Software Engineering Department
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Capstone Project Phase B

Augmented reality in Industry 4.0

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Abstract

This project addresses the challenge of engaging youth in advanced manufacturing education through an innovative application. Utilizing Augmented Reality (AR) technology, the app complements guided tours at a manufacturing institute, allowing users to scan 3D models and access interactive information. By integrating educational mini-games and multi-language support, the application bridges the gap between physical exploration and digital learning. Despite development challenges, the resulting prototype demonstrates the potential of AR in enhancing inspiring interest in manufacturing careers among teenagers.

Introduction

Who doesn't remember themselves as a child on a school trip with their classmates to a museum or science center? We all remember the excitement of leaving school and the experience of traveling to the tour, the snacks we shared on the bus, and the friends we played with.

But who remembers something they learned during the tour? Or an important message they took away? The vast majority would testify that they don't.

This gap between the social experience and the educational value of field trips poses a significant challenge in the education system [1].

In this project, we tackle this challenge by developing an innovative application that incorporates augmented reality technology to increase motivation for learning and improve the educational experience in field trips.

In addition to the application we've developed in this project, we are also conducting research examining the impact of integrating AR technology on the level of interest and engagement of teenagers, the extent of improvement in understanding the material learned, and its effect on teenagers' perceptions of their professional future in the field of advanced manufacturing.

The application we've developed is intended for teenagers visiting the Advanced Manufacturing Institute in Karmiel.

By incorporating interactive games and scanning models in augmented reality, the application allows students to experience the tour in a new and fascinating way [2].

Our vision is that the teenagers who come to the institute will leave excited and remember that the world of manufacturing industries offers them a variety of challenging and interesting employment options.

This research represents an important step in understanding the potential of innovative technologies to bridge the gap between the tour experience and its educational value, and offers important insights for educators, technology developers, and managers in the field of education.

General Description

The system we developed is an application designed for teenagers visiting an advanced manufacturing institute. The app's purpose is to expose young people to the world of industry, enrich users' knowledge about 3D printing technologies, increase youth engagement during the tour, and generate interest and excitement about the diverse possibilities in manufacturing fields. The application is built around tasks that incorporate Augmented Reality (AR) technology, allowing users to scan three-dimensional models and receive information about them. By combining the scanning of physical models throughout the institute through the virtual world, we connect both the physical and virtual realms, encouraging teenagers to explore the institute premises. The app also includes short games that integrate educational terms and encourage users to actively experiment and learn about the 3D printing process. The interactive structure of the application helps increase user interest and deepens understanding of the material among young people.

1.BACKGROUND AND RELATED WORK

1.1. The fourth industrial revolution

The industrial revolution refers to a transformative period characterized by the emergence of new dynamic technologies, products and industries that revolutionized the entire economic structure, led a leap forward in development and accelerated cultural, social and even ecological changes.

The industrial revolution is an ongoing process with four primary waves. The first revolution (1784) was centered on the invention of the mechanical weaving loom, which led to the establishment of mechanized workshops powered by steam. The Second Revolution (1870) introduced the industrial conveyor belt and electric power, allowing factories to produce at higher rates. The third revolution (1969) brought programmable controllers, electronics, communications and computers, enabling automated production. The ongoing industrial revolution transformed production through mechanization, electrification and automation, leading to significant advances in productivity and efficiency [7].

Industry 4.0 denotes the fourth industrial revolution, which focused on the digitization and automation of production through smart technologies such as machine learning, big data, and the Industrial Internet of Things (IIoT) [12]. This revolution is driving the emergence of smart factories with connected machines that share real-time data across the supply chain [13]. The combination of advanced technologies, including augmented reality (AR) and cloud computing, optimizes processes by minimizing costs, maximizing product quality and increasing flexibility in response to rapid market changes [16]. The application of Industry 4.0 poses challenges, mainly ensuring a safe interaction between humans and robots, a task that requires the industry to produce new intuitive interfaces for this purpose [8]. Other hurdles include enabling affordable technological connectivity and developing agile data-driven policies to respond to evolving conditions through big data analytics [14]. AR is proposed as a solution, increasing spatial awareness in complex factory environments through visual data [8]. In conclusion, Industry 4.0 represents the latest industrial revolution, applying decision- making from real-time data and intelligent automation to production. Although it offers productivity benefits, it also presents many challenges that require innovative technological solutions and operational strategies.

1.2. Augmented reality

Augmented reality (AR) is an emerging technology that superimposes virtual information, such as text, images, 3D models, and multimedia, onto the real environment through computer simulation, serving as a bridge between the digital and physical worlds. This technology enables users to experience and interact with their surroundings in novel and revolutionary ways [5].

AR garnered significant attention from users with the development of the so-called Google Glass in 2013. These glasses represent a Head-Mounted Display (HMD) device in the form of eyewear, allowing users to view applications and web pages in an augmented reality environment [19] Microsoft also attempted to implement its version of 3D glasses using AR technology, resulting in the creation of the "HoloLens", a Head- Mounted Augmented Reality Display (HMARD) device designed to be worn on the head. Another AR application exploited by the well-known Nintendo Switch home console is represented by the game "Mario Kart Home Circuit". This new game takes full advantage of AR technology [2].

However, AR systems are not limited to specific wearable devices but are also implemented on smartphones through improved algorithms. Notably, in 2016, a game application called "Pokemon Go" was launched by Niantic and Nintendo, which experienced a surge in downloads within just one week.

The continuous advancements in augmented reality technology across various platforms and devices demonstrate its growing significance and potential for revolutionizing human-computer interactions in diverse contexts.

1.2.1. Augmented reality in the industry

The emerging augmented reality (AR) technology facilitates the integration between humans and their technological environment. Moreover, it contributes to the optimization of employee training, enhances the availability of real-time information for employees, and ensures the improvement of safety conditions in industrial environments.

One of the most crucial aspects of AR is the interaction between users and the devices, which can be wearable or non-wearable. However, the interface must be intuitive and straightforward to promote effective user engagement [16].

There are many devices available for AR uses for example:

- Head mounted device (HMD) - a display device that is placed on the head or as part of a helmet and displays images of the real virtual environment over the user's perception of the world.
- Handheld devices - small computing devices with a display that the user can hold in his hands. It uses video systems to upload visual metrics and uses sensors such as digital compasses and GPS units.
- Other display devices - desktop computer monitors, etc.

The application of augmented reality in the industry are in first place with 35% smart glasses, in second place with 27% tablet, then with 16% screen, projector with 15% and finally. A smart phone with 7% [9].

1.2.2. The effect of augmented reality on the learning experience

Currently, the use of technology to improve teaching and learning experiences in the classroom is promoted. One of these technologies is AR, which allows layering of virtual information on a real scene to increase the user's perception of reality.

In the educational context, it has been proven that augmented reality offers a number of advantages such as increased involvement in learning and increased understanding when it comes to spatial skills [10].

Most of the research projects examined the framework of the cognitive theory of multimedia learning and the cognitive load theory (CTML) [4].

The CTML theory is based on 3 basic assumptions about how humans learn from words and images: The theory assumes that humans have different channels for visual, auditory, and verbal information. In addition, it assumes that each channel has a limited capacity to process information and that learning is an active process of filtering, selecting and organizing information [3][17].

1.2.3. The effect of augmented reality on learning in a science center

Augmented reality (AR) technology has demonstrated promising effects on learning in informal science education settings, such as science centers and museums, by enhancing learning through multiple visualizations and digital information. This approach leverages the advantages offered by theories such as the cognitive theory of multimedia learning, allowing learners to interact through various channels and engaging visitors through a combination of physical objects and virtual enhancements [11]. Another example is a study by [19], where the researchers compared learning outcomes between an AR-enhanced exhibit on geology concepts and a non-AR exhibit. The AR group, using handheld devices to view 3D visualizations, showed better knowledge gains on geology tests, and qualitative data indicated that AR increased engagement and collaborative learning.

The advantage of AR for students lies in the production of dynamic environments where motivation and interaction are the main features [10]. From an additional article, it emerged that within the study framework, the implementation of augmented reality in an educational context was successful for children of different ages and at different school levels, positively impacting children's satisfaction and confidence. Notably, the effect of AR was to increase the speed of learning and understanding.

However, from the tests conducted, the challenge discovered in the field is that, although understanding was good, the improvement in knowledge retention is minimal. Thought must be invested in creating an augmented reality experience that leads to meaningful learning, and adapting to AR can be complicated for some students [18].

1.3. Motivation and gamification

The term motivation describes why a person does something. It is the driving force behind human actions that is the process that initiates, guides and sustains goal- directed behaviors [6].

There are several motivation theories, the most important of which is the self-determination theory (SDT).

1.3.1. Self-determination theory (SDT)

Self-determination theory is a theory of motivation and personality that concerns people's innate tendencies and innate psychological needs. It concerns the motivation behind people's choices in the absence of external influences and distractions. The theory compares internal and external motivations with a growing understanding of the dominant role played by internal motivation in individual behavior, which relates to performing an action for personal satisfaction versus performing an action to achieve an

external goal (extrinsic motivation).
The theory proposes three main internal needs involved in self-determination: the universal and innate need for autonomy, competence, and connectedness.
In this study, we would like to test our ability to influence the motivation of the youth to take an active part during a tour of an advanced manufacturing institute and learn about the emerging field of Industry 4.0 using an augmented reality application.
In our application we will base on the theory of self-determination in that the youth will use the application with little prior training (autonomy).

They will work in small groups so that each group will receive a tablet for independent work (connection) and they will be asked to deal with more challenging tasks than they know from normal classroom learning through the use of an augmented reality application and the application of creative and critical thinking (competency). We expect that learning through the application and the curiosity to experience elements of augmented reality may increase the motivation of the youth for active participation and even a growing interest in the industry and its range of capabilities [15].

1.3.2. Gamification

Gamification is a strategy that integrates entertaining and immersive gaming elements into nongame contexts to enhance engagement and motivate certain behaviors. Gamification uses game design and mechanics, such as badges, leaderboards, points and rewards, to encourage active participation and make task enjoyable [25].
In an academic article that explores the intersection of motivation and gamification, the research focused on how gamification techniques can effectively enhance user motivation. Despite the fact that our research primarily focuses on the pedagogical approach to teaching intricate subjects within the industrial sector, we made the deliberate decision to integrate gamification components into our study. The rationale behind this choice lies in our aspiration to augment user motivation and foster increased engagement and participation among the participants [14].

2. Description of the solution

The AR-Institute application is an augmented reality (AR) mobile application designed to enhance the educational experience of teenagers during tours at the Institute for Advanced Manufacturing. The solution integrates AR technology with interactive educational games, providing an engaging, immersive experience while facilitating learning through modern digital tools. This section outlines the architectural design, components, and key features of the solution.

2.1. Application Structure and Components

The AR-Institute application is structured to leverage both client-side and server-side functionalities, with a focus on AR interactions, multilingual support, and real-time feedback mechanisms.

Client-Side (Mobile Device) Components:

- **MainMenu:** The central hub for navigating through the app, providing access to the AR components and educational games.
- **ARCamera:** Enables the AR functionalities by using the mobile device's camera to identify and interact with physical models (e.g., Astronaut, Groot, Minion).
- **GameManager:** The core script that manages game logic, ensuring smooth transitions between mini-games, AR scenes, and other app functionalities.
- **ModelTargets:** A set of 3D models recognized by the AR camera, which serves as the foundation for delivering educational content.
- **UnusedScreens:** A collection of screens temporarily disabled, such as the Superman model scan, which has been archived for future use.
- **SettingsHolder:** Allows users to customize settings such as language, volume control, and app exit.
- **PopUpManager and Canvas (UI Elements):** Responsible for managing user interface elements, providing visual feedback and prompts during gameplay.

Server-Side (Game Server) Components:

- **LocalStorage:** Stores multilingual JSON files and game-related data. This local database ensures that the application operates efficiently, even when offline, by retrieving the necessary game data and language files.
- **Game Scripts:** Responsible for the logic behind each mini-game (CycleGame, MemoryGame, TriviaGame, QuickGame). These scripts ensure the accurate execution of game rules, user scoring, and progression through the educational content.
- **Email Service:** Integrated to allow users to send souvenir photos taken within the app to their email address, providing a personalized takeaway from their experience.

2.2. AR and Multilingual Implementation

The AR-Institure app utilizes advanced AR technologies through the integration of **Vuforia Engine** and **Google ARCore XR Plugin**, ensuring a seamless AR experience on Android platforms. These tools enable the application to recognize real-world physical models and overlay digital content that is contextually relevant to the user's location and the identified object.

Furthermore, the app is multilingual, supporting English, Hebrew, and Arabic. This is achieved through the use of JSON files that store translations for all text displayed within the app. The **LanguageController** dynamically loads these files based on user preferences, ensuring that the educational content is accessible to a diverse audience.

2.3. Games and Educational Interaction

The educational experience is driven by a series of interactive mini-games designed to engage users with the presented educational material. Each game focuses on different cognitive and learning aspects, ranging from memory recall in the **MemoryGame** to logical thinking in the **CycleGame**. These games are interwoven with the AR experiences, which provide real-time feedback and learning opportunities by interacting with recognized physical objects.

2.4. User Flow and Experience

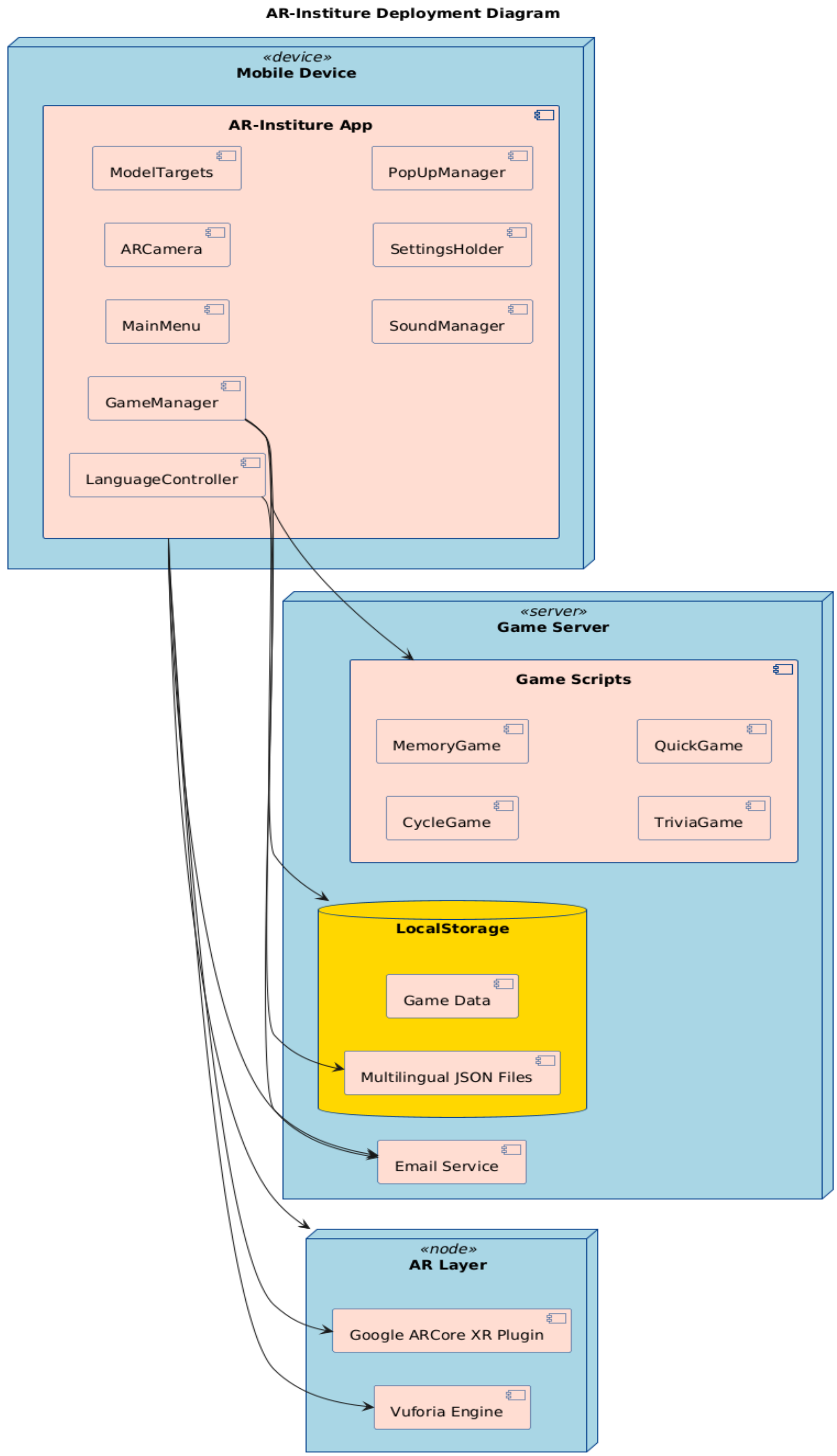
The app follows a structured flow, beginning with the registration screen and transitioning through various educational activities. The process starts with AR-based tasks such as scanning the Astronaut, followed by quick mini-games and trivia to reinforce the learned material. The flow culminates in a **CameraCaptureToEmail** feature, which allows users to take and send personalized souvenir photos.

2.5. Architecture and Deployment

The deployment architecture follows a client-server model, where the mobile device hosts the AR-Institure app and communicates with the game server for data management. The AR functionalities are powered by the **Vuforia Engine** and **Google ARCore XR Plugin**, which work in tandem to provide seamless object recognition and AR interactions. The server component handles storage and retrieval of multilingual content and game data, while the **Email Service** supports real-time photo sharing functionality.

The architectural design of the AR-Institure app prioritizes modularity and scalability, allowing for future expansion, such as the addition of new AR models or mini-games. The use of a centralized **GameManager** ensures cohesive interaction between AR and game components, while the **LocalStorage** allows for efficient offline operation.

The AR-Institute application represents an innovative blend of AR technology and educational gaming, providing an engaging, interactive learning experience for its users. The solution's robust architecture supports seamless AR integration, efficient game logic management, and multilingual capabilities, ensuring that the app meets the educational needs of a diverse audience. Through its combination of AR interaction, interactive games, and real-time photo capture, the AR-Institute app delivers a memorable and educational experience to teenagers on tour at the Institute for Advanced Manufacturing.


AR-Institure Deployment Diagram
«device»
Mobile Device
AR-Institure App
ModelTargets
PopUpManager
ARCamera
SettingsHolder
MainMenu
SoundManager
GameManager
LanguageController
«server»
Game Server
Game Scripts
MemoryGame
QuickGame
CycleGame
TriviaGame
LocalStorage
Game Data
Multilingual JSON Files
Email Service
«node»
AR Layer
Google ARCore XR Plugin
Vuforia Engine

The deployment diagram illustrates the key components of the **AR-Institure** application, their deployment on different nodes, and how they interact.

- **Mobile Device** hosts the **AR-Institure App**, which consists of key components like the **MainMenu**, **ARCamera**, **GameManager**, **LanguageController**, and others. These components manage user interaction, AR functionality, and the overall flow of the app.
- **Game Server** contains a **LocalStorage** database that holds the multilingual JSON files and game data, along with **Game Scripts** (for different mini-games like CycleGame, MemoryGame, etc.) and the **Email Service**, which facilitates sending emails to users.
- **AR Layer** includes the **Vuforia Engine** and **Google ARCore XR Plugin** for managing AR interactions and object recognition.

The diagram shows the connections between the **AR-Institure App** and both the **AR Layer** for AR functionality, and the **Game Server** for data management and email services. This deployment ensures seamless AR experiences, game management, and real-time email interaction.

3. Project Timeline

Phase 1: Project Initiation and Requirements Gathering (June)

The project commenced in June with an initial client meeting to align expectations and define system requirements and functionality. The client emphasized the importance of a user-friendly interface accessible to teenagers, with particular attention to language options within the application.

Phase 2: Planning and Resource Allocation (June-July)

Following the initial planning phase, a development schedule was created, and necessary resources were identified. A subsequent meeting in July presented these requirements to the client. Required resources included:

1. Educational content for the application

2. 3D models for the model scanning feature

3. 3D model of the printer

4. Content translation into multiple languages

5. Tablet devices for application installation

Phase 3: Application Development (July-August)

Concurrent with resource gathering, the development focused on building the application framework. Key components included: Audio system, pop-up notification system, settings interface, application hierarchy and user interface (UI) design.

During this phase, the team encountered constraints due to delays in receiving content and resources from the client. A follow-up meeting in July addressed these issues, providing a detailed list of required content for each game module and additional resources needed.

Phase 4: Testing and Debugging (July-August)

We created an application build and conducted tests on tablet devices. This process revealed previously unidentified bugs, such as: Issues with JSON file loading on mobile devices, camera flipping functionality problems and screen resolution discrepancies.

Despite these challenges and the extensive development time required, we successfully resolved all identified bugs. They utilized various resources, such as: peer support from fellow students, online developer communities and forums and internet tutorials and YouTube videos.

Phase 5: Initial Version Release and Client Feedback (August)

In August, we released the first version of the application and conducted a meeting with the client at the Advanced Manufacturing Institute. This meeting involved: demonstrating progress, conducting tests and gathering additional requirements and improvement requests.

One notable change resulting from client feedback was the modification of a sub-game. Initially designed to match materials to printers, it was adapted to match materials to existing physical models at the institute, enhancing the connection between the physical tour and the application.

Phase 6: Refinement and Final Presentation (September)

Following additional development efforts and bug fixes, the team presented the final version at the institute in September. The client expressed high satisfaction with the finished product and completed a feedback questionnaire.

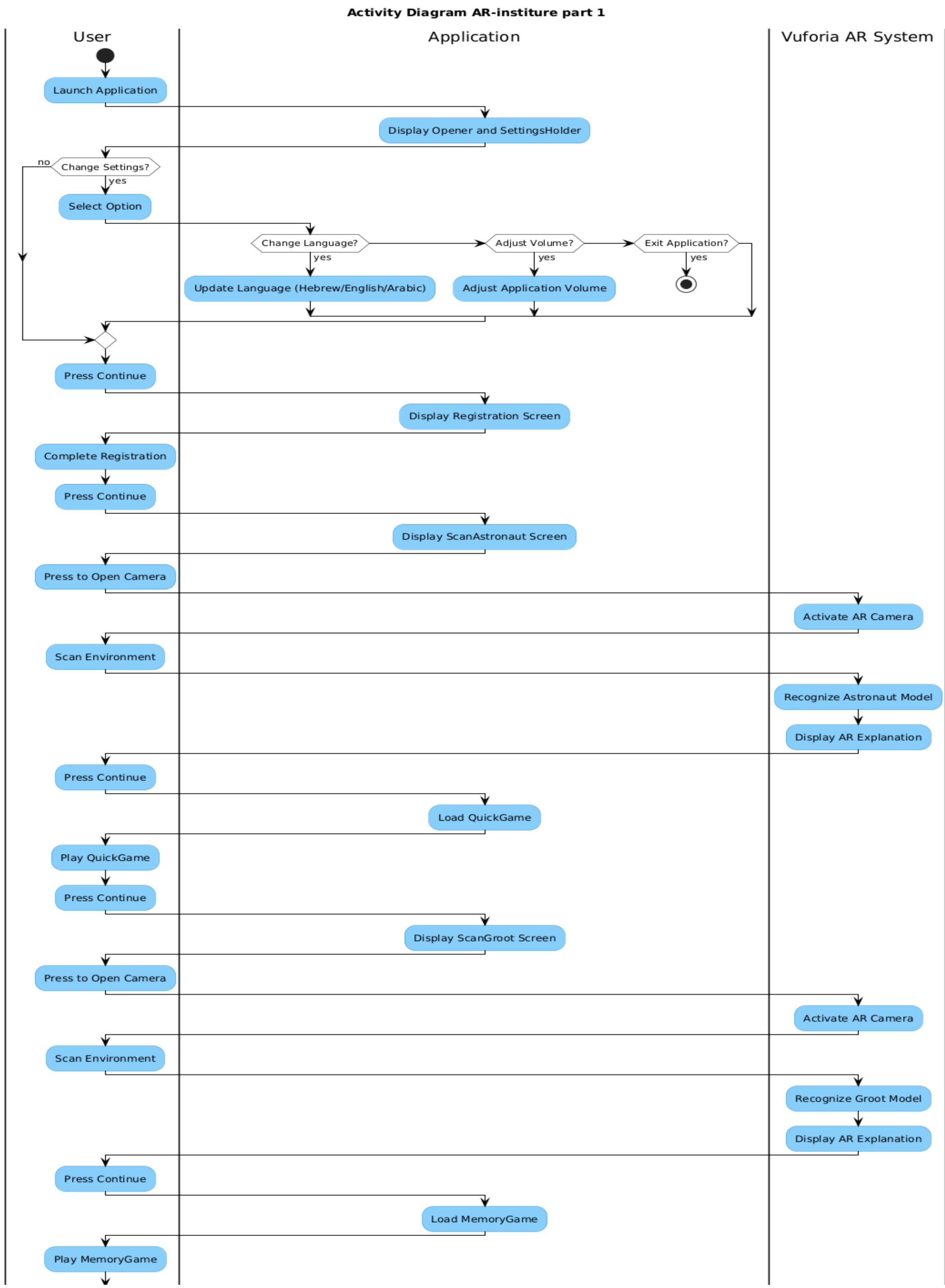
Testing and Evaluation

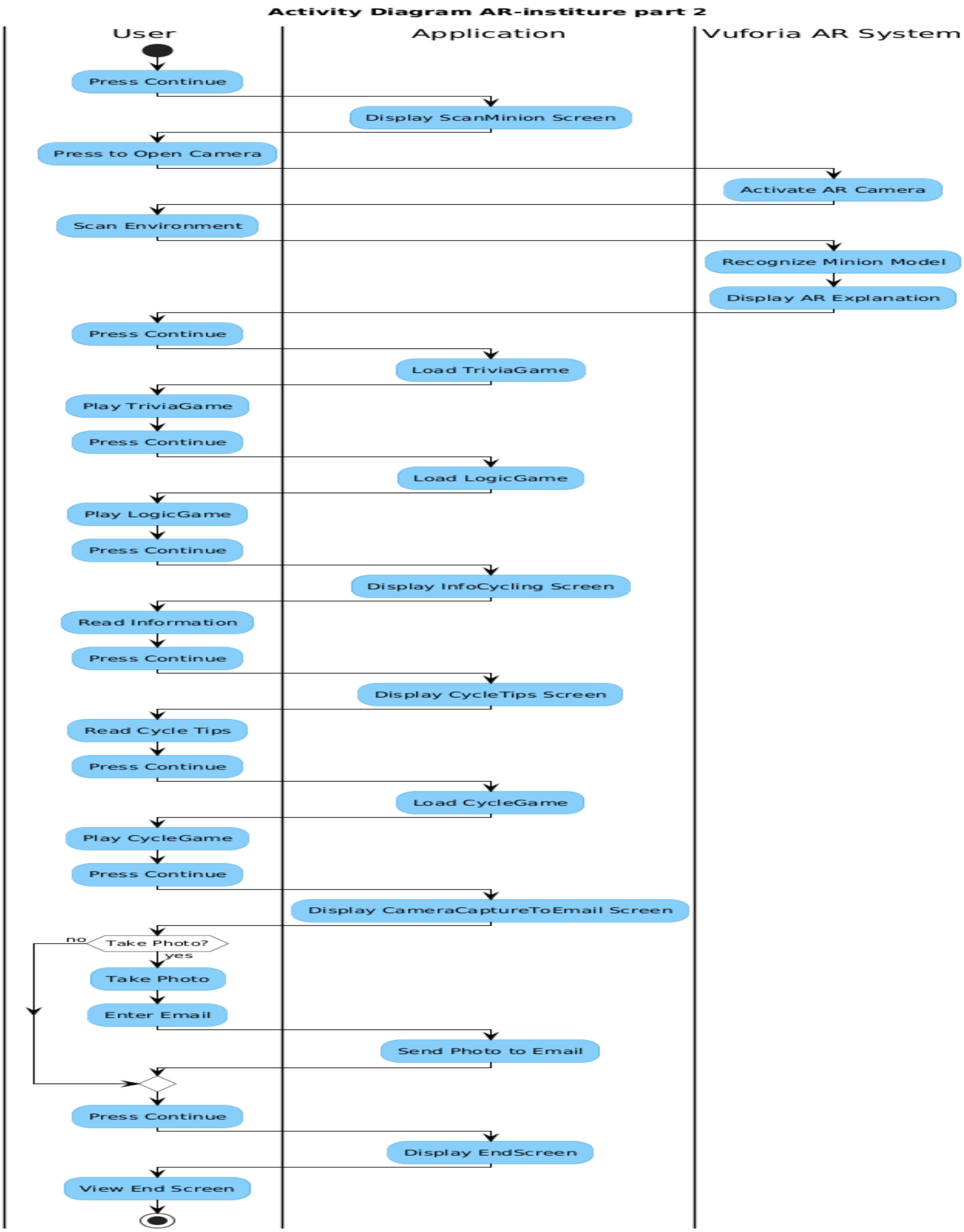
Throughout the development process, we conducted ongoing tests focusing on the functionality.

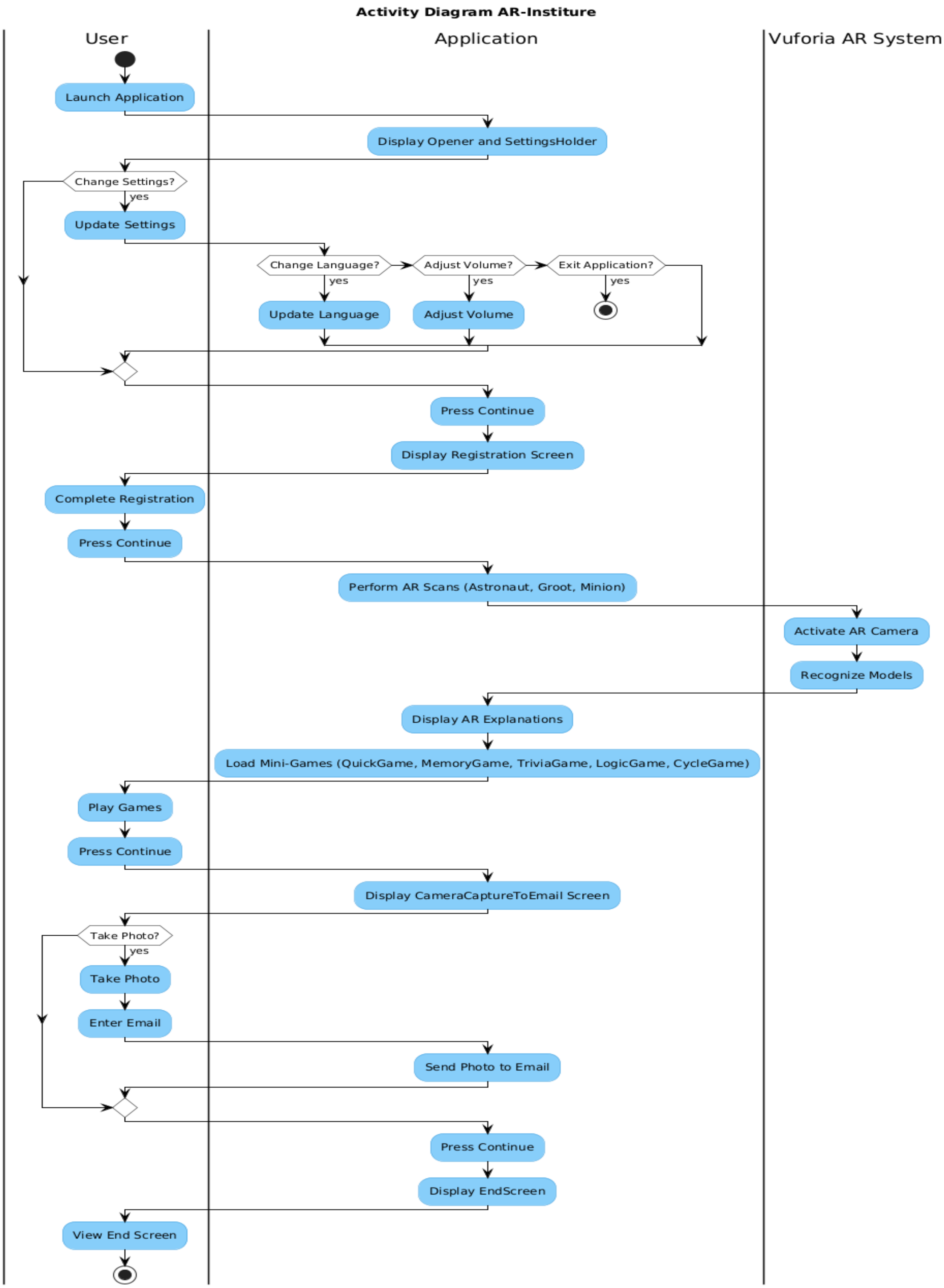
Each client meeting included additional testing to ensure the system met expectations. Upon completion, 15 adult users evaluated the application, completing questionnaires that assessed the impact of the application on understanding and learning experience of the material.

It is important to note that due to various constraints, testing could not be conducted on children at the Advanced Manufacturing Institute. Instead, adult users were employed for the evaluation process.

4.Activity Diagram




Activity Diagram AR-institure part 2
User
Application
Vuforia AR System
Press Continue
Display ScanMinion Screen
Press to Open Camera
Activate AR Camera
Scan Environment
Recognize Minion Model
Display AR Explanation
Press Continue
Load TriviaGame
Play TriviaGame
Press Continue
Load LogicGame
Play LogicGame
Press Continue
Display InfoCycling Screen
Read Information
Press Continue
Display CycleTips Screen
Read Cycle Tips
Press Continue
Load CycleGame
Play CycleGame
Press Continue
Display CameraCaptureToEmail Screen
no
Take Photo?
yes
Take Photo
Enter Email
Send Photo to Email
Press Continue
Display EndScreen
View End Screen



Activity Diagram AR-Institure
User
Application
Vuforia AR System
Launch Application
Display Opener and SettingsHolder
Change Settings?
yes
Update Settings
Change Language?
yes
Update Language
Adjust Volume?
yes
Adjust Volume
Exit Application?
yes
Press Continue
Display Registration Screen
Complete Registration
Press Continue
Perform AR Scans (Astronaut, Groot, Minion)
Activate AR Camera
Recognize Models
Display AR Explanations
Load Mini-Games (QuickGame, MemoryGame, TriviaGame, LogicGame, CycleGame)
Play Games
Press Continue
Display CameraCaptureToEmail Screen
Take Photo?
yes
Take Photo
Enter Email
Send Photo to Email
Press Continue
Display EndScreen
View End Screen

The **Activity Diagram** for the AR-Institure app illustrates the user’s journey through the application, from launching it to completing various tasks. The process starts with displaying the opener and settings, where users can adjust preferences such as language or volume. Following registration, the user interacts with AR features by scanning models (Astronaut, Groot, Minion), after which they play mini-games like QuickGame, MemoryGame, TriviaGame, and more. The app also provides an option to take and send photos via email. The process concludes with the display of the end screen, marking the end of the user session.

5.Development Process

5.1. Development Process Description

1. Opening the project in Unity:

We created a new project using the AR template to implement AR capabilities in the application. We configured the project for the Android platform and set up a simulation for a tablet device to work in a resolution-appropriate manner from the start.

2. Downloading packages from the Unity Asset Store:

We downloaded packages from the Unity Asset Store, including: UI package, animated character package, audio and sound package, and icon package.

3. Connecting Vuforia and using Model Target:

We downloaded models from a dedicated site provided by the client (UltiMaker Thingiverse). Then we performed a 360-degree scan of the models using the Model Target plugin, trained the models, and uploaded them to Unity.

4. Building hierarchy and logic in Unity:

We defined generic folders for audio, models, UI, scripts, images, and more.

5. Developing the game:

We wrote scripts for game logic and defined transitions between different screens in the game.

6. Working on user interface design:

We designed the screens, created buttons and interactive elements, and incorporated sound effects and background music.

7. Conducting tests and bug fixes:

We performed tests for model recognition and interactions.

8. Writing technical documentation and user guide.

5.2. The tools and systems we used

The App	The use
Unity	The game development engine we used to build the app. We used it to build the UI and create the scripts. With it we could build the hierarchy of the game and add elements of augmented reality.
unity Asset Store	A source for resources such as models, textures, UI, sounds, icons and other plugins.
vuforia	An AR platform that we used for training 3D model recognition and implementation in conjunction with Unity.
plasticscm	A tool for version management and collaboration between developers. We used it to manage the code, track changes and perform integrations between the system components.
Canva	A graphic design platform that we used to create the user interface including the design of buttons, titles and images.
ChatGPT	A tool for writing content, research and getting ideas. ChatGPT assisted in creating educational content for the app, drafting documentation and helping with technical questions during development.
Thingiverse	A database of files for 3D printing, from which we took models that we implemented in the application and printed in 3D.
POWTOON	A tool for creating animated videos and presentations. PowToon was used by us to make an introduction video for the application.

5.3. The agile development approach

The development of the application was conducted adhering to Agile principles, emphasizing continuous communication and adaptations in accordance with the needs of the client and target audience.

Initially, on June 26th, we convened with the client at the Advanced Manufacturing Institute. During this meeting, we presented the concept for the application and attentively listened to the client's expectations for the system. We deliberated on the core functionality and features that the application would offer to users. This early alignment of expectations was crucial to ensure that the development would align with requirements from the outset.

A subsequent meeting with the client was held at the institute on July 28th, where an initial version of the application was demonstrated. The purpose of this meeting was to examine the application in a real-world environment and obtain preliminary feedback from the client regarding its functionality, design, and interactivity. During this encounter, we received comments and suggestions for improvement from the client, which we subsequently incorporated into the ongoing development of the application.

The Agile approach we adopted was a key factor in the project's success, as it allowed for flexibility and productive collaboration with the client, ensuring that the final product would be precisely tailored to the needs and requirements defined at the project's inception.

This iterative process, characterized by regular client interactions and responsive adjustments, exemplifies the benefits of Agile methodologies in software development, particularly in projects where user experience and client satisfaction are paramount.

5.4. The challenges

1. A significant early challenge in our application development was implementing effective version control among project collaborators. After experimenting with various solutions, we successfully integrated Plastic SCM as our version control system. This tool proved crucial for efficient collaboration, allowing seamless merging of changes and the ability to revert to previous versions when necessary. The implementation of Plastic SCM marked a pivotal improvement in our development process, enhancing team productivity and providing a robust foundation for managing our evolving codebase. This experience highlights the critical role of appropriate version control tools in collaborative software development projects.

2. A key challenge in our project was using Unity without prior experience. This led to difficulties in understanding project structure, writing efficient C# code, and

implementing basic game development tasks. To overcome this, we utilized Unity's official documentation, YouTube tutorials, peer support, and online forums such as Unity Forum and Stack Overflow. This diverse approach to learning was crucial in mastering Unity, highlighting the importance of adaptability and resourcefulness when adopting new development platforms.

3. A key challenge was testing the application's model scanning capabilities with limited access to physical models at the Advanced Manufacturing Institute. To address this, we employed Vuforia's training database, utilizing virtual models for scanning and system training. This solution enabled remote testing of the scanning algorithm and necessary adjustments, ensuring proper functionality with physical models. Our approach demonstrated the effectiveness of virtual testing environments in overcoming geographical constraints in augmented reality development, while maintaining application quality and accuracy.

4. During the system development process, we encountered significant challenges in meeting our predefined objectives, primarily due to software defects discovered throughout the implementation. Modifications made to enhance specific functionalities often resulted in the emergence of deficiencies in other areas of the system. Furthermore, post-deployment of the APK file, a critical issue was identified wherein Json files failed to be properly recognized on tablet devices.

5. Collaboration with the client was accompanied by several substantial obstacles. Firstly, there was a delay in receiving the requisite content from the client. Secondly, contrary to the initial agreement, the client refrained from providing 3D-printed models, which led to a significant delay in conducting model scanning tests. Moreover, our primary point of contact within the client organization, who had been integrally involved in all planning and execution processes, concluded their tenure. Consequently, the implementation of several previously agreed-upon decisions was jeopardized. The most critical challenge arose when the institution failed to approve the acquisition of tablets as previously negotiated, preventing us from conducting the anticipated on-site implementation and testing procedures as outlined in our research protocol.

6. User File - AR-Institute

Introduction

The app is designed for teenagers visiting the Advanced Manufacturing Institute in Carmiel. Its purpose is to support the physical tour at the visitors' center and teach users about 3D printing technologies through interactive games that incorporate basic concepts of 3D printing.

System Requirements

- The app can be downloaded on any Android device running version 8 or above.
- Required storage space for download: 222.5 MB

Installation

Downloading the app

The app can be downloaded through a private link available in the drive owned by the Advanced Manufacturing Institute.

While downloading, ensure that the device is in developer mode and that debugging is enabled.

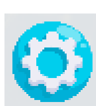
There are two download options:

- A link for downloading the app with 5 games
- A link for downloading the app with 3 games

Installation Process

1. First, download the file to the device by clicking the link.
2. Then, check the device settings to ensure that camera and microphone access is enabled.

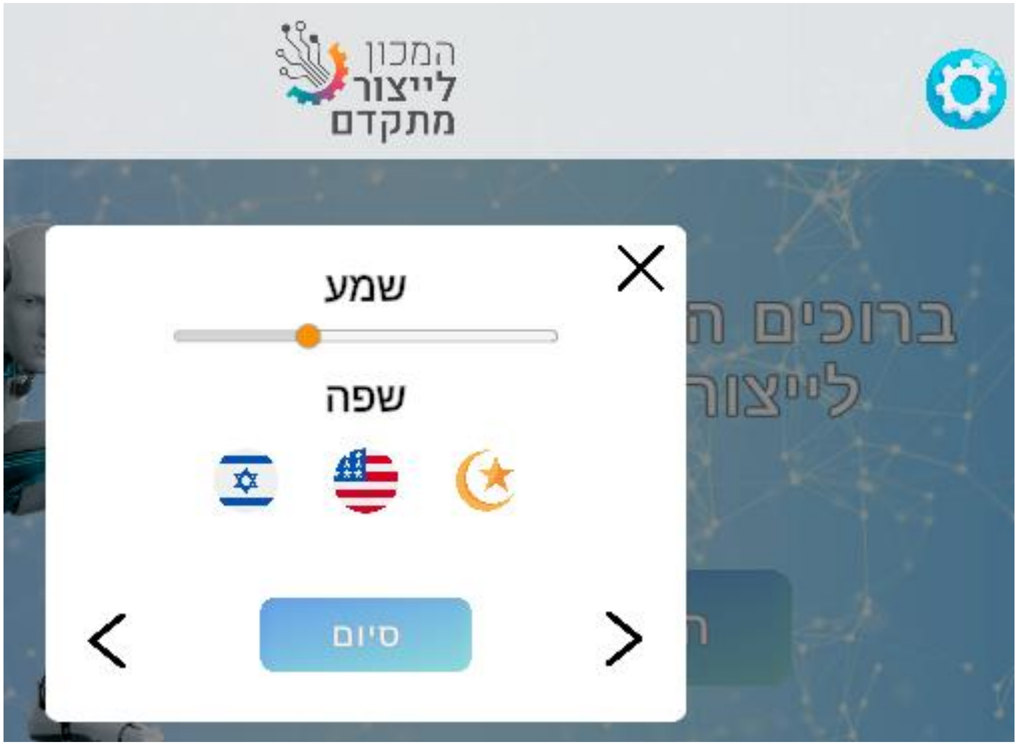
Main Menus

Settings Button 

- Sound: Control the sound system, increasing or decreasing the volume.
- Language: Select the display language. Choose between Hebrew, English, or Arabic.
- Exit: Option to exit the app.

Navigation Arrows

- Right arrow for going back to the previous screen.
- Left arrow for proceeding to the next screen.



Top Bar

- Right arrow for returning to the previous screen.
- Left arrow for moving to the next screen.
- Exclamation Mark: Provides help within the app. Clicking this button at any stage allows replaying the game/level instructions.

Bottom Progress Bar

- The progress bar tracks the user's advancement in the app, including scoring based on progress.

Main Usage Scenario

Game Sequence The game is structured chronologically, with increasing difficulty at each level. At the beginning of each level, participants must solve a riddle, the solution of which is a 3D model located at the institute. After identifying the model, they scan it by pressing the camera button in the center of the screen. After reading the material, users proceed to the game by pressing the continue button on the left. After scanning the model, the user will play a game, which starts with a screen explaining the game's objective and how to play. Progress in the app is tracked via the bottom progress bar and the score that accumulates as the user advances.

Usage Scenario

<u>Opening Screen</u>

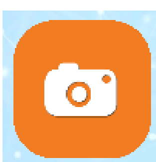
- Start: Begins the game.

Registration Screen

- Upper text box: Enter the group's name.
- Lower text box: Enter the names of the group members.
- Character Selection: Choose a character for the player.

After completing the details, click the save button, followed by the continue button.

Find the Model Game



Answer the riddle and scan the correct model as the solution. To scan the model, press the camera button in the center of the screen, which opens the device’s camera.

Position the camera directly in front of the model without moving. Once scanned, an explanation will appear, along with a continue button.

Quick Game

Accumulate a total of 5 points. Every few seconds, an image of an item will pop up on the screen. If the item is related to 3D printing, click on it while it appears. Each correct click earns a point. If you click on an unrelated item, a point will be deducted.

Materials Game

Match each 3D-printed model to the material from which it was printed by clicking once on the material and then on the model. If matched correctly, the buttons will turn gray, and you won’t be able to click on them again. The game ends when all models are matched with the correct materials.

<u>Memory Game</u>

Match all pairs of cards, where each card of a concept corresponds to the card with its definition. To select a pair, flip two cards by clicking on them.

<u>Trivia Game</u>

Answer the questions correctly. Each time, a question in orange will appear on the screen, followed by four possible answers. Select the correct answer within 30 seconds. The timer appears in the center of the answers. If correct, the answer will be highlighted in green; if wrong, in red.

Recycling Materials

Click on the three buttons on the screen and read the displayed information. You can move to the next stage by clicking the arrow on the top bar to the left.

Recycling Tips

Click the green button on the left after reading each tip. After confirming five tips with the green buttons on the left, proceed to the next stage by clicking the left arrow on the top bar.

Recycling Game

Drag each item to the appropriate recycling bin. If correctly matched, the item will remain in the bin and will no longer be movable. If incorrectly matched, the item will return to the list of items at the top of the orange-colored screen.

End Screen

Press the Finish button to exit the app.

Common Troubleshooting

- Issue with scanning a model: You can move to the next task by clicking the settings button on the top right bar and then clicking the left arrow to proceed to the next page.
- If the game freezes: Exit the app and reopen it.

Notes

- At the end of use, ensure the device is charged by connecting it to electricity.
- Ensure the device is protected by a screen protector and an external case during use

7. AR-Institute Application Maintenance Guide

Introduction

This maintenance guide is intended for developers and IT professionals responsible for maintaining and updating the AR-Institute application. The application enhances the tour experience for teenagers visiting the Institute for Advanced Manufacturing in Karmiel, focusing on 3D printing technologies and material recycling.

System Requirements

Development Environment

- **Unity Version**: 2022.3.22f1
- **Version Control**: Unity Version Control (similar to Git)
- **Programming Language**: All scripts and code in the project are written in **C#**.

Target Platform

- **Operating System**: Android
- **Minimum API Level**: Android 8.0 "Oreo" (API level 26)
- **Device Orientation**: Landscape mode (optimized for tablets)

Minimum Hardware Requirements

- **Processor**: Quad-core 1.5 GHz or higher
- **RAM**: 4 GB or higher
- **Storage**: 1 GB of free space
- **Camera**: Rear-facing camera with autofocus
- **Display**: 7-inch or larger tablet screen with 1280x720 resolution or higher
- **Sensors**: Accelerometer and gyroscope

Required Unity Packages

- Vuforia Engine AR (version 10.25.4 or compatible)
- AR Foundation
- Google ARCore XR Plugin
- TextMeshPro
- Unity UI

Build Settings

- **Scripting Backend**: IL2CPP
- **API Compatibility Level**: .NET Standard 2.1
- **Target Architecture**: ARMv7 and ARM64

Installation Instructions

1. Ensure the target Android device meets the minimum requirements specified in section 2.3.
2. Enable "Install from Unknown Sources" in the Android device settings.
3. Transfer the APK file to the Android device.
4. Locate the APK file on the device and tap to install.
5. Follow the on-screen prompts to complete the installation.

Updating the Application

Preparing for an Update

1. Open the project in Unity 2022.3.22f1.
2. Sync the latest changes from the version control system.
3. Resolve any conflicts if they exist.

Making Changes

1. Implement the required changes or new features.
2. Update any affected documentation within the scripts.
3. Test the changes thoroughly in the Unity Editor.

Building the Update

1. Open Build Settings (File > Build Settings).
2. Ensure the correct scene order is maintained.
3. Click "Build" and choose a location for the new APK.

Deploying the Update

1. Test the new APK on a development device.
2. If successful, distribute the new APK to the target devices.
3. Uninstall the previous version before installing the update.

Maintenance Tasks

Regular Maintenance

1. Check for Unity and package updates monthly.
2. Test the application on new Android versions as they are released.
3. Review and optimize performance quarterly.
4. Update AR models and content as needed.

Troubleshooting

- **AR Tracking Issues**: Ensure the lighting conditions are adequate, and AR markers are not damaged.
- **Application Crashes**: Check the logcat for Android-specific errors.
- **Performance Issues**: Profile the application using Unity Profiler and optimize as necessary.

Data Management

1. Regularly back up the project, including all assets and scripts.
2. Maintain a changelog for all updates and modifications.

Inactive Screens

If certain scenes or games are not needed, the UnusedScreen scene can be utilized. Move the scenes to UnusedScreen within the Unity project to temporarily disable them. This feature ensures the application can run smoothly and allows for disabling certain screens as needed by the tour guide.

Extending the Application

Adding New AR Models

1. Create or obtain the new 3D model.
2. Import the model into the Unity project.
3. Set up the model in Vuforia Model Target Generator.
4. Add the new model target to the AR camera in the new scene.

Adding New Mini-Games

1. Create a new scene for the game.
2. Implement the game logic in a new script.
3. Design and implement the UI for the game.
4. Add the new game to the GameManager's flow.

5. Update any relevant UI scripts to include the new game option.

Email Service Information

The AR-Institute application includes a feature for users to take souvenir photos during the tour. These photos can be sent to the users' personal emails through the application.

A new email account has been created for this purpose:

- **Email**: arinstitureapp@gmail.com

The password for this account will be provided to relevant parties upon request. This email is solely for sending users their photos from the tour as a memento.

Contact Information

For any questions or issues regarding the maintenance of this application, please contact the developers:

- **Ido Saada**: idosaada1811@gmail.com | Phone: 0547911119
- **Bar Steiner**: barsteiner812@gmail.com | Phone: 0526341110

8.Testing Process Description

The AR-Institute application underwent a comprehensive testing process aimed at ensuring functionality, usability, and performance for its target audience—teenagers on a guided tour at the Institute for Advanced Manufacturing.

Testing Phases:

- **Unit Testing**: Key components like the GameManager, SoundManager, and AR camera were tested individually to verify that each performed its intended function correctly.
- **Integration Testing**: Once components were validated, they were tested together to ensure cohesive functionality, including AR features, UI elements, mini-games, and backend systems.

Testing Methods:

- **Manual Testing**: This involved navigating through the app, testing the AR camera's ability to recognize models (Astronaut, Groot, Minion), and ensuring smooth transitions between game screens.
- **Device Testing**: APK builds were deployed to different Android devices to check for compatibility, ensuring smooth performance across varying screen sizes and hardware configurations.
- **Beta Testing**: Conducted at the Institute, beta testing focused on object recognition, app performance, and user feedback. Teenagers, employees, and external testers contributed insights that helped refine the app.

Acceptance Testing:

- The app was evaluated against key criteria, including AR object recognition and performance under different lighting conditions. Regular regression testing ensured that new features did not disrupt existing functionality.

Test Results:

- The AR camera consistently recognized 3D models, and the app maintained stable performance across various devices. Feedback from users was highly positive, confirming the app's intuitive interface and reliable functionality.

Overall, the testing ensured the AR-Institute app met high standards of usability, technical accuracy, and educational effectiveness.

Table 1: Game Functionality Testing

Test #	Test Case	Expected Results	Result	Status
1	Quick Game: Earn 5 points	User clicks correct 3D printing items, points accumulate correctly	5 points earned successfully	Pass
2	Materials Game: Correct material matching	All models match correctly, buttons turn gray	All matches successful, buttons locked	Pass
3	Memory Game: Match concept cards	All pairs matched correctly, game finishes	Game finishes successfully	Pass
4	Trivia Game: Answer within 30 seconds	Correct answers turn green, incorrect answers turn red	Answers highlighted correctly	Pass
5	Recycling Game: Drag items to correct bins	Items matched with bins, incorrect items return to the list	All items correctly matched	Pass

Table 2: JSON Data Display Test

Test #	Test Case	Expected Results	Result	Status
1	JSON data for games displayed correctly	Game data (questions, materials, etc.) loaded from JSON file	Data displays successfully	Pass
2	Correct rendering of game content from JSON	Game content loads smoothly without errors	Content rendered correctly	Pass

Table 3: Settings and User Preferences Testing

Test #	Test Case	Expected Results	Result	Status
1	Change language in settings	Application language switches successfully	Language changed successfully	Pass
2	Adjust volume settings	Volume increases or decreases as per user selection	Volume settings respond accurately	Pass

Table 4: User Flow and Transition Testing

Test #	Test Case	Expected Outcome	Result	Status
1	Successful transition between screens	Each stage transitions smoothly to the next without delays	Smooth transition between screens	Pass
2	Successful scan of models	User scans models, information displays correctly	Models scanned successfully	Pass
3	Capture photo with front camera	Front camera captures photo successfully	Photo captured successfully	Pass
4	Capture photo with rear camera	Rear camera captures photo successfully	Rear camera switch successful, photo captured	Pass
5	Retake photo	User retakes photo after the first attempt	Retake function works properly	Pass
6	Email photo successfully	Photo sent to user's email, system confirms	Email sent successfully	Pass
7	Invalid email input	System informs user of incorrect email format	Error message displayed for invalid email	Pass

Table 5: Registration and User Input Testing

Test #	Test Case	Expected Results	Result	Status
1	Enter group name and member names	Names entered and saved successfully	Data entered and saved correctly	Pass
2	Select character	Character selected or default assigned if none chosen	Character selected or default assigned	Pass
3	Successful navigation after saving registration	Save and continue buttons function as expected	User proceeds to the next screen after saving	Pass

9.Project Results Analysis and Conclusions

In the first part of our project, we set out to define expected achievements. To evaluate our success, we carefully compared these predefined goals against what we actually managed to implement in the application. Here are the key achievements and outcomes of our project:

- Augmented Reality Integration: We successfully integrated augmented reality (AR) technology into the application using the Unity game platform in combination with Vuforia. This allowed us to train 3D models for recognition during scanning. We added a layer of textual information over the reality layer, incorporating educational content from the Institute for Advanced Manufacturing. We met our target of less than 5% error rate in model scanning.
- Educational Content Implementation: We defined and implemented almost all the intended educational topics in the application's various games, using content received from the Institute for Advanced Manufacturing.
- Client Collaboration: We maintained regular contact with the Institute for Advanced Manufacturing, updating them on our progress and holding joint planning sessions. The application was designed to complement guided tours rather than replace them, aligning with the client's vision.
- Gamification Elements: We successfully incorporated several gamification elements, including a progress bar, a scoring system, sound feedback for actions, and five different types of games (memory game, material recycling game, speed game, trivia game, and model matching game).
- Multimedia Information: We added extra information through both text and images, ensuring that content is absorbed both visually and verbally.
- Multi-language Support: We built a language system allowing users to choose between Hebrew, English, or Arabic, catering to the diverse target audience of Jewish and Arab youth.

Despite these successes, we faced one notable challenge:

- Interactive 3D Models: We were unable to implement interactive 3D models as planned, due to difficulties in obtaining a scanned model of a
- printer from the manufacturer.

Throughout our work on the application, we maintained regular contact with the Institute for Advanced Manufacturing. We updated the client on our progress and held several meetings for joint thinking on how to use the application and integrate it into the physical tour of the Institute. The client specified that the application is intended to be part of a guided tour for students with an instructor, designed to add knowledge and test the knowledge gained by students during the tour, but not to replace the guide. From this, it was decided that some of the topics we intended to cover in the application would be conveyed by the guide physically, ensuring that we met the content mission in a way that suits the client and provides them with the best solution.

Working on the language system was particularly challenging and required significant effort. We had to adapt different fonts for each language, adjust the direction of writing, translate all texts in the application, build identification keys for translation, and overcome many other difficulties.

In conclusion, we met most of the project goals we set for ourselves. We faced many challenges along the way and learned a lot about the process of developing an application from the idea level to execution, while collaborating with the client and meeting their requirements, and of course, with a main emphasis on the needs of the application users.

10. Lessons Learned from the Project

Throughout the course of this project, we encountered several challenges that provided valuable lessons for future endeavors. One significant issue arose from an early agreement with the client representative regarding the purchase of tablets for our use. Unfortunately, budget constraints led to delays and ultimately prevented this acquisition within our defined timeframe. Similarly, we had planned for a component of the application that relied on a 3D model from the printer manufacturer, but our client was unable to get the model, resulting in this feature not being implemented. These experiences underscore the importance of securing all necessary resources and permissions early in the project timeline, as well as having contingency plans for potential setbacks.

We also faced difficulties in adhering to our initially defined timeline. Client-requested changes often took longer to implement than anticipated, highlighting the need for more flexible scheduling and better estimation of task durations. Communication with the client occasionally proved challenging, with significant delays in obtaining required content and collaboration. This emphasizes the importance of establishing clear communication channels and setting explicit expectations for response times and deliverables from all parties involved.

Another hurdle we encountered was related to the printing of models using the Institute's printer. Unexpected resistance from the Institute's management regarding the budget required for material printing emerged, stressing the need for comprehensive stakeholder alignment on all aspects of the project, including auxiliary costs.

On the technical side, we faced numerous development challenges and bugs. Particularly notable was our difficulty in reading certain JSON files on the target device, an issue we only discovered late in the development process when building and running the application on the actual hardware. This experience highlights the critical importance of early and frequent testing on target devices throughout the development cycle.

Lastly, the lack of a dedicated pedagogical expert to craft the educational content meant we had to repeatedly revise and correct this material ourselves. This underscores the value of involving subject matter experts from the outset of content development to ensure accuracy and educational effectiveness.

These experiences, while challenging, have provided invaluable insights that will undoubtedly enhance our approach to future projects. By anticipating potential obstacles, improving communication strategies, conducting more rigorous testing throughout development, and ensuring the involvement of necessary expertise from the project's inception, we can significantly streamline our processes and improve overall project outcomes.

11.Considerations in Decision Making Throughout the Project

Throughout the development of our educational augmented reality application, our decision-making process was guided by a complex interplay of factors. Foremost among these was our commitment to delivering an effective and engaging educational tool that aligned with the Institute for Advanced Manufacturing's vision. This primary goal influenced many of our choices, from the selection of AR technology to the integration of gamification elements.

We consistently prioritized user experience, recognizing that the application's success hinged on its ability to captivate and educate young users from diverse backgrounds. This consideration led to our decision to implement multi-language support and to carefully design interactive elements that would appeal to our target audience.

Technical feasibility was another crucial factor in our decision-making. We had to balance our ambitions for advanced features, such as interactive 3D models, with the practical limitations of available resources and technologies. In some cases, like with the virtual printer simulation, we had to adapt our plans when faced with unexpected obstacles in acquiring necessary assets.

Time management was a constant consideration, influencing decisions about feature implementation and project scope. We had to weigh the benefits of additional features against the need to meet deadlines and deliver a functional product within the agreed timeframe.

Collaboration with the client was a key factor in our decision-making process. We strived to incorporate their feedback and requirements, sometimes needing to adjust our plans to better align with their vision or to accommodate changes they requested. This collaborative approach, while sometimes challenging, ensured that the final product would meet the client's needs and expectations.

Lastly, we considered the long-term sustainability and scalability of the application. Decisions about technology choices and architecture were made with an eye towards future updates and potential expansions of the application's capabilities.

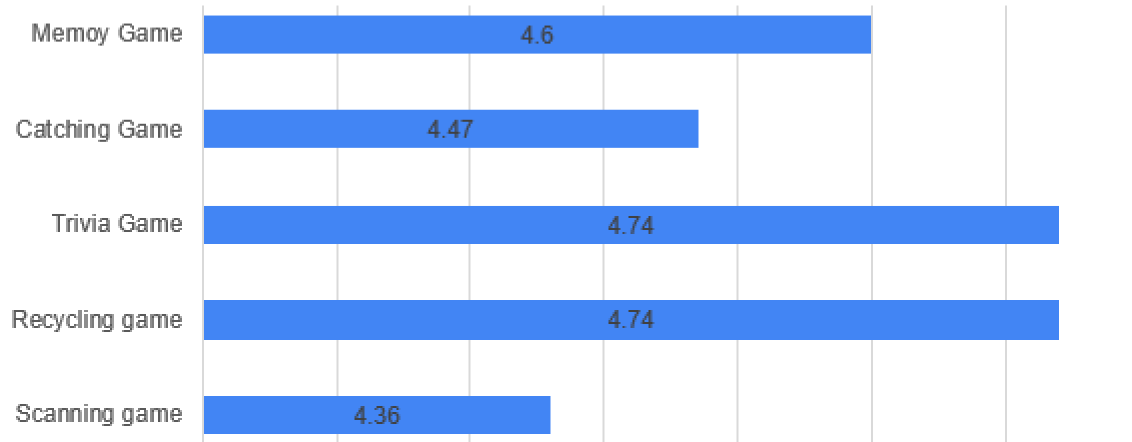
These multifaceted considerations often required us to make complex trade-offs, balancing ideals against practical constraints. While not every decision led to perfect outcomes, this thoughtful approach allowed us to navigate challenges and ultimately deliver a product that met most of our key objectives.

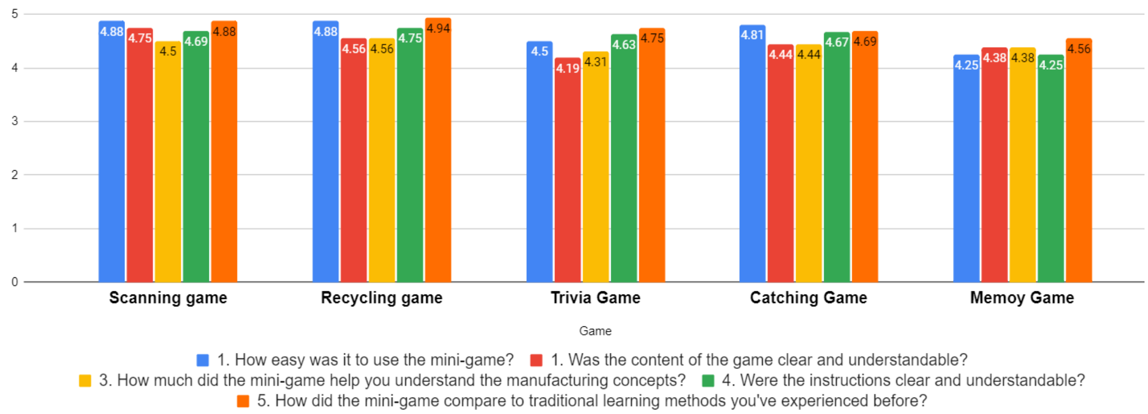
12. Evaluation findings

To assess the effectiveness and user experience of the AR-Institute application, we implemented a survey based on the work of Diaz, Hincapié, & Moreno (2015). This survey was designed to evaluate how the type of content in educative augmented reality applications affects the learning experience. We addressed five games – scanning, catching, trivia, memory and recycling game.

For each game, the survey included the following key questions:

1. How easy was it to use the mini-game?
2. Was the content of the game clear and understandable?
3. How much did the mini-game help you understand the manufacturing concepts?
4. Were the instructions clear and understandable?
5. How did the mini-game compare to traditional learning methods you've experienced before?





At the end of the survey, we asked general questions:

1. Were there any technical issues that hindered your experience with the AR application?

Half of the participants answered “no”. Those who addressed problems, mostly referred to minor problems such as scanning, or moving in the screen (which eventually was solved).

2. What are the advantages of using AR for learning about advanced manufacturing?

The participants answered: Clear (4), Fun (4), Understand concepts (2) and play and understand the technological capabilities in progress (3), Accessibility and user comfort (1).

3. What suggestions do you have for improving the AR application?

Only half of the participants answered, the main ideas were sharing with friends (2), additional feedback (2), and more information about AR technologies (1).

4. Did you find the AR experience engaging and motivating?

All the participants answered "yes". One wrote "It's nice to have the option to scan a model, and also have to guess what it is - adds more interest to learn. As soon as you scan, an explanation appears that is more interesting to read like this than just a written explanation...". Another said "At a very high level, an interesting and very relevant topic today".

12. References

[1] **DeWitt, J., & Storksdieck, M**. (2008). A short review of school field trips: Key findings from the past and implications for the future. *Visitor studies*, *11*(2), 181-197.

[2] **Akçayır, M., & Akçayır, G**. (2017). Advantages and challenges associated with augmented reality for education: A systematic review of the literature. *Educational research review*, *20*, 1-11.