scores (4.05 Vs 3.63) for learning motivation towards the concepts being taught [71].

Also, study conducted on 81 kindergarten kids in Korea, who were 5-6 years old showed that the satisfaction level of group which was taught with AR enabled devices was much higher, and they were motivated to use AR experience in future for learning [72].

Less distracting than other digital mediums of learning

As AR is an immersive technology which allows real time interaction with user, it keeps learner more engaged and thus gives less scope for being distracted, unlike other digital learning techniques [73].

A study done by Yeom in 2011 on medical students to study effectiveness of teaching anatomy through use of AR enabled 3D anatomy images and haptic feedback also showed that due to immersive images and haptic feedback they found it more interesting to interact with the system, which eventually decreased chances for distraction and improved their understanding of concept [68].

As mentioned by R(Roda and Thomas, 2006), AR systems are capable of detecting students location, delivering task reminders and provide alternatives to refocus attention, thus such attention-aware features of AR may help in decreasing interruption during student's learning experience [74].

Enhances collaboration

A study was done on 40 undergraduate students divided into two groups with task to discuss and acquire knowledge about elastic collision phenomenon, where in first group used an AR enabled collaborative system and other 2D simulation. Assessment of acquired knowledge by both groups demonstrated that the group which utilised an AR enabled system for collaboration performed better than the 2D simulation collaborative system [75].

Morrison and fellow researches conducted a study on students, providing them a task to navigate a specific neighbourhood with use of AR map or digital map. The collaboration between students proved to be more effective in case of AR maps. AR application allowed them to create shared space to collaborate, in contrast to individual experience of students clubbed together in case of digital maps based on GPS [70].

Improves memory retention

An experimental study was done on participants divided into two groups, who were provided information about product and assembly instructions via paper based manual and augmented reality based medium. Pre-test was done for both groups to assess existing knowledge about the product and post test was conducted after 48 hours to assess the information retention, and it was found that mean score of group utilising augmented reality based system was 8.89, significantly higher than other group that had a mean score of just 6.33 [76].

Another study conducted on 40 first year polytechnic students divided into two groups and taught about fundamental mathematical concepts like geometric

equations, vectors addition, cross product through augmented reality based 3D interactive system and a 2D simulator showed that due to immersive nature of augmented reality based application learners had better memory retention and recall even after 3-4 weeks as compared with their counterparts[77].

Another study done on long term memory retention on Avionics students showcased that students who opted for AR experience to learn about turbines were able to recall more information after one week, compared to other group that chose to study from textbooks and videos [78].

Supported by researches and study discussed so far in this thesis, augmented reality that blends physical space with virtual/digital world is a promising technology that can be exploited to bring out the best of physical and digital mind maps techniques together to enhance overall learning experience of students.

4
Solution

In previous chapters, we provided background related to relevant concepts and ideas with which we intend to offer a solution to the problems presented in the introduction part of this thesis. It is important to consider all relevant concepts and information provided in background and finding and analysis sections to have better understanding of the solution being offered. This section outlines not only technical requirements, but also an overview of how the proposed solution is conceptualised before we can proceed further with implementation.

As already mentioned previously in this thesis, the main goal of this study is to study effectiveness of mind mapping over traditional note-taking technique and integrate benefits of physical and digital mind maps together to enhance learning experience for students. The first question here was about which technology can be used to integrate these two mind mapping techniques ? The answer to which is augmented reality, based on its capabilities to merge real and virtual world. This is also backed by analysis of past researches and surveys in the field of effectiveness of augmented reality in educational settings.

Further, in this chapter, we will give an insight on how we plan to address the research questions defined in the introductory chapter of this thesis.

RQ1: *What differences exist between physical and digital mind mapping tools and techniques, and what is their impact on how people learn?*

To address this research question, it is required to perform literature review of existing researches and surveys done in past which were specifically aimed at studying advantages and disadvantages of physical and digital mind mapping techniques in various educational settings. We have answered the difference between physical and digital mind maps in detail in the previous chapter "Analysis and Findings" and also discussed their impact on the way people learn. We have also discussed the tools and techniques of physical and digital mind mapping in the previous chapter.

RQ2: *How Augmented reality can be used to integrate Physical Mind maps with digital media to enrich information and make it more interactive?*

This is the core question that needs to be tackled in this thesis, as this will serve as the foundation of the solution being proposed. To address this question, it is required to do a literature review of existing studies related to effectiveness of augmented reality in field of education. This analysis will help to support why we choose augmented reality as the technology behind the solution being proposed.

Further, while designing the solution it should also be considered that both physical and digital mind maps have their specific advantages which should not be undermined. Our work is focused on the user who works in school or university and wants to keep ease of use and flexibility of physical mind mapping on one hand, but also missing out on the multimedia content offered by digital mind mapping technique which could enhance overall learning experience.

The application should provide two core functionalities: the User should be able to scan a physical mind map through the camera of a supported device and allow the user to enrich it with digital information by adding text, image and other multimedia files, thus offering an augmented mind map. Also, user should be able to retrieve information of existing augmented reality mind map by scanning an appropriate marker and allow user to modify the content.

Below section shows the process flow related to mentioned core functionalities that should be offered by the application.

The user draws a physical mind map on paper that can be scanned by the camera of a supported device running the application. Once mind map is detected by AR mind map application, user can add multimedia files as information or node over augmented view visible on device. This AR mind map with added information is automatically saved in the database for future use. This process is shown in figure 4.1.

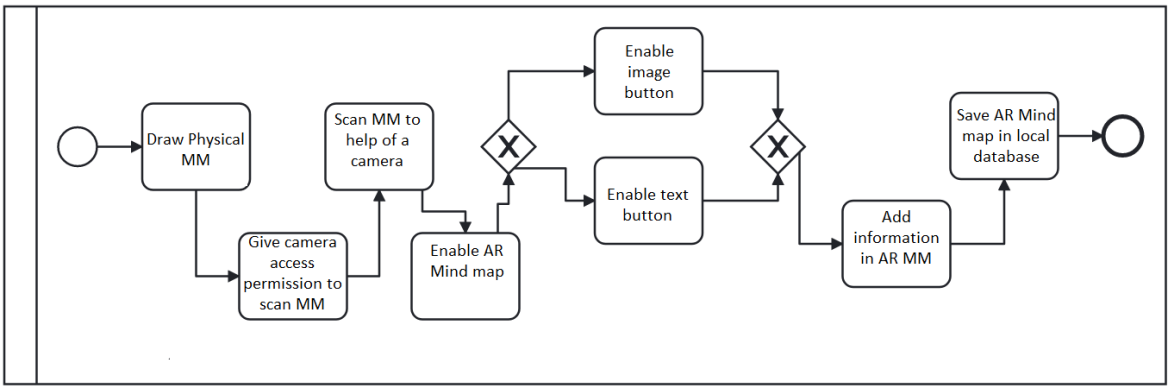


Figure 4.1: BPMN model of first application interaction from user

Fig. 4.2 shows the relationship between system and user interface perspectives on the process of going from a Hand draw mind map to an AR mind map. The process is described in detail as illustrated in Fig 4.2.

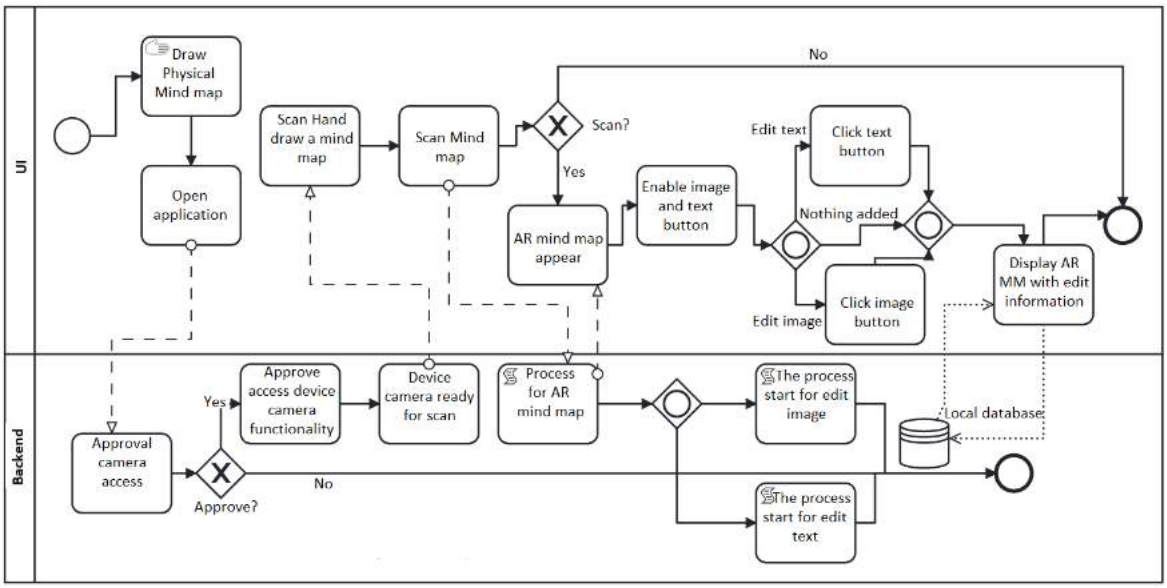


Figure 4.2: BPMN of Edit information in AR mind map

There are two option in which the user can use the application for editing information.

Below process shows how a user can add an image to AR mind map. The user has two options while inserting an image, i.e. taking a photo with the camera or using an existing photo on the device. This process is shown in figure 4.3

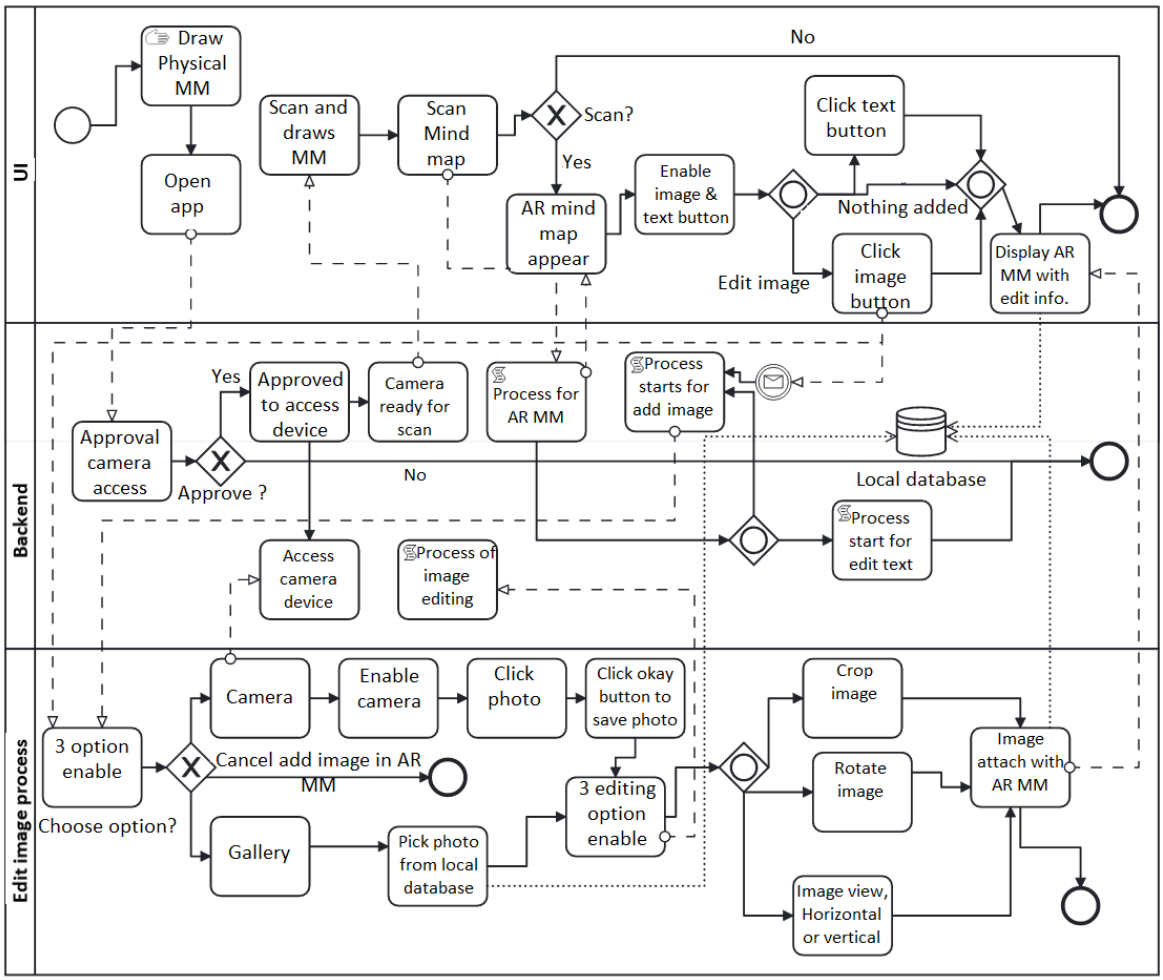


Figure 4.3: BPMN of Edit image in AR mind map

The application also allows user to add textual information on nodes in AR mind map. This process is shown in figure 4.4

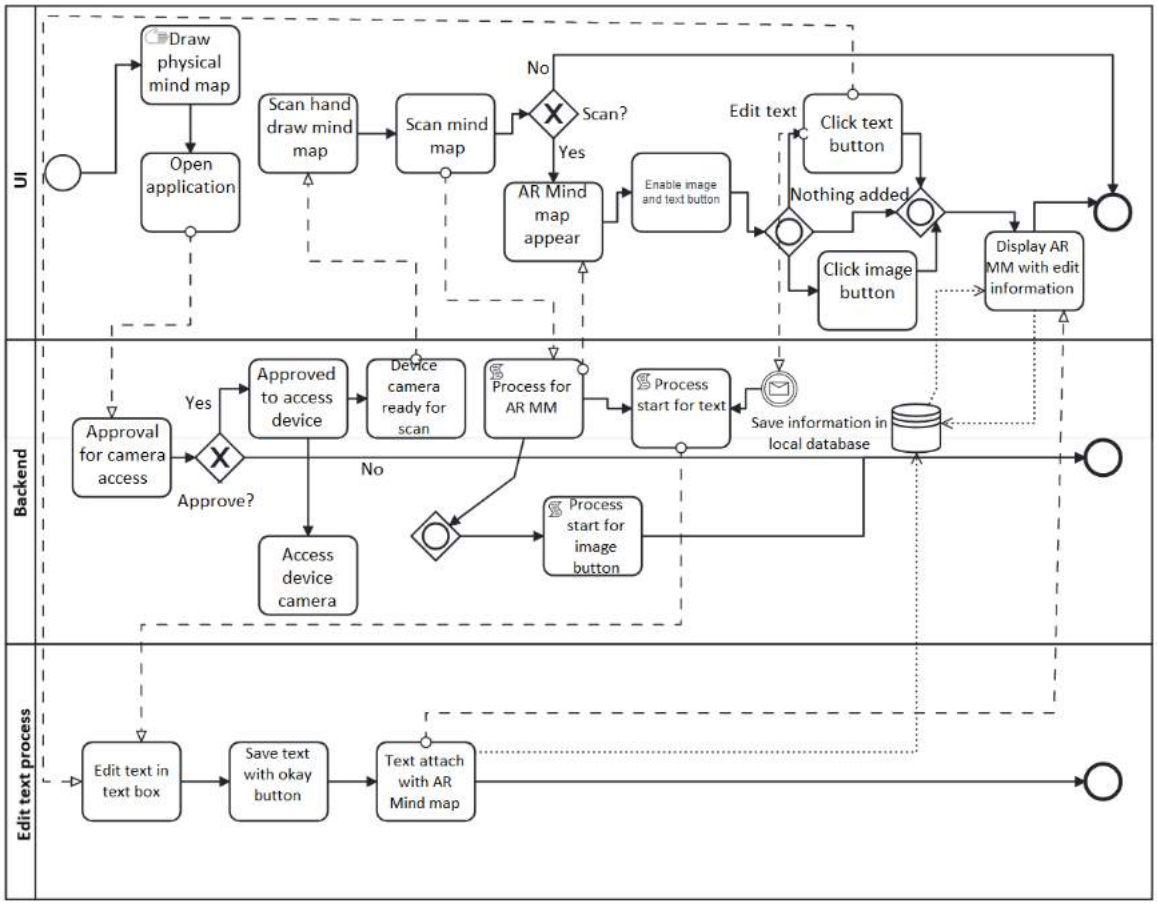


Figure 4.4: BPMN of Edit text in AR mind map

The second core functionality to be offered by the application is the ability to retrieve additional information added to the existing physical mind map in AR view. This should be possible by scanning the physical mind map possessed by the user with help of AR markers. Once the application detects the AR markers on physical mind map, it should display the augmented information added by user in past and should allow user to view/edit the information as per own requirements. This process is shown in figure 4.5.

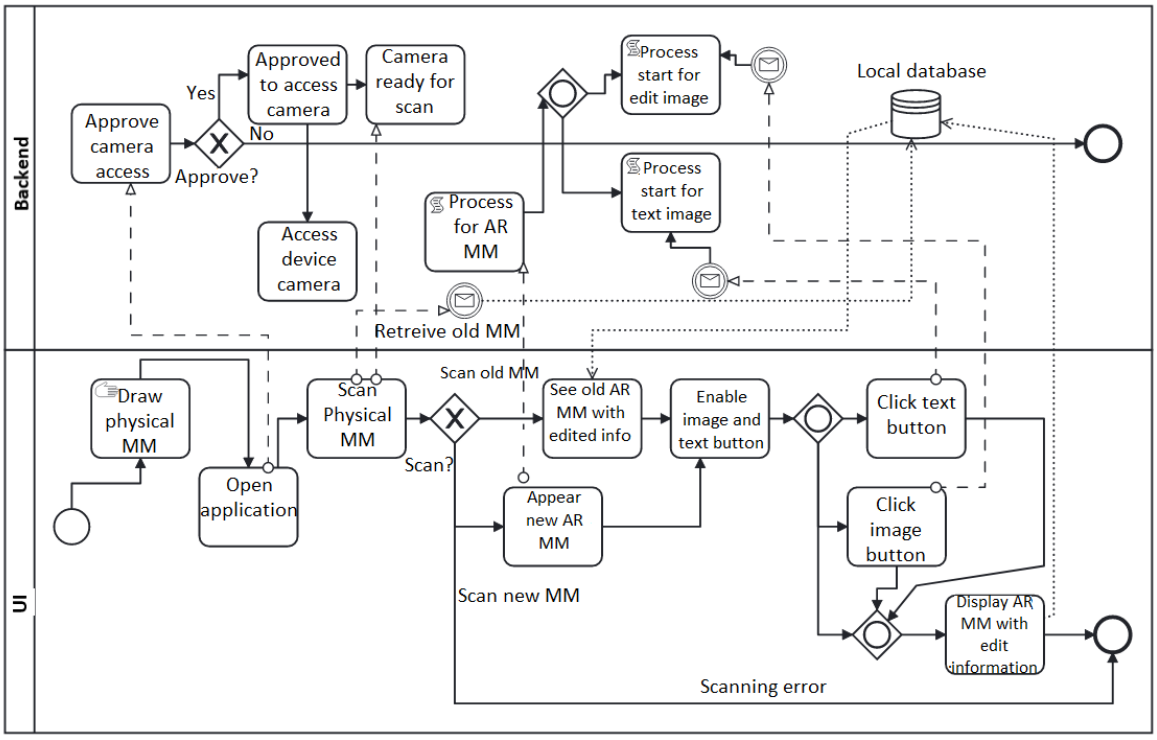


Figure 4.5: BPMN of Retrieve mind map from database

RQ3: What tools are available in the market that can be used to implement a user-friendly Augmented reality based mind mapping application?

We have to consider the tools that allow us to develop a mobile based application, which at the same time implements augmented reality resources, that would allow the user to enrich physical mind maps with overlaying digital information. It is crucial to evaluate all the tools and technologies that function well together and choose those that are best suited to accomplish desired goals of application.

RQ4: How to implement a solution that allows integration of advantages offered by digital and physical mind maps?

This research question can be addressed in three parts, where in the first part deals with analysing existing studies and surveys relevant to pros and cons of physical and digital mind maps and their effectiveness in academic setting. This will help to uncover benefits of both techniques which will serve as input for the second part which takes care of analysing available tools and technologies which

are compatible to each other and capable of developing an augmented reality based application. The last part is for the implementation of proposed solution, which will require to expand our existing knowledge related to development environments and tools related to augmented reality and integrate various components to create a working prototype based on proposed solution so far.

5 Implementation

In this chapter, we discuss the reasons behind choosing specific tools and frameworks that should be adopted to develop the proposed application. As discussed in previous chapters, the main objective of the application being developed is to combine the benefits of physical and digital mind maps with the help of augmented reality. Thus, the first part of this section analyse available tools and technologies that were considered to choose the best fit for our purpose. Afterwards, we present the conceptual design of the application and its architecture.

5.1 Analysing Augmented Reality tools

Augmented reality (AR) technology has been growing at a fast pace in the past few years. It allows users to see digital data superimposed on top of the real world. Different types of AR applications are available in market suitable for use in various industries like education, medical, navigation, and aviation etc. The popularity of this technology has caused a flurry of activity among software developers and programmers on how they can make use of it in their own applications to provide exceptional user experience. Various tools and development frameworks are also available in market that allows software developers to create application with unique experience. This section will discuss various AR development tools available for developers, together with their strengths and limitations. [79] [80]

5.1.1 ARKit

ARKit is a software development kit offered by Apple that enables developers to integrate augmented reality into their applications. It makes use of device motion tracking, camera scene capture and display convenience to build an augmented experience for the user [81]. The app allows developers to create 3D content on iPhones and iPads. Using real-world cameras and sensors, developers can interact with immersive environments using real-time rendering, environmental understanding, motion tracking and so on. [80] [79]

Advantages	**Disadvantages**
As ARKit is offered by Apple for developing augmented applications for iOS devices, it is available free of costs to developers.	Though ARKit is designed to detect less visible objects, however, sensing capability of the camera of a supported device might impact the usefulness of ARKit.
With Apple A9 and Apple A10 processors, ARKit provides your app with optimised renderers, motion tracking and new particle engines to help you develop awesome augmented reality experiences.	As this SDK is aimed to facilitate development of application for iOS devices, it supports all iPhones, iPads, and iPod touch devices across all generations but not available for android user.

Table 5.1: Advantages and Disadvantages of ARKit [79]

Though, ARKit allows developer to develop awesome augmented reality application for iOS devices, however, considering share of Android users across the world which is much higher than iOS users, it does not seem to be a perfect match for our purpose considering it will significantly limit the user base of our mobile based application.

5.1.2 Vuforia

Vuforia is a software development kit for developing augmented reality applications for mobile devices. The Vuforia platform is capable of detecting and tracking images in 2D space, as well as 3D objects in real-time. This platform can be integrated with different programming languages and operating systems. The Vuforia platform can be used to embed 3D models into live images such as video, photos,

or videos shot at different angles to create a 3D Website. [79] [80]

Advantages	**Disadvantages**
Integration with third-party tools makes Vuforia platform more flexible.	The code used by Vuforia is bulky and can be tedious to write. This can also be a barrier for people who are only familiar with JavaScript or Python.
Beginners can benefit from the free version, which is easily accessible online. The software is easy to use and even has a free trial.	Tracking of markers is quite complex in terms of programming where developer might have to write hundreds of line of code, which is considered tedious.
	Connecting to native modules can be challenging for Vuforia.

Table 5.2: Advantages and Disadvantages of Vuforia [79]

Though Vuforia offers advantages like third-party tools integration and platform independence, however, considering the efforts that need to be put in to learn the framework and complex programming that is required for AR marker detection as compared to what is offered by other development tools, we decided not to adopt Vuforia for development of application in this thesis.

5.1.3 ARCore

Augmented reality (AR) is a real-time concept that has been developing rapidly over the past few years, especially in the mobile industry. ARCore allows developers to create applications capable of recognising and being responsive to the user's environment. These capabilities provide developers with a platform for creating full-featured AR experiences on any Android device. ARCore developers can access a variety of APIs to support objects in the environment, motion tracking using the phone camera data, environmental understanding, and integration with the phone sensors [79] [80]. ARCore, being a product of Google was available for Android development, however, to expand the reachability of application developed on ARCore it has compatible APIs that can be used for other platforms and is available now for Java (Android), Unity (iOS and Android), Unreal Engine and iOS [82]

Advantages	**Disadvantages**
ARCore is built into Android OS, it makes it easier to run AR enabled applications on supported mobile, without need of specialised accessories.	As ARCore is integrated into Android operating system, it also means that older version of devices will not be able to support it.
The user base of Anroid enabled device is over 100 million, which is significantly higher than iOS and other mobile operating systems. Thus, ARCore based applications have a better outreach to public..	ARCore is a tool that can be used to develop AR applications without supporting devices. AR apps are typically developed using Android Simulator, which has limited capabilities and is still in its development stages.
Google, the leading providers of ARCore technology, have allowed app developers to publish their AR apps on the Google Play Store. With this platform, there is a steady supply of applications and knowledge sharing across the industry. Extensive documentation and community support is also available for ARCore.	
By using ARCore with Unity 3D, you can create augmented reality applications for your Unity app. By incorporating maps, email, or other dynamic objects, developers can add many new features to existing apps.	

Table 5.3: Advantages and Disadvantages of ARCore [79]

Ease of use of ARCore software development, combined with the user base that can be exploited and extensive documentation and community support, makes it one of the most promising candidate for our purpose. However, we will do an in-depth comparison of available features and capabilities in later part of this chapter to reach to a conclusion.

5.1.4 Wikitude

The Wikitude platform is an SDK for augmented reality that allows users to create applications using motion tracking and scene understanding, as well as light estimation within the environment. It combines development capabilities with other cloud services that enable users to use its studio without necessarily writing code. The AR editing capabilities allow users to provide videos, images, and text without any expert skills. Wikitude SDK is a commercial solution, but not limited to Google play store or Apple App Store. It is also available as a free trial version with some limitations like the Wikitude logo in the cam view etc [79][83] [84].

Advantages	**Disadvantages**
It is easy to use and has a simple interface that can be operated without any technical knowledge.	As it is a third party tool, most of advanced functions needs to be purchased.
It also supports different platform like Android and iOS.	The tools lack originality because it combines the functions of various other AR toolkits, which makes it vulnerable to bugs.
	Wikitude is less preferred for expert application developers due to its weaknesses. Their SDKs are poorly designed and use too much processing power, poor UI performance, and lack extensible.

Table 5.4: Advantages and Disadvantages of Wikitude [79]

As Wikitude SDK have quite a number of disadvantages like vulnerability to bugs due to combined ARKits, Poor design causing requirement for high processing power and most of advanced functions available only to paid users, we decided not to use it for our purpose.

5.1.5 Kudan

It is an Android based solution that enable developers to create application based on the recognition of simple images and 3D objects. It also offers a specific framework for developing applications with 3D assets, which can be easily exported to

other platforms. The framework supports markerless tracking and SLAM, meaning that it can recognise objects without using visual markers placed on them, using sensors such as stereo and visual-inertial depth cameras for deeper realism[84] [85].

Advantages	**Disadvantages**
Kudan offers robustness against scenery changes and dynamic objects, that helps in recovering from a number of failure states. It also provides for transparent handling of state transitions [86].	Kudan use markers, however, does not provide functionality to create them in the platform. [84].
The Kudan platform is a fully functional, scalable and reliable solution for the SLAM problem (Simultaneous Localisation and Mapping) problem [84].	The free version for Kudan is for testing purpose only [87].

Table 5.5: Advantages and Disadvantages of Kudan

Based on the fact that the free version is only for testing purpose and with limitations of platform to allow generation of markers which is one of requirements to be tagged to physical mind maps, and user base restricted to Android, this SDK does not seem to be a perfect fit for our application development.

5.2 Comparison of Augmented Reality Tools

The table 5.1 below shows comparison of available features and capabilities of software development kits analysed so far in this chapter.

Comparable field	**Augmented Reality Tools**				
Tools	**ARCore**	**ARKit**	**Wikitude**	**Kudan**	**Vuforia**
Platform	Android iOS Unity	iOS Unity	Android iOS Unity Window	Android iOS Unity	Android iOS Window Unity
Facial tracking	Yes	Yes	No	No	No
Point cloud	Yes	Yes	Yes	Yes	No
Anchors	Yes	Yes	Yes	No	Yes
Light estimation	Yes	Yes	No	No	Yes
Environment probes	Yes	Yes	No	No	No
Collaboration	Yes	Yes	No	No	No
Occlusion	Yes	Yes	Yes	No	No
Ray-casting	Yes	Yes	Yes	No	Yes
Pass-through video	Yes	Yes	Yes	Yes	Yes

Comparable field	**Augmented Reality Tools**				
Tools	**ARCore**	**ARKit**	**Wikitude**	**Kudan**	**Vuforia**
Session management	Yes	Yes	Yes	No	Yes
Camera	Yes	Yes	Yes	Yes	Yes
IMU	Yes	Yes	Yes	Yes	No
GPS	Yes	Yes	Yes	Yes	Yes
Open source	Yes	No	No	No	No
Price	Free	Free	Paid	Free, paid	Free, paid

Table 5.6: Comparisons of several available features in Augmented Reality Tools[85]

5.3 Analysis of AR frameworks and development environment for ARCore

5.3.1 Targeting of AR frameworks

There are several frameworks available that facilitate rapid prototyping and development of AR (Augmented Reality) apps. Among the most popular ones are : ARCore, ARKit, Kudan, Wikitude and Vuforia in Fig 5.1. Besides the fact that ARCore and ARKit are free of charge and continuously evolving, they already caught the attention of the market [88].

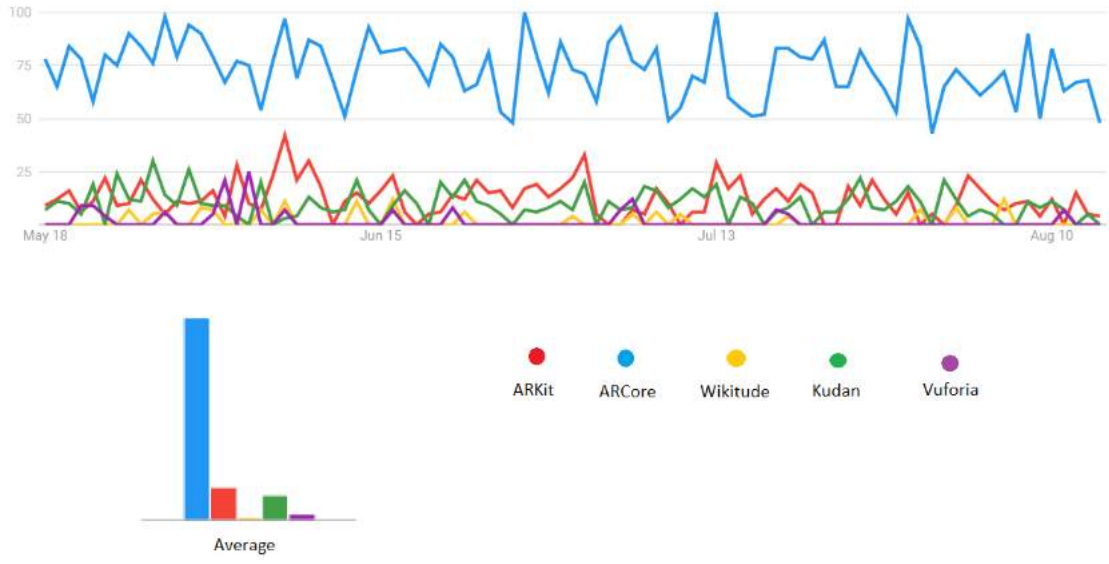


Figure 5.1: Popular AR frameworks are gaining popularity around the world. (Source: Google Trends) [89]

Where a graph showing the popularity of a term relative to the highest point on the chart for the given region and time. A value of 100 is the peak popularity for the term. A value of 50 means that the term is half as popular. A score of 0 means there was not enough data for this term [88].

5.3.2 Targeting of Development environment of ARCore

There are four development environments for Arcore that are available to facilitate rapid prototyping and development of AR (Augmented Reality) apps. Among the most popular ones are: Android, iOS, Unity and Unreal in Fig 5.2. According to Statistic, Android is leading the global mobile app development market, holding a dominate position with nearly 95% share. As of January 2022, Android owns the major share with 69.7%. Android is a more profitable option for businesses targeting Asian and European markets. Research suggests that android apps are growing in popularity as a result of this trend, but businesses outside of Asia also have an opportunity to benefit from the platform. Smartphone to customise, Android, is the clear winner. Google provides more freedom to its developers than Apple, which offers a closed system and does not provide the source code to the developers. It becomes challenging to make any changes to the feature on Apple devices. Hence, Android is ultimately the better platform if customisation is your priority. The Google Play Store is the world's most popular app store, with a

catalogue of 3.48 million apps on offer. This means that users are able to find millions of apps for the Android devices [90].

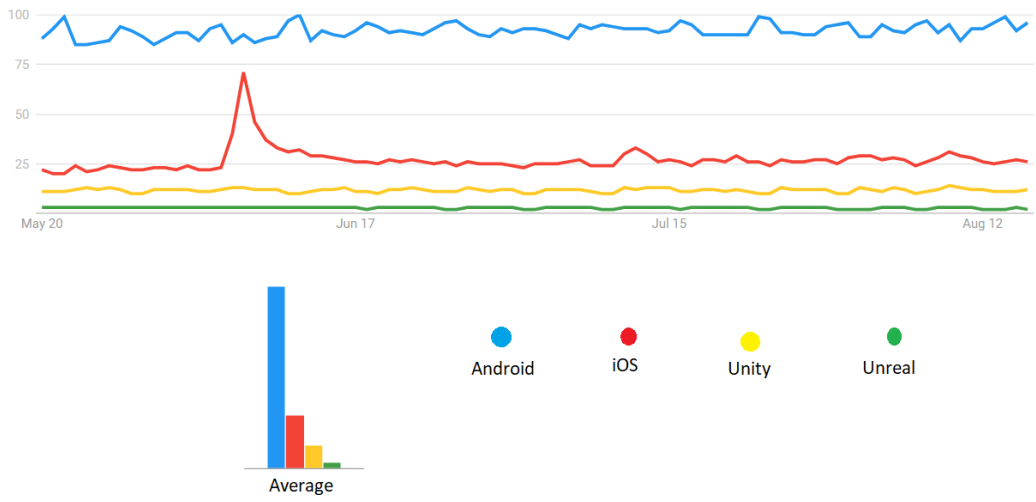


Figure 5.2: Popular Development environment of ARCore are gaining popularity around the world. (Source: Google Trends) [91]

5.4 Android Studio

Android Studio is the official IDE by Google. It is used to design and develop Android applications in a more efficient and faster way. The Android Studio gives you the ability to view real-time design changes of your android app. The IDE includes tools that are helpful for developing an android app, such as live text previews, source code analysis, and run/debug configurations. It also provides various options for debugging apps using its built-in tools.Besides the fact that the IntelliJ IDE, which was created specifically for creating Android apps, Android Studio is compatible with all the major operating systems, including Mac, Windows, Linux, and others has user centred, Gradle built apps. However, Android Studio requires more memory than Xcode. Android studio is the most flexible and open source when compared with others [92] [93].

After careful analysis of advantages and disadvantages of various tools as mentioned in this chapter, it was decided to use ARCore as the software development kit for proposed augmented mind mapping application based on below reasons.

- Though being a product of Google, ARCore was primarily focused on enabling development of applications for Android, however, in recent years it

expanded its reach by offering APIs that can be used to create an augmented experience for both Android and iOS users. As the application that we will be developing as part of this thesis is mobile based, it is essential to choose SDK that offers wider mobile user base.

- ARcore had a good community support and extensive documentation is available to guide both first time developers and experienced. This could be really helpful to solve various issues that could be encountered during development and testing phase of application. As very limited knowledge existed with us related to augmented reality based application development, it is suitable to choose well-supported SDK than the ones which offers more functionalities but are complex to use and have little community support.

- As ARCore is built into Android operating system, it allows use of AR content on supported mobile devices without need of specialised hardware or third party software application to enable the device for AR experience. Thus increasing affordability for user.

5.5 Design and Architecture of Application

The ecosystem of our application is quite basic, which is shows in figure 5.3. When the mobile application is started by the user, it asks for camera permissions to be able to scan the AR marker attached to a physical mind map. Once the application scans the physical mind map successfully, it will be displayed on the augmented view on the user's mobile screen. User can then superimpose digital information like text, image, hyperlinks etc. on mind map in AR view. Once edited, information related to the augmented mind map is saved to a local database. User can also retrieve the information in future as it is tagged to specific and unique AR marker and augmented map can be further edited in AR view on mobile screen.

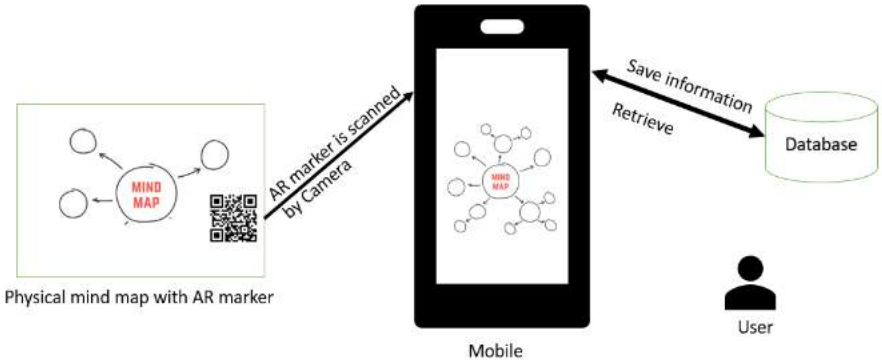


Figure 5.3: Design and architecture of application

6
Use Cases and Prototype

The first part of this chapter describes the use cases to which a user has access. The second section shows flow charts depicting various flows related to the solution that should be implemented. Lastly, we demonstrate a prototype and functionalities it offers.

6.1 Use case

Use case of application	
Name	**Creating AR Mind map**
Detail	User scans physical mind map with help of camera and add digital information like text, image with help of augmented reality based application. User then can save the contents of mind map. For modifications, the user can scan the physical mind map and edit the information stored in the mind map.
Pre-Conditions	1. User requires minimum Android minSdkVersion 7 or higher. 2. User need to give camera access permission to application. 3. User should draw or already have a mind map to be scanned by application.
Post-Conditions	Augmented mind map is created/modified by user.
Actors	User
Error situations	1. Physical mind map is misplaced. 2. By mistake, user declines the access permission of camera for application. 3. The user's phone was reset or the data from the local storage may be corrupted/lost. 4. The device used by the user is not supported.

Use case of application	
Name	**Creating AR Mind map**
System state in event of error	1. When camera permission is declined by user, the application does not generate any error prompts, but user have option to start the scan again, which will prompt for camera permission. 2. When a mind map is in storage is corrupted/lost from database, the application will not proceed further on scan of physical mind map.
Alternative procedure	1. User creates a physical mind map. 2. User starts the application. 3. By mistake, user decline camera access permission to application. 4. User try again to open application and give camera access permission to application. 5. Scan physical mind map and create AR mind map with help of AR view. 6. User can add text and images to AR mind map. 7. The information is saved in local database automatically. 8. The user can access the information again in the future by scanning the same physical mind map. 9. User need to recreate the AR mind map with help of new physical mind map when original physical mind map is misplaced.

Use case of application	
Name	**Creating AR Mind map**
Standard procedure	1. User creates a physical mind map. 2. User starts the application. 3. User gives camera access permission to application for AR view. 4. User scans physical mind map and get AR mind map with help of AR view. 5. User can edit text and image in AR mind map. 6. The information is saved in local database automatically. 7. The user can access the information again in the future by scanning the same physical mind map.

Table 6.1: Description of Use case element uses in application.

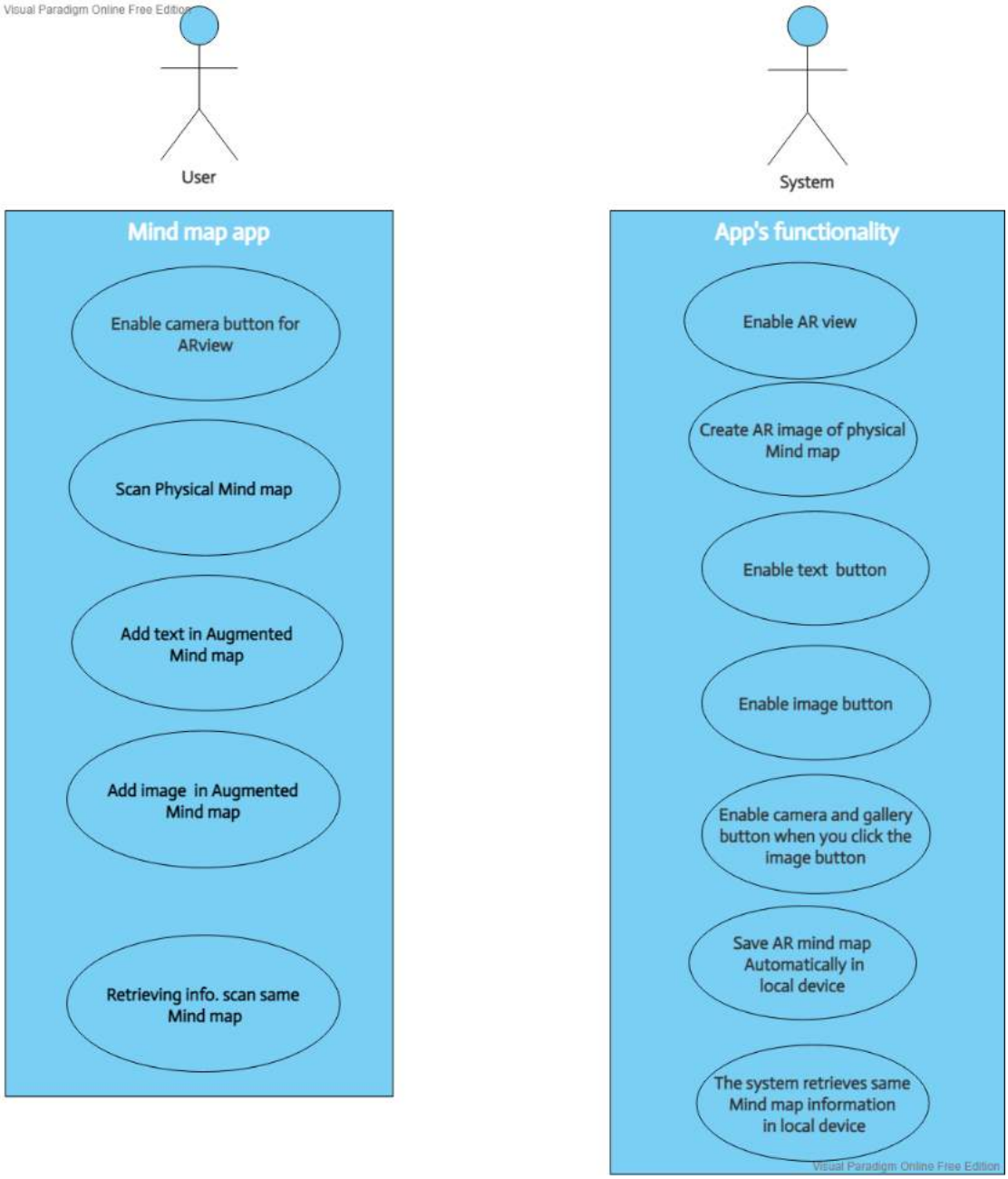
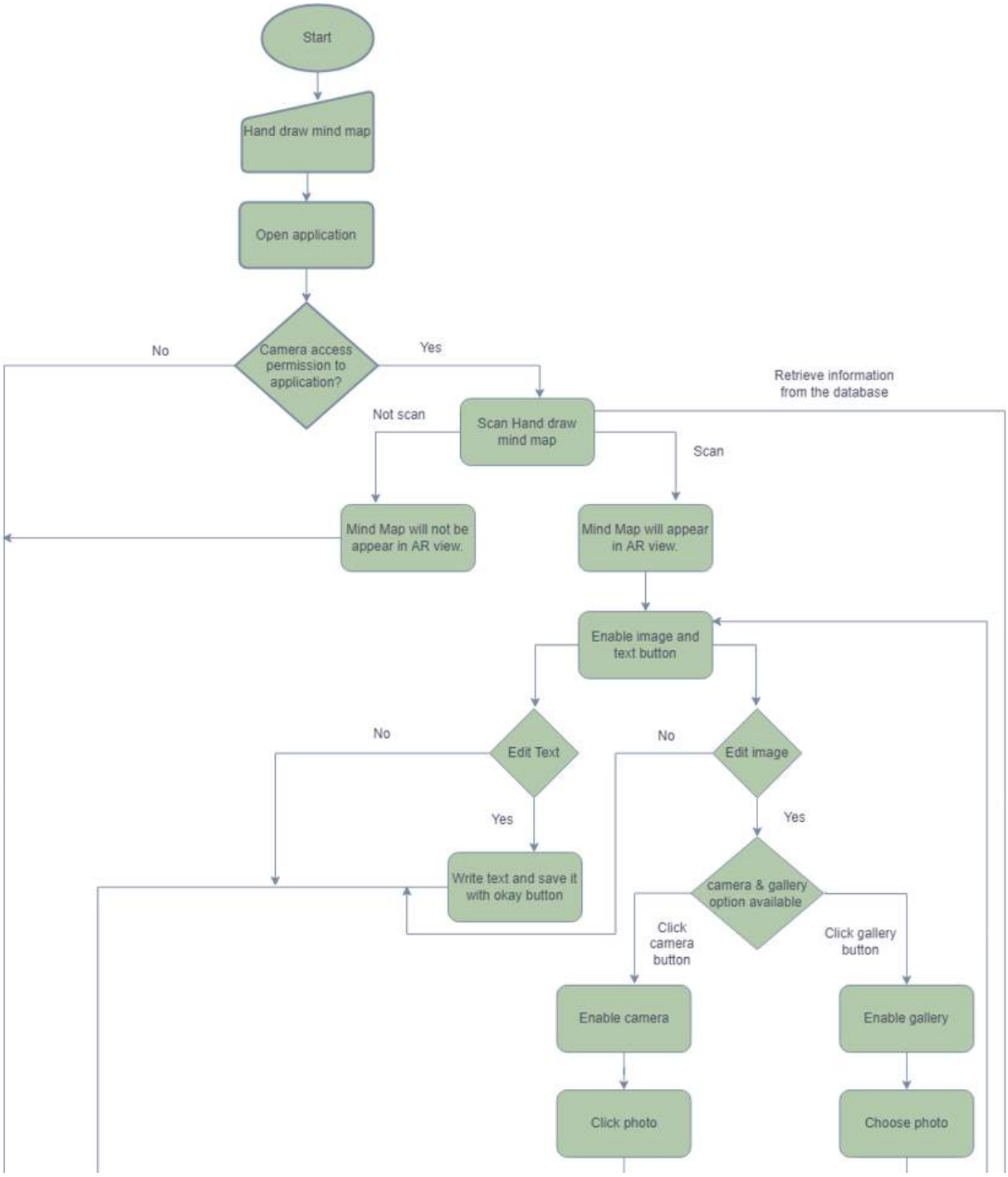


Figure 6.1: Use Case diagram for application

6.2 Flow chart of application



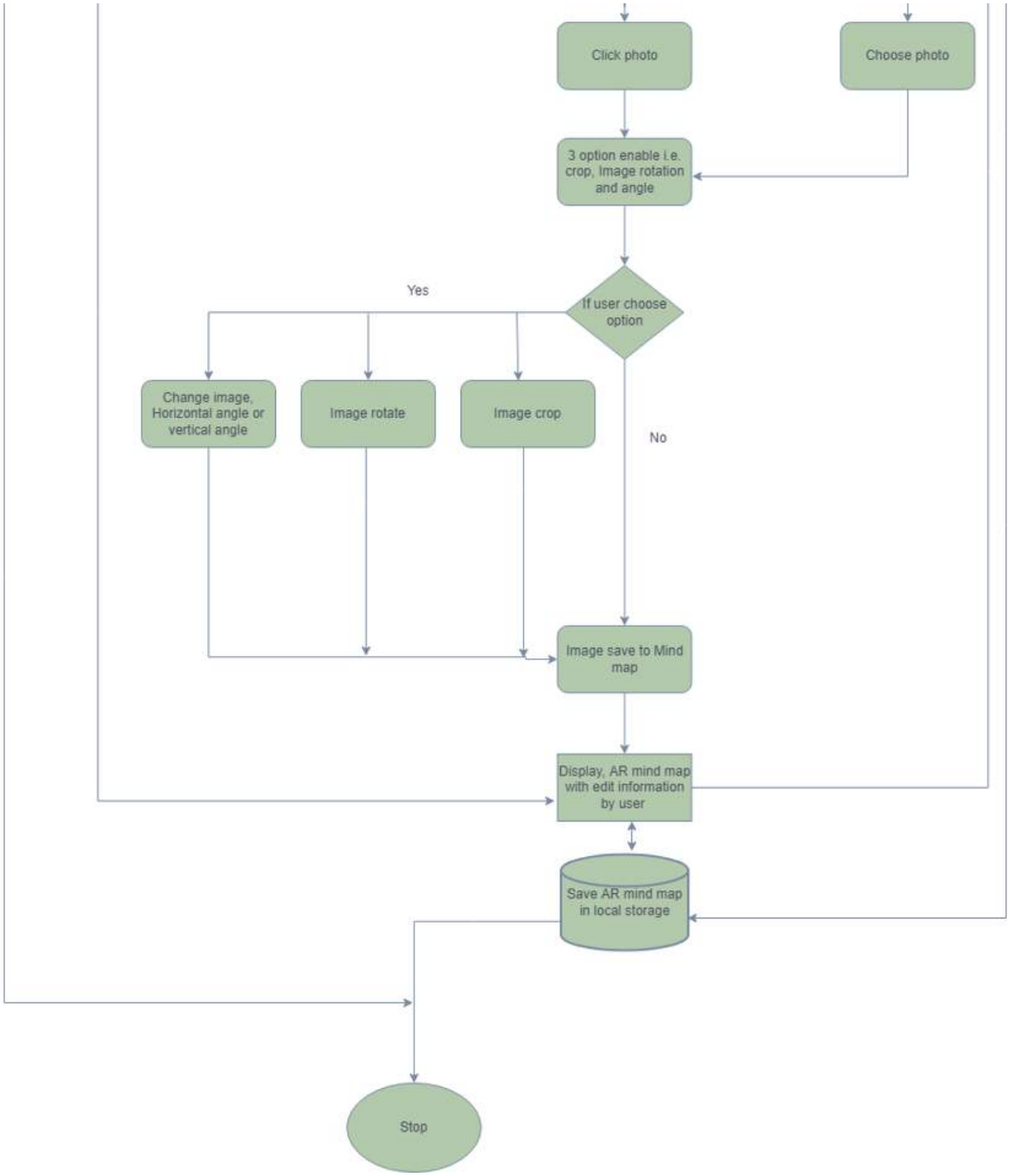


Figure 6.2: Flowchart for application

6.3 Prototype of Application

6.3.1 Access to application

When a user starts the application, they can scan already available image with help of the camera.

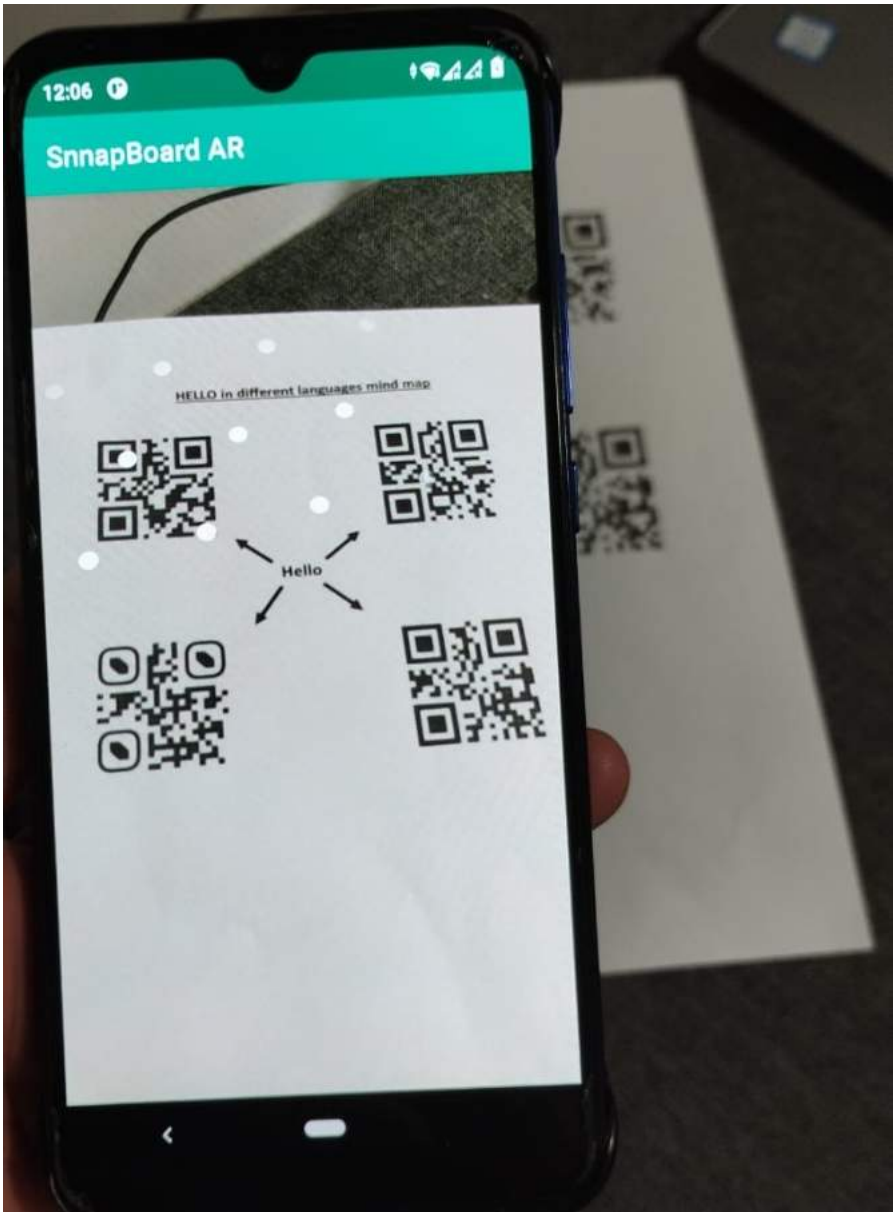


Figure 6.3: Access to the application

6.3.2 Detect the QR code in AR mode

QR coded markers can be scanned to retrieve information of mind map.

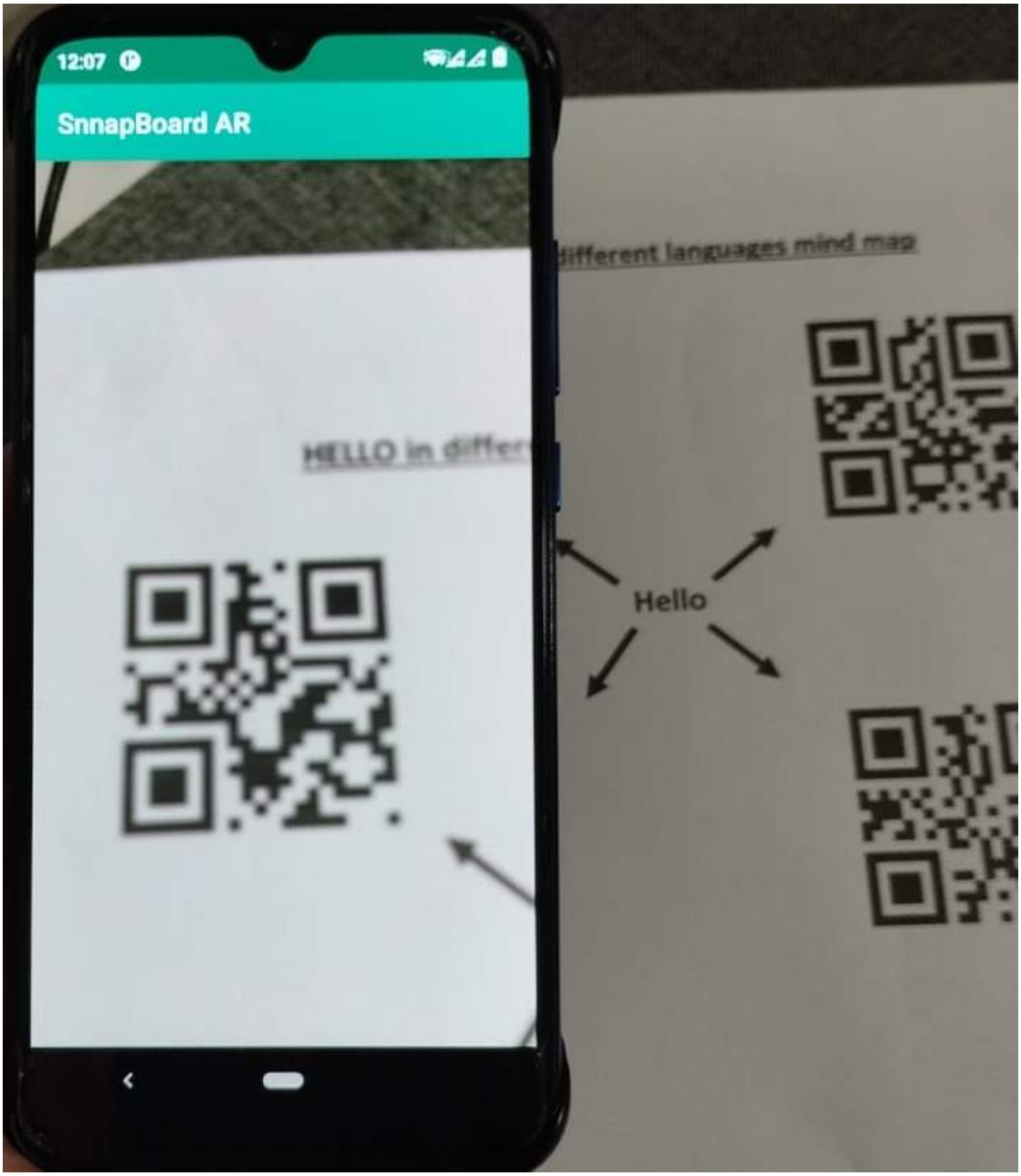


Figure 6.4: Scan QR code in AR view

6.3.3 Display augmented image

Once the user scans the QR Code, the system will display an augmented image with two buttons— “ADD TEXT” and “ADD IMAGE”, as shown in Figure 6.5. When the user clicks on the first button, a new overlay window will appear for entering text and save it. In the same way, when the user clicks on “ADD IMAGE” button, it will show a new overlay window for browsing files where the user can choose any picture or document to be linked to mind map. These steps are described in detail below

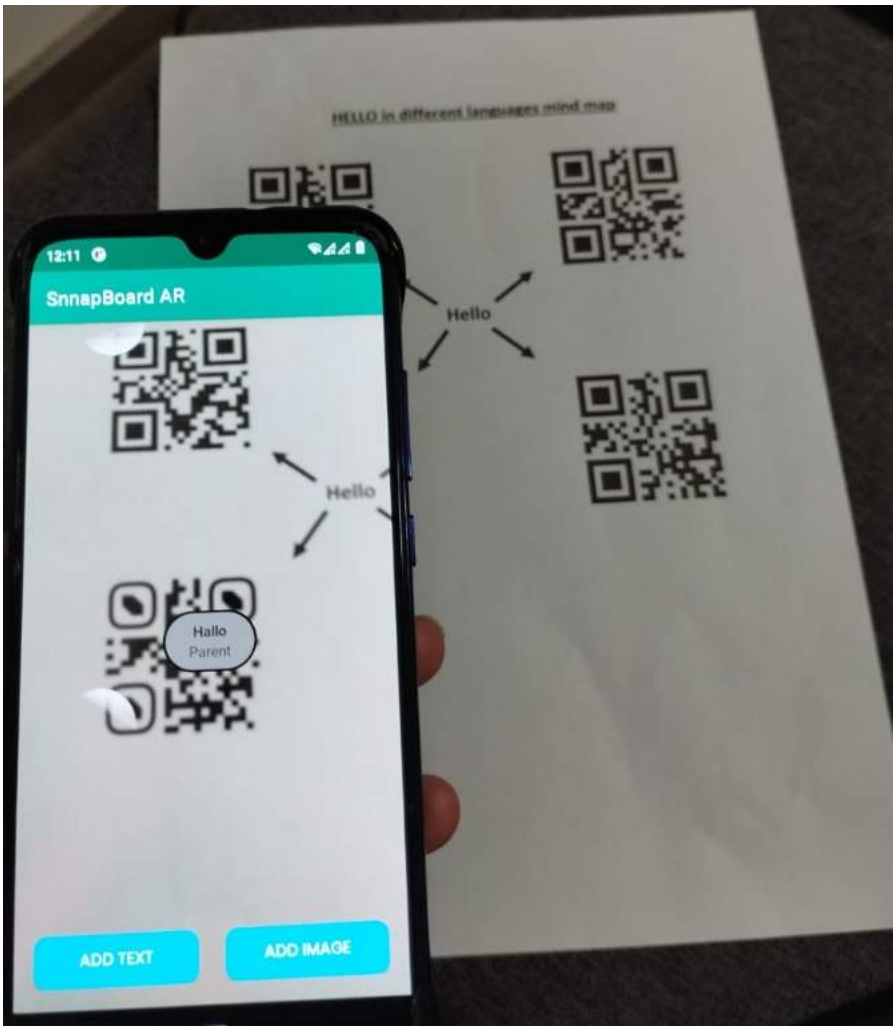


Figure 6.5: Detect QR code in AR view

6.3.4 Add text in mind map

Once the "ADD TEXT" button is displayed in the application, the user clicks on the button that opens a new overlay window for entering text and then save it, as shown in Figure 6.6.

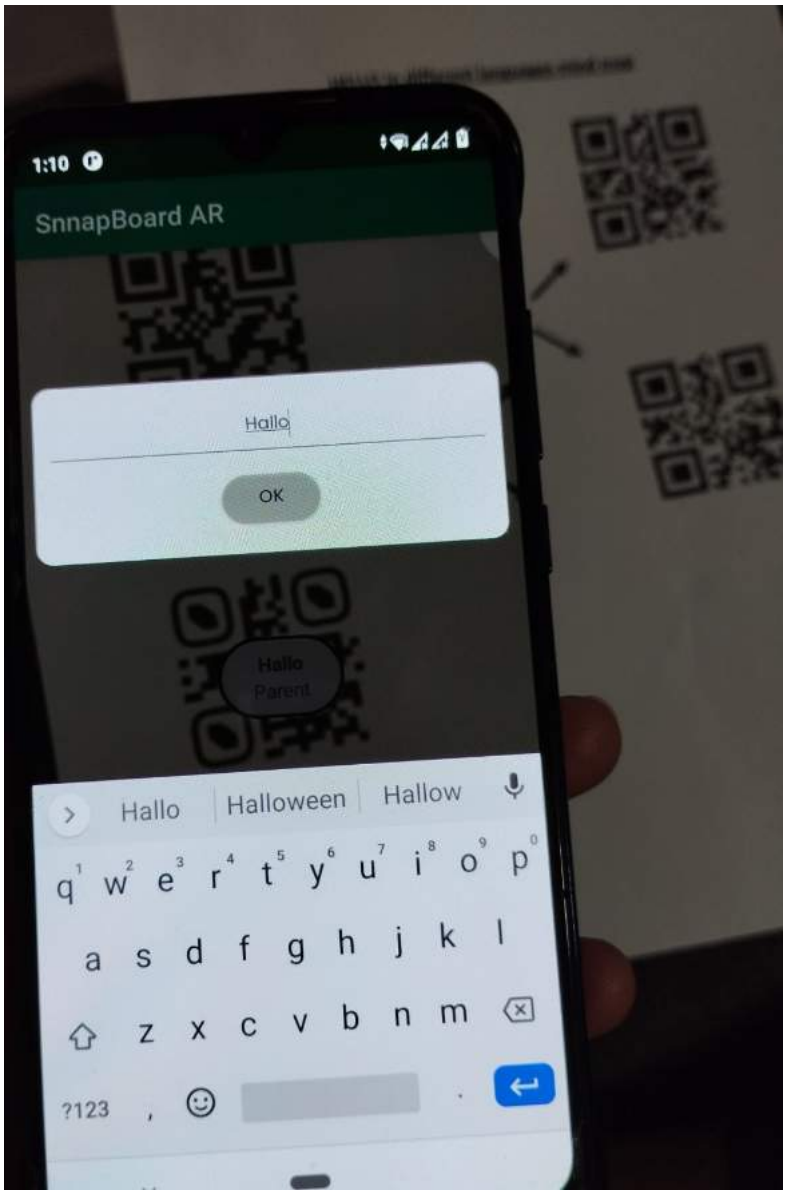


Figure 6.6: Edit text in AR mode

6.3.5 In the mind map, text was inserted

User can add text by clicking on button “ADD TEXT”, as shown in Figure 6.7.

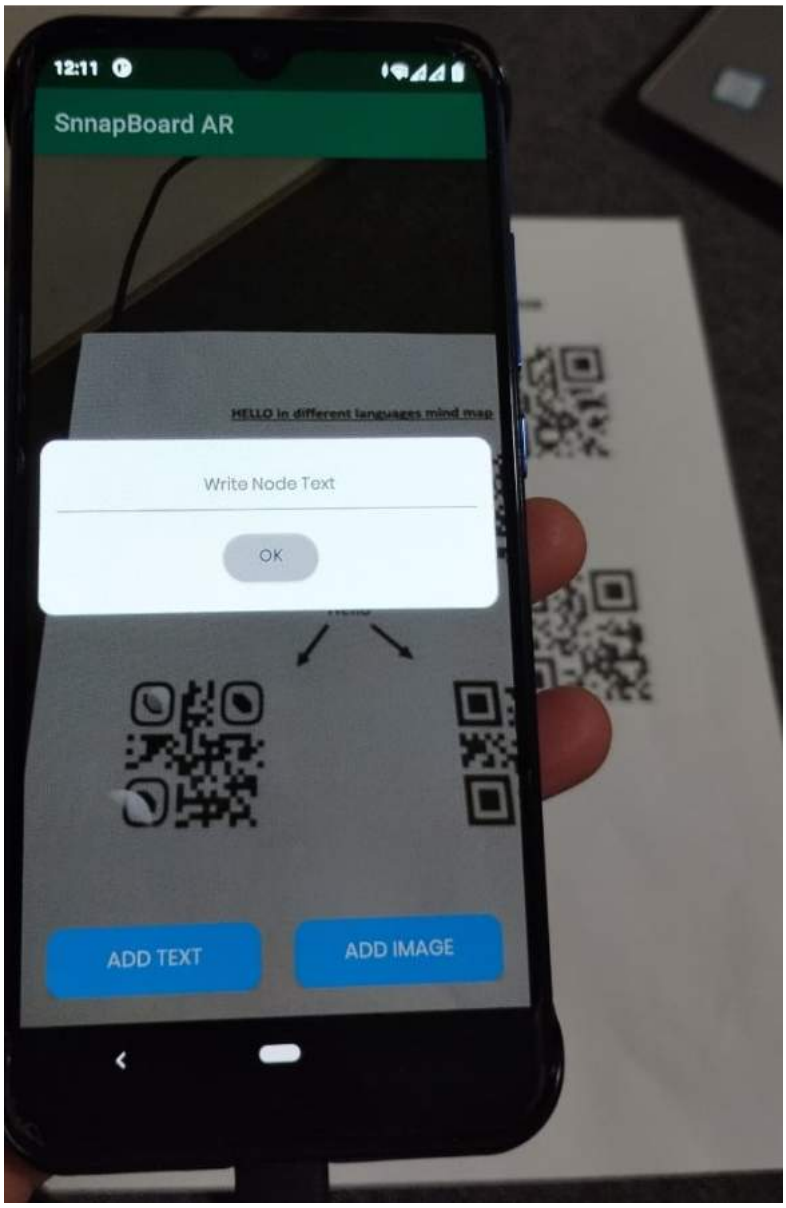


Figure 6.7: Display Edit text

6.3.6 In the mind map, text will display on the screen

Once the user saves inserted text, it will be displayed on the screen in augmented reality, as shown in Figure 6.8.

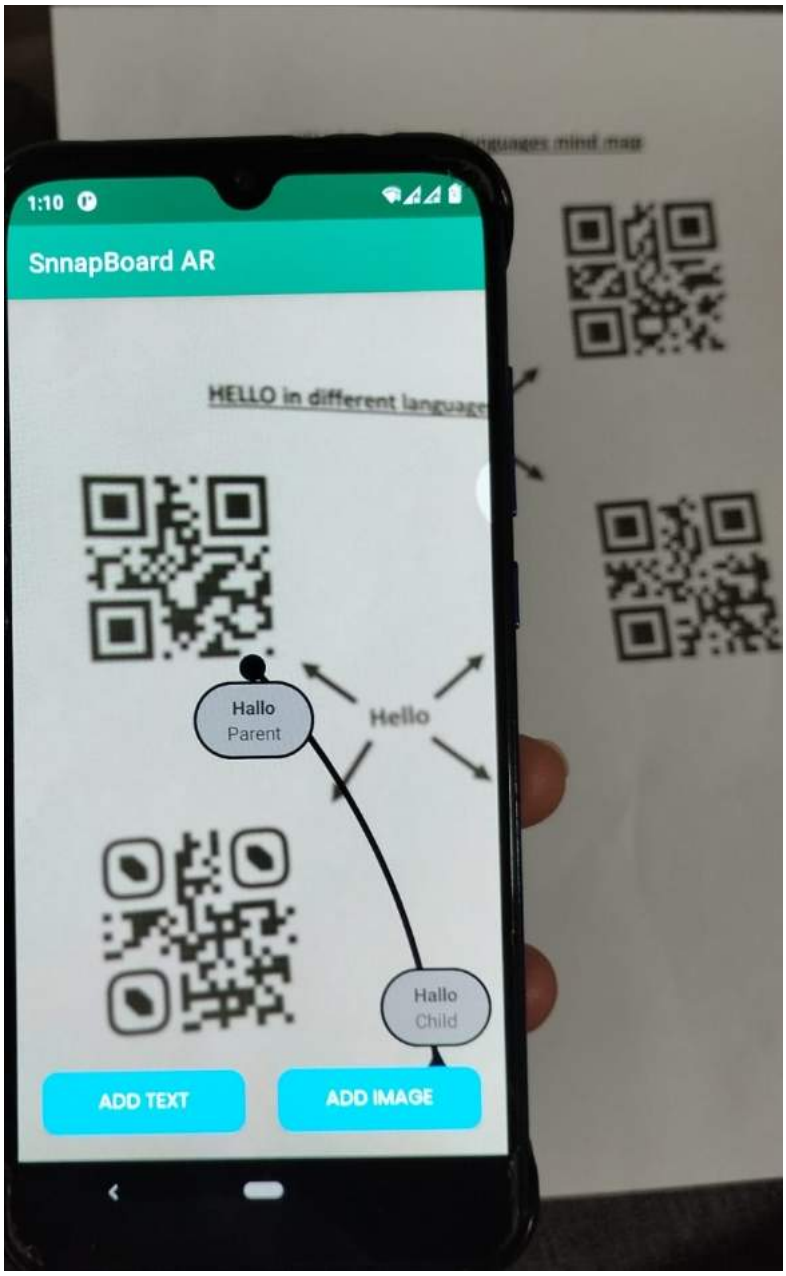


Figure 6.8: Display Text in mind map

6.3.7 Add Image in mind map

The user can browse files on their device and add them to the AR mind map. To do so, the user clicks the "ADD IMAGE" button, which opens a new overlay window where they can browse for an image from local storage. Once an image is selected, the image will be added to the mind map and will appear in the mind map view, as shown in Figure 6.9

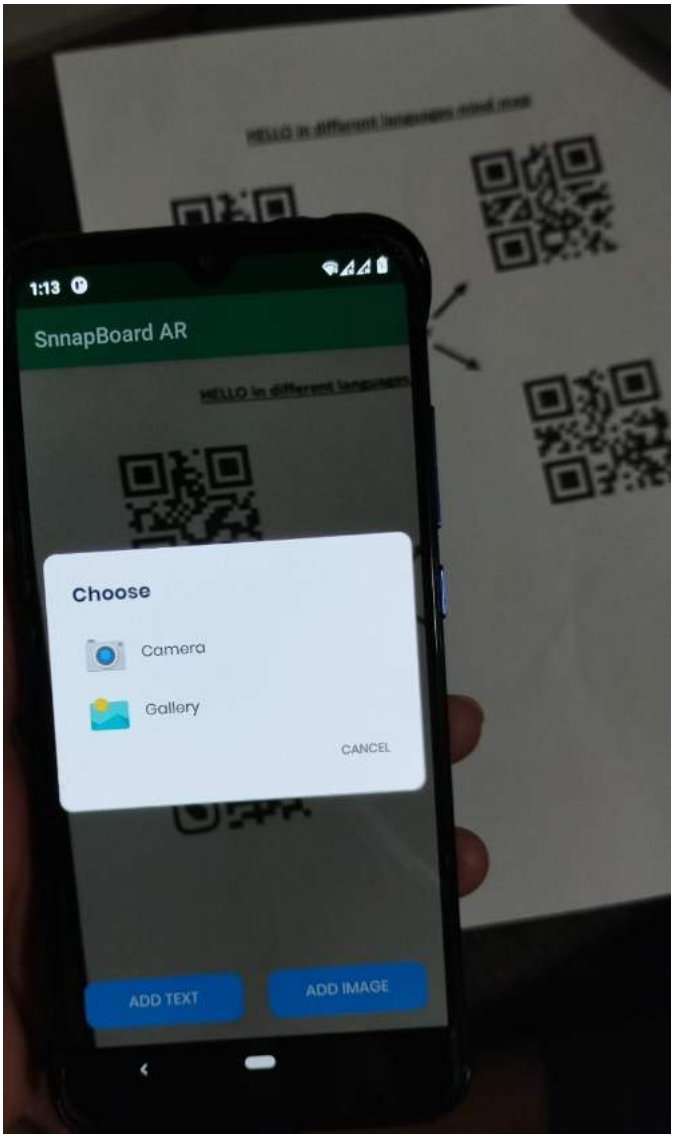


Figure 6.9: Edit Image from Gallery or camera

6.3.8 Crop Image

Once user choose an image to be inserted, it can be cropped as well, as shown in Figure 6.10

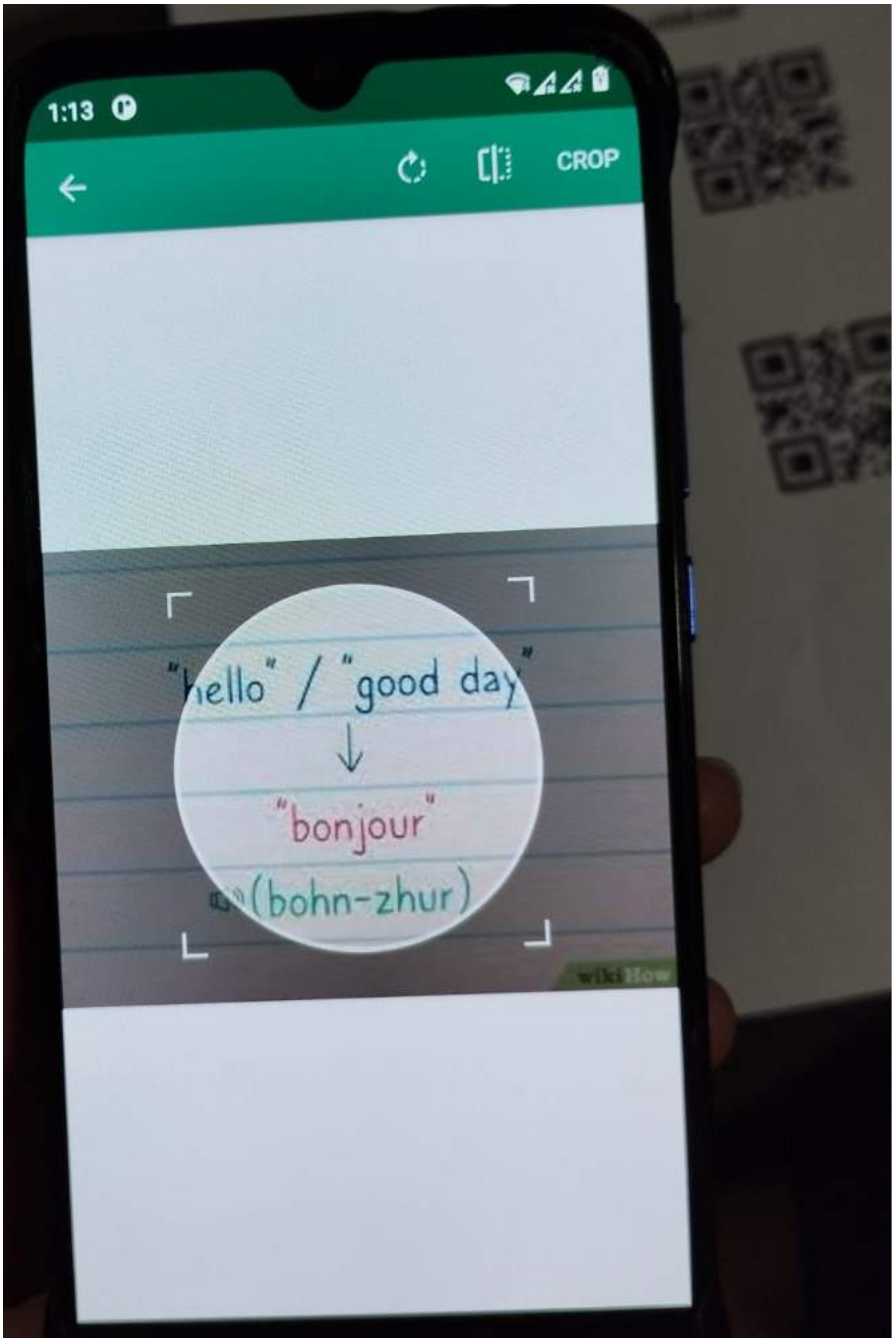


Figure 6.10: Crop Image

6.3.9 Rotation of photo

Once user choose the image to be inserted, it can be rotated as well, as shown in Figure 6.11.

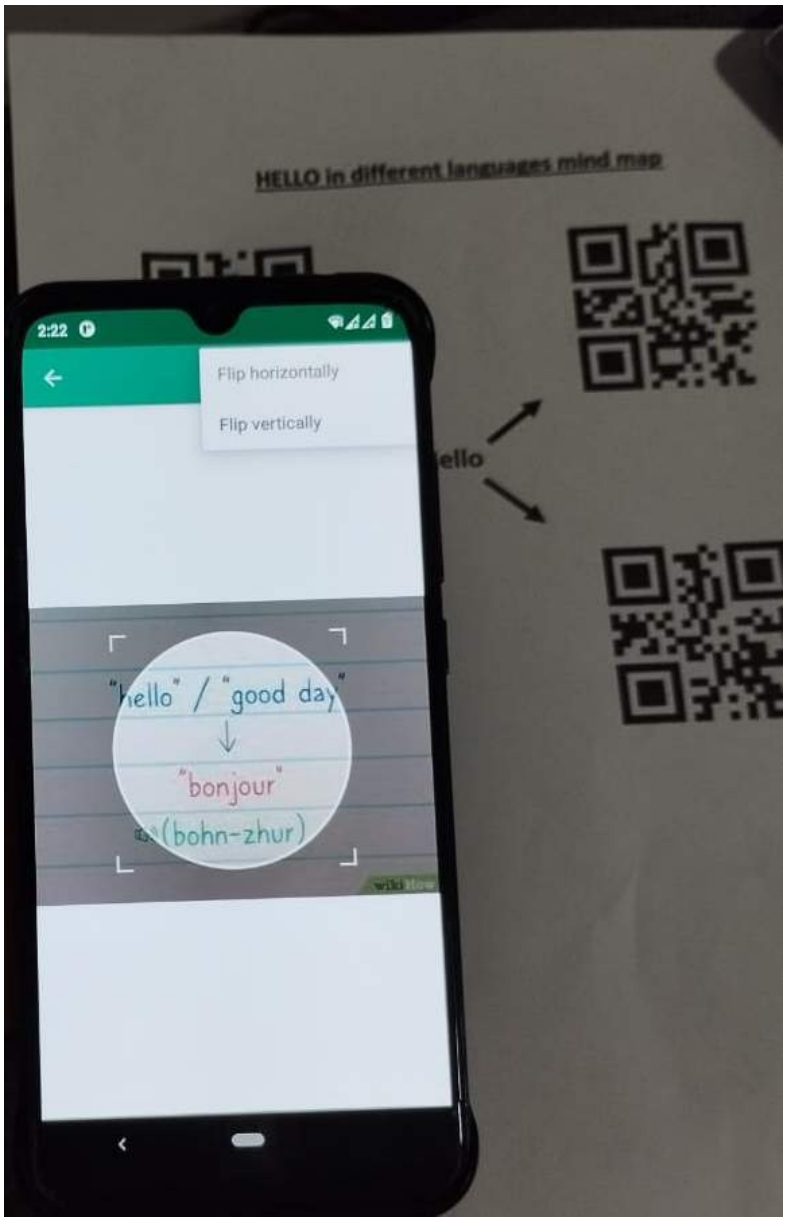


Figure 6.11: Rotation Image option display option

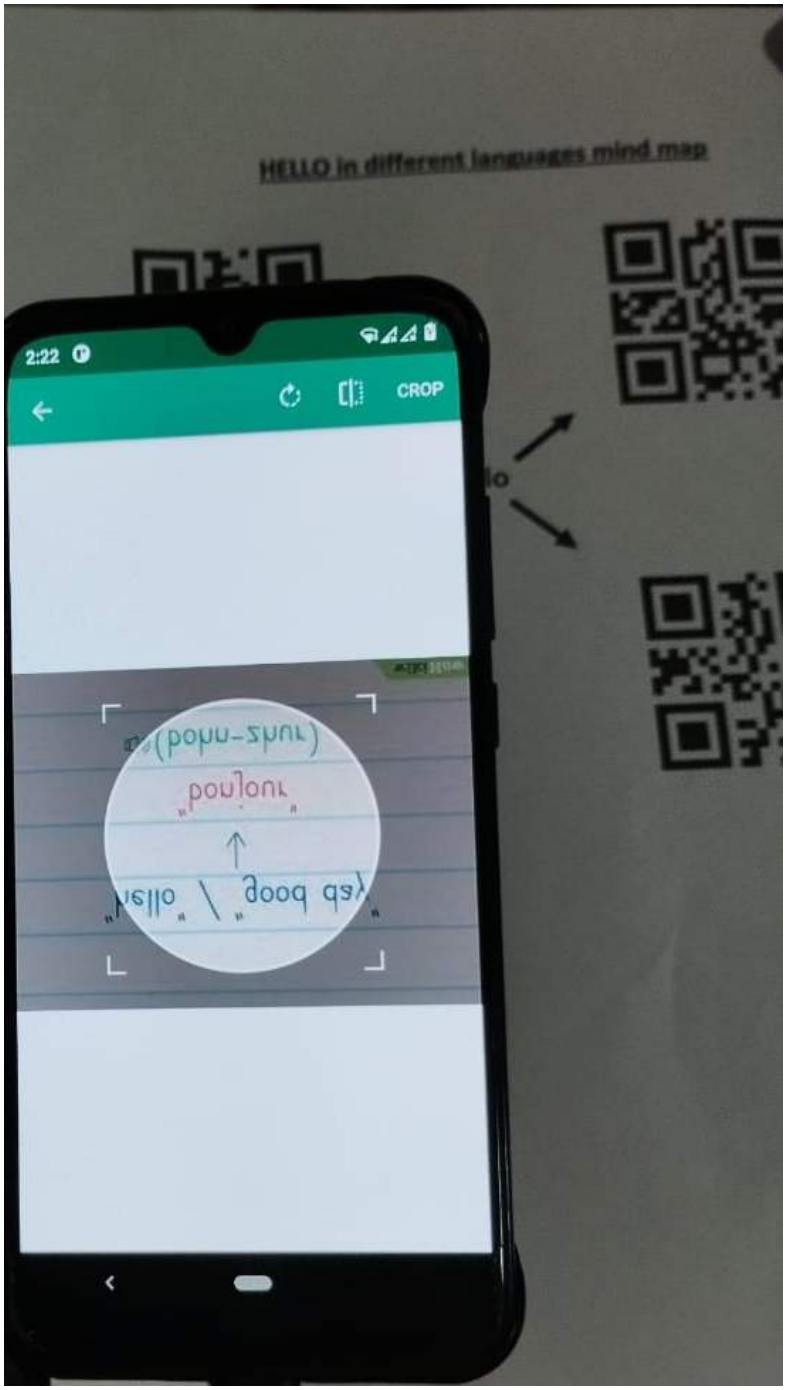


Figure 6.12: Rotated image

6.3.10 Mind map created with AR view

After image and text were inserted as mentioned in previous steps, the physical mind map is augmented with information via additional nodes, as shown in Figure 6.13.

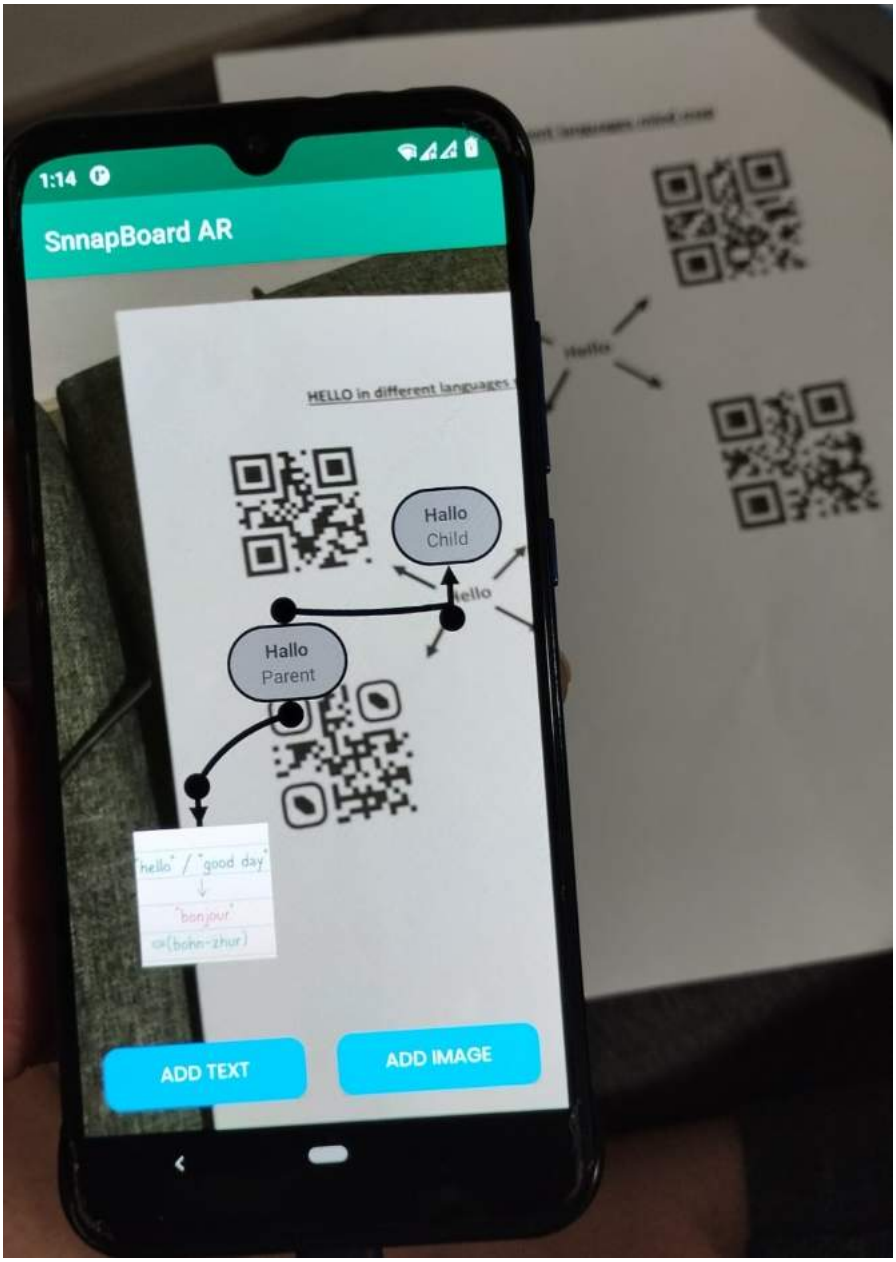


Figure 6.13: Mind map created with AR view

6.3.11 Move child node in AR view

Once a node is added to a mind map, its position can be freely changed in view, as shown in Figure 6.14.

Figure 6.14: Move child node in the AR mode

The code of the prototype can be found in below Git repository url: `https://github.com/himanshisaxena/Enhance-learning-experience-with-augmented-reality-mind-map`

7
Future Work

A lot of efforts were put in this thesis to review literature, analyse and implement a prototype, however, going by the saying that "nothing is perfect", we believe that further knowledge can be built over this thesis. This section outlines a few suggestions for future work that can be undertaken in this area.

7.1 Improvement of Augmented Reality UI (user interface)

Due to limited exposure to augmented reality application development, the user interface developed for the application's prototype is quite basic. For instance, it is not possible to add personalised colours to nodes, lines, and text that could make mind maps more visually appealing. Also, AR the prototype presented in this thesis utilises 2D augmentation which limits the information that can be stored in mind maps, however, a 3D augmented user interface could be developed to overcome this limitation, as that would allow nodes to be visible through different angles without overlapping, thus making them more interactive and interesting for user to work with.

Further, the prototype developed in this thesis is targeted for mobile devices, but it could also be interesting to explore the addition of other augmented reality interfaces like Google Glass or other head mounted wearable, as these could make it easier for users to interact with the application, compared to mobile.

7.2 Development of unfinished functionalities of proposed application

Multiple challenges faced during development of the application ranging from basic errors to integration errors with augmented reality toolkit, combined with confined AR development knowledge, resulted in limited functionalities implemented in the prototype. Therefore, further development of unfinished functionalities can be undertaken for further research.

7.2.1 Addition of audio/video to mind map nodes

One of the unfinished functionalities is to enable the application to add audio and video content to the nodes of mind maps, which could be taken up as future development.

7.2.2 Navigable hyperlink

The application is able to store information of hyperlinks as text, which means hyperlinks are not navigable. Development of this functionality will make nodes more interactive.

7.2.3 Integrate with central database

The current implementation of the application uses local storage on the mobile device to store information. Thus, the application should be integrated with a central database to store and retrieve information. This would allow sharing and collaborate on mind maps efficiently. The database that should be used for this application should be able to store and retrieve multiple formats of digital content like text, image, hyperlinks, audio, and video and capable of integrating with Augmented Reality applications. Thus, analysis on different database technologies can be performed to integrate the most efficient database with augmented reality mind mapping application.

7.3 Mobile to Web based application

As the developed application as only accessible via mobile device for now, another area of research could be to make the proposed application accessible through internet. That is, to make a web enabled version of the application, which would increase the user base of the application and allow them to access it from different devices, thus making it platform independent.

8
Conclusion

8.1 Conclusion

This thesis was undertaken to analyse the benefits offered by mind mapping over traditional note-taking technique, comparing pros and cons of physical versus digital mind mapping in education and to come up with a solution and working prototype capable of integrating the benefits of physical and digital mind maps together to enhance the learning experience of students.

Based on intensive literature review and analysis of surveys done in the past to study effectiveness of mind maps in educational settings, this thesis outlines that mind mapping has an edge over the traditional note-taking technique and offers multiple advantages: enables meaningful learning, improves memory retention and recall, increases engagement, triggers creativity and enhances productivity.

Also, the comparison of pros and cons of physical and digital mind maps done in this thesis demonstrate that both techniques have their fair share of advantages and the debate of which one is best in isolation could be a never ending. One of the techniques could be better in the specific setting than the other one, for instance, physical mind mapping could yield better performance in classroom setting but for collaboration over distance digital mind maps proved to be more effective. It is found that a gap still exists in both techniques, and it would be more beneficial to have a solution that could integrate advantages of both techniques.

Augment Reality which has capabilities to combine the real and virtual world turned out to be a perfect fit for this purpose based on literature review done on effectiveness of AR during this thesis. It is found that AR offers multiple advantages: inclusion of third dimension that improves understanding, increased motivation, less distracting, improved memory retention and enhanced collaboration that could be exploited to enhance mind maps.

Further, an analysis of available tools and technologies in the market was done to develop a working prototype of augmented reality based mind mapping application which allows users to enrich physical mind maps with digital content like text, image and hyperlinks. The application also allows users to share and collaborate on mind maps to enhance the overall learning experience of the user.

9
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