UiT The Arctic University of Norway

Faculty of Science and Technology
Department of Computer Science

Sorterius

Game-inspired App for Encouraging Outdoor Physical Activity for People with Intellectual Disabilities

Magnus Stellander

Well, thank you.

"I've never played for a draw in my life."
–Sir Alex Ferguson

Preface

The impact of physical activity and physical and mental health is a well-known fact. Mobile applications are rapidly evolving to help people with motivation and reach activity goals, both directly related to training but also through ex-ergaming. But when creating such apps, have society forgotten someone?

For ten years, I have been working for people with various disabilities. My work experience has been from schools and as a personal assistant. Through this work, I discovered the immense enjoyment of mobile games and the extensive engagement when learning new things.

Working as a personal assistant, I have seen the great enjoyment of playing the augmented reality game Pokemon Go. Playing Pokemon Go led to daily walks to the city to catch pokemon. The only downside was that he could not play it by himself. He relied on others to use his mobile phone when playing because the application was too complicated.

When I started my studies in computer science, I promised my friend, which I have been working with for the last ten years, to use my knowledge to create something valuable for people with disabilities in the future. As I'm a man of my words, this is my first contribution to fulfilling my promise.

In the past nine months, people with intellectual disabilities, physical activity, and augmented reality have been the top priority. The ups and downs have been many. On one side, the big engagement related to this project and creating such an application has been truly unique. On the other side, developing an augmented reality application on my own has been challenging. However, as this was my first mobile application and first time working with augmented reality, this was expected to be challenging.

First, I want to thank my primary supervisor Gunnar Hartvigsen for his great support. Guiding me through the research and thesis writing, combined with all the insights, tips, and weekly meetings, have helped me throughout this project. Thank you for this and for always being in a happy mood.

To all my co-supervisors, Santiago Martinez, Keiichi Sato, Susanna Pelagatti, Erlend Johannessen, Vebjørn Haugland, and André Henriksen, thank you for attending meetings, good conversations and answering all kinds of questions that I have put out there.

I also want to thank my co-supervisors, professor, and Chief physician Audy Anke and psychologist Henriette Michalsen. Your insight into people with intellectual disabilities and arranging usability testing, even during COVID-19 restrictions, have been a great value for this project.

A big thanks go to the boys I have been studying with for the last five years. Without all the wonderful coffee breaks and good conversations, these years would not be the same.

Lastly, I want to thank my family that has supported me for the last five years. You have made these years easier through countless dinners and support.

Magnus Stellander - Tromsø, Norway, May 2021

Abstract

People with intellectual disabilities have difficulties in reaching the World Health Organization's (WHO) suggested level of physical activity. Previous research shows that participating in physical activities often is related to self-efficacy in a physical activity setting and personal motivation. As physical activity has significant effects on physical and mental health, this thesis aimed to develop a mobile application that could help people with intellectual disabilities be more physically active.

In the process of creating an encouraging and user-friendly mobile application, this project includes literature reviews, meetings with experts in the field, discussions with special education teachers and teachers working with people with intellectual disability, and the author's own experience with this user group. The project relies on guidelines and theory to create a user interface to fit people with intellectual disabilities.

This thesis presents a cross-platform mobile application that combines the digital and real world. Using augmented reality, players walk around in the real world looking after digital garbage. As they walk, they will find garbage on the ground and get the option of sorting the garbage in the correct garbage bins. The game's main objective is to look for garbage and throw it in the correct garbage bin. As users progress throughout the game, they earn stars based on their step count while playing the game. Together with family members or assistants, they can add weekly physical activity goals and earn special rewards created by family members or assistants.

Usability testing is mainly done on special education teachers, social workers, psychologist, and researchers working with people with intellectual disabilities. It revealed that creating a mobile application focusing on everyday life scenarios can have a potential value for the targeted user group. However, testing also showed that using augmented reality can be challenging. Long-term testing on individuals with an intellectual disability will start in the upcoming weeks in a study conducted by the University Hospital of North Norway (UNN), in collaboration with UiT The Arctic University of Norway.

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Introduction

1.1 Background

Physical activity is known to have significant health benefits[1]. According to World Health Organisation (WHO), regular moderate physical activity can improve mental and physical health. Improving physical activity levels can also improve fitness, energy levels, and weight control and help prevent depression. WHO recommends that young adults reach a minimum of 150 minutes of moderate physical activity every week or 75 minutes of practical training [2]. In addition, it is recommended that people spend at least two days doing muscular training every week.

Individuals with an intellectual disability are known to have difficulties in achieving recommended levels of physical activity (PA) [3]. Compared to the general population, they have lower physical activity levels and worse health [3, 4]. A study by A. Dixon-Ibarra et. al. [5] shows that one of the barriers to being in physical activity for these individuals is lack of personal interest. Another and important aspect related to barriers is low physical activity related self-efficacy [5]. Some individuals with intellectual disabilities have difficulties believing that they have the capacity to perform specific tasks [5], such as initiation of physical activities [6].

Over the past ten years, there has been improvements in applications that help people improve their levels of physical activity and facilitate motivation for physical activity. Strava and Runkeeper are applications that has set a trend

for sharing physical activity data and thereby creating a social platform where people can share their runs and hikes with other friends. These applications can be great tools for people without disabilities but can be too complex and advanced for people with intellectual disabilities.

By examining the results from a previous project, developed by Haugland [7], it seems promising to use Augmented Reality (AR) to target people with intellectual disability, focusing on improving physical activity levels. However, evaluating that project revealed that there were still many missing features for the game to satisfy the users. The old game could not track physical activity, store data, and did not challenge all users. Also, testing revealed that the old game still had some room for improvement in usability. The new solution uses the findings from the old project but we want to implement and design a new application. This thesis presents a new application with different content, new architecture, and made cross-platform.

This project is part of the research project "Effects of physical activity with e-health support in individuals with intellectual disabilities" [8] The project focuses on The project focuses on mHealth support for increasing physical activity in youth and adults with intellectual disabilities. The project aims to investigate the effects of physical activity and to increase the research activity in this field.

1.2   Context

In a recent study by members of the leading research project "Effects of physical activity with e-health support in individuals with intellectual disabilities.", care staff and family members were interviewed [6]. The study's main objective was to get their perspective on motivational factors for participating in physical activity for people with intellectual disabilities. Through interviews, several individuals said that people with intellectual disabilities were more likely to participate in physical activity if the activity had a different purpose than the activity itself [6]. Two of the parents said that:

". . . we always have to find things to recycle and walk by a container and throw it in. And there is no lunch before we have been out walking for a while, and then it's just a matter of how long you can stretch it. (mother)"

". . . it's the same for our boy, as I hear others talk about, that it should be another purpose with the activity than the activity itself. The best is to bring a good lunch to eat on the top of a mountain or do practical chores like walking by the grocery store to a recycling bin. (father)"

This project aims to do just that - develop a game that is more fun and encouraging than doing the activity itself. Encouraging users is done using augmented reality combined with an everyday scenario. Users walk around collecting trash and throwing it in the correct garbage bins along the way.

1.3   Scope and research problem

In this project, we want to develop an augmented reality game that encourages and motivates individuals with intellectual disabilities to improve their daily and weekly activity levels. The goal is to develop a game that helps users reach the recommended amount of physical activity through outdoor walking. The project aims to create an application that is easy to use and can track the amount of physical activity achieved. The main research research problem is stated as followed:

> RP: *How can we design and implement a mobile game for people with mild to moderate intellectual disability that encourages physical activity?*

1.3.1   Sub-Problems

From the research problem, we further divide this into sub-problems.

One of the findings in the evaluation phase of the previous project was that the solution did not fit all users [7]. The application was challenging enough for some, but others felt that it was too easy. The application targets people with mild to moderate intellectual disabilities, and therefore adjustable levels of difficulty are considered essential.

The first sub-problem is stated as followed:

> RP1: *How can we personalize the application to fit users with different severities of intellectual disabilities?*

Secondly, as the main focus of the application is to motivate users to increase their physical activity level (PA), we want to do this using WHO physical activity recommendations [9]. WHO states that young adults should reach a

minimum of 150 minutes of moderate physical activity every week. This equals 20 minutes of moderate physical activity per day. Participants in the study may combine the application with other activities to increase their level of PA per week. Small increases in PA are of value for health for people with intellectual disabilities [10]. We want to focus on one of the same sub-problems stated in the earlier version but somewhat modified. In Haugland's project, the focus was to encourage users to throughout one session. The goal of this project is to help users increase their overall PA weekly. This sub-problem focuses on adding more aspects to the game to achieve this goal. We can state the second sub problem as follows:

> RP2: *How can we improve the application to encourage users to use it throughout the week?*

We are creating a game for people with intellectual disabilities, and their particular needs must be in focus when designing the entire application. Having a complicated user interface can cause users to give up before the game even starts or the user lose focus. Using a mobile phone when walking outside can cause an additional cognitive load, which can distract the users from their main task [11]. Creating a user interface tailored towards this user group is considered one of the main challenges to reach the application's primary goal; encourage physical activity. This leads up to the third sub-problem:

> RP3: *How can we design the application using user interface guidelines for supporting people with intellectual disabilities?*

Lastly, the possibility for parents or care takers to personalise the physical activity to different kind of users is something we want to implement in this version. Personalising the game is something we consider important for the targeted user group, and being able to adjust and add rewards tailored to a specific user is a feature we want in this version. Thus, we state the last sub-problem as follows:

> RP4: *How can we encourage increased physical activity through person-alised goals?*

1.4 Assumption and limitations

Because the project aims to develop an augmented reality application, an assumption is that people using it can interact and use a mobile device. Thus, the application's primary focus is people with mild to moderate intellectual disabilities.

Testing the effect the application has on actual increasing physical activity levels is hard to conduct due to the limited time frame of this project. A limited time frame, combined with the development, makes testing this application rely on usability.

Testing of the application is limited to usability testing. Evaluating the application was done by teachers, psychologists, special education teachers, and health care workers. Due to COVID-19 restrictions and the limited time frame, usability testing did not include actual users. Testing the user interface and gameplay on people with intellectual disabilities would be beneficial to verify the final product.

1.5 Methods

The project primarily focuses on an engineering approach to the development stages, stated in the paper "Computing as a discipline." [12]. Before starting the design, the project had a vision that augmented reality could encourage people with intellectual disabilities to engage in physical activity. The design paradigm consisted of stating requirements, stating specifications, designing the system, and testing the application. Re-entering the design paradigm, requirements, and specifications continuously changed before ending up with the final product. Lastly, people from the environment around individuals with intellectual disabilities tested and evaluated the application.

Establishing a proper theoretical background is done through reviewing literature related to this project. Further, the project relies on feedback and conversations with intellectual disability professionals, special education teachers, and a phycologist. We enabled re-designing the user interface and features efficiently to fit people with intellectual disabilities through the iterative feedback loop.

1.6   Contributions

The project creates and mobile application that can help individuals with intellectual disabilities towards a more active life. The solution provided is a mobile application focusing on physical activity and learning. Bringing a learning interest combined with the environment is considered a contribution to both people with intellectual disabilities and social involvement by involving garbage collection. As a side effect, the application can help raise awareness about the environment and benefit physical and mental health.

Due to positive results in this project, the application developed will contribute to a pilot study as part of the project *Effects of Physical Activity with e-health support in Individuals with Intellectual Disabilities*. The pilot study is a study conducted by the University hospital of North Norway (UNN), in collaboration with UiT The Arctic University of Norway. The study aims to provide people with intellectual disabilities options for doing physical activities. As part of this, several people will have the possibility to try out this application, Sorterius.

1.7   Organization of the thesis

The rest of this thesis is organized as followed:

Chapter 2 - Theoretical background presents relevant background information related to this project. This chapter presents general information about intellectual disability, serious games, and the current state-of-the-art augmented reality games. In addition, this chapter describes aspects related to developing an accessible user interface for people with intellectual disabilities and presenting the literature review performed in this project.

Chapter 3 - Method this chapter describes the research paradigms, methods used, and the usability testing phase.

Chapter 4 - Requirement Specification describes how the project identified requirements and goes through the functional and non-functional requirements.

Chapter 5 - Design present the design of the application by describing the game scenario and all views within the application. It also covers design choices and the overall design.

Chapter 6 - Implementation covers a detailed description of implementation-

specific details.

Chapter 7 - Test and Results presents the usability test results and general feedback.

Chapter 8 - Discussion evaluates test results and research problems. In addition, challenges and future work is discussed.

Chapter 9 - Conclusion summarizes the project, the results and presents concluding remark.

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Theoretical Framework

This chapter describes the topics used to form the theoretical framework for this thesis.

2.1 Levels of Intellectual Disability

The Norwegian directory of health (Helsedirektoratet) describes intellectual disability as a disability characterized by significant limitations in intellectual functioning and adaptive behavior expressed in conceptual, social, and practical adaptive skills, originating before age 18 [13][14]. A doctor or psychologist assesses the diagnosis through standardized tests, and a full-scale intelligence quotient (IQ) score of 70 to 75 indicates a significant limitation in intellectual functioning. The IQ score must be interpreted in the context of the individuals' difficulties in general mental abilities and everyday functioning. The individual with intellectual disability requires specialized care, adapted health services, and training. In most cases, intellectual disability is caused by a genetic aberration or a chromosomal failure and is usually congenital [15].

2.1.1   Four types of Intellectual Disability

In the United States, two different systems classify intellectual disabilities: *the American Association on Intellectual and Developmental Disabilities (AAIDD)* and *the Diagnostic and Statistical Manual of Mental Disorders, 5th Edition (DSM-5)*. DSM-5 uses three main criteria for the diagnosis of intellectual disabilities (published by the American Psychiatric Association), and these are the criteria used on the NHI website and are listed above [16].

The earlier version of DSM-5 (DSM-4/DSM-IV) focused on the IQ when classifying the level of intellectual disabilities. DSM-5 focuses on the amount of support the individual needs to function correctly [16].

Severity	Approximate Percent Distribution of Cases by Severity	DSM-IV (severity based only on IQ category)	DSM-5 Criteria (based on daily skills)	AAIDD Criteria (based of support needed)
Mild	85%	Approximate IQ range 50-69	Can live independently with minimum levels of support.	Intermittent support needed during transitions or periods of uncertainty.
Moderate	10%	Approximate IQ range 36-49	Independent living may be achieved with moderate levels of support, such as those available in group homes.	Limited support needed in daily situation.
Severe	3.5%	Approximate IQ range 20-35	Requires daily assistance with self-care activities and safety supervision.	Extensive support needed for daily activities.
Profound	1.5%	IQ < 20	Requires 24-hour care.	Pervasive support needed for every aspect of daily routines.

Table 2.1: Intellectual disability - classification of severity levels [17]

Mild Intellectual disability

As we can see from table 2.1, most of the individuals classified with intellectual disabilities fall under the severity level of mild, and the IQ is usually in the range 50-69. People with mild intellectual disability may no be identified if they do not require support for daily activities as they do not have difficulties holding conversations, and most of them achieve complete independence. On the other side, many have problems reading and writing, and academic school-work is considered one of the main challenges they face. However, they can master these challenges by having a reliable and well-structured educational system built to support their needs. Not having strong writing language or reading skills does not prevent them from working, and many people with mild intellectual disabilities will prefer different types of practical work. Some may face emotional or social problems [16, 18].

Moderate Intellectual disability

Individuals with moderate intellectual disabilities can learn the most basic reading, writing, and counting skills. In order to achieve these skills, they also need to rely on a well-structured educational program. When becoming adults, practical work is often preferred, and achievable under supervision[18]. In combination with motor disabilities, achieving complete independence and self-care are rarely accomplished. Achieving complete self-independence does not mean that they can not live independently, but they would need support[16]. On the other side, the majority can potentially be physically active, interact with others and participate in social activities [18].

Severe Intellectual disability

Only 3-5 % of the individuals with intellectual disabilities fall under this category. People with severe intellectual disabilities usually do not learn to read or write. They understand speech, but many will communicate with a combination of speech, signs, gestures, and through symbols and pictures. Among people with intellectual disabilities, around 30% of the population require services from the community [19]. Individuals with intellectual disabilities more often have health problems, and visual problems are frequent. Some also have motor impairments [18].

Profound Intellectual disability

Profound intellectual disability causes even bigger challenges. Their ability to communicate is limited, and it may be difficulties with understanding speech or instructions [18, 16]. Individuals with profound intellectual disabilities can not live independently and will need close attention from supervisors. Supervision includes constant help for fulfilling their everyday needs [18].

2.2   Serious game

Playing games have been found to increase motivation and can change behavior through entertainment [20]. Serious games try to bring real-life knowledge to the game and not entirely focus on entertainment systems [21]. The use case for serious games can appear in many different areas, such as education, healthcare, and the military. The main focus when designing a serious game is trying to motivate and encourage behavior change through gamification. Gamification describes the development process related to a non-entertaining area or goal [22]. Physical activity can often be associated with non-entertaining, but adding gamification to a topic can help make it appear more fun for the user. When regular games reward players through entertainment systems, serious games try to reward participants through the real-life skills or knowledge intended for the game.

By adding challenging tasks, good feedback, and meaningful tasks, serious games can reduce boredom and motivate repetitive activities [23].

Exercise games

Where serious games focus on achieving real-life knowledge, exercise games (exergames) combines gaming and exercise. The main focus of an exergame is to motivate players to physical activity during gameplay [24]. Exergames have proven to help individuals boosting their activity level from an intensity of mild to moderate [24]. The level of intensity also depends on the intensity focus of the game. The level of entertainment when doing exercise while training has also proven to be promising, and especially for people with obesity (highest level of body mass index) [25]. In summary, exergames integrate technology and body movement, which can help reach the daily recommended level of physical activity.

2.3 mSpider

This project aims to encourage physical activity through gameplay. Therefore, collecting activity data was needed to evaluate the impact of the application in the future. Hosting and gathering activity data are done in mSpider - an experimental system implemented by Henriksen et. al. [26]. mSpider is a system created to collect and host activity data automatically, using consumer-based activity trackers. The system consists of three modules, and is illustrated in figure 2.1:

Web front-end

The front-end is responsible for managing surveys and handling user authorization.

Server back end

The server back end stores the user authorization data, handles data transfer between mSpider and cloud services, and stores activity data.

Mobile application

When activity data can not directly get transferred from the provider's cloud service to the server back end, the mobile app is responsible for authorization and data transfer to the back end.

2.4 User interface

2.4.1 Accessibility

To succeed in developing an application targeting people with intellectual disabilities, designing the app's quality and nature of user interaction should be taken into account from the very start [27]. The accessibility of the application plays a significant role for the users. Without knowledge about both the various user groups and how they processes information, an application will not reach its purpose. Dealing with accessibility allows people with different intellectual disabilities variations to navigate, interact and understand the application [27]. The following section presents key features to enable a mobile application to make it as easy and intuitive as possible for a wide range of users with various
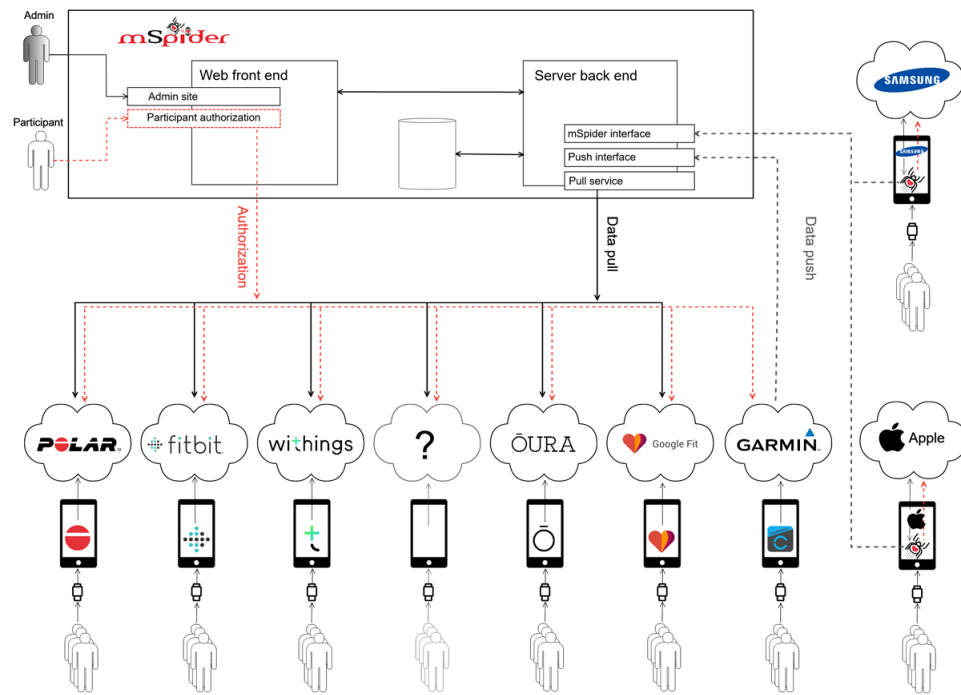
Figure 2.1: Structure of mSpider - reprinted with permission [26]

intellectual disabilities. Over the years, researchers developed guidelines for designing user-friendly websites and applications [28, 27, 29]. The coming section focuses on the guidelines provided by the Web Accessibility Initiative (WAI) standards [30].

Reading comprehension

People with intellectual disabilities face some unique challenges in processing information on websites and mobile phones. The information presented to users needs to be precise and uniquely presented for users to understand. As mentioned, avoiding building complex user interfaces is a key to succeed when building an interface for people with intellectual disabilities. In a paper by N. Pavlov [27], the author outlines difficulties and suggests some guidelines for overcoming these challenges. The author states that even though the paper provides specific guidelines for people with Autism Spectrum Disorder (ASD), it is not limited to people with ASD.

Some of the difficulties they face relate to reading. The information in the text should focus on presenting text along with images when it is not overly complicated. Aligning images to the left and text to the right helps the users

using the information in the best possible way. Focusing on simplifying is essential, and if there are some tricky words, these words should be rephrased using easy words. The text used must contain a maximum of two typefaces, where Arial, Helvetica, and Times New Roman are examples of clear typefaces. As the selection of a clear typeface is essential, the font size should also be at least 14. Adding text to the interface should not be done using images as the background. Having a picture in the background makes it difficult to read, and plain background is preferred when designing the user interface. When adding pictures, boxes, and buttons, they should be colored as much as possible [27].

Adaptable

The information available should be presented in a form that can be understood by all users. In order to fulfill this the application should be implemented in such a way that the information can be presented vocally or in a simpler visual layout.

- Correct reading sequence
- Do not restrict the view as much as possible (vertically/horizontally)
- Identify input purpose - assist the user to fill out

Enough time

Compared to most users, completing a task can differ for a person with an intellectual disability. Completing a task can relate to their response time, reading capability, or low vision that can make some tasks take longer. With this in mind during implementation, the primary approach should focus on removing time constraints or giving users more time to complete tasks. Success criteria (WAI) [30]:

- Enable adjustments (turn off, adjust, extend)
- Allow user to stop, pause or hide
- Do not let time affect the score or competitive aspect of the game

Navigable

[noitemsep] Making the app easy to navigate, helping users find the content they need or keeping track of where they are within the application is another important aspect of accessibility [27]. Navigation should have two main focuses:

- tell the user where they are

- enable the user to go somewhere else

As mentioned above, the content, including navigation, should be adaptable and therefore be presented vocally. Vocally presenting content needs to be done in a linear order not to confuse users. Using both adaptive guidelines and the information about reading comprehension, this is achieved by implementing clear headings for both literal and through speech. Some of the success criteria listed are (WAI) [30]:

- Descriptive titles/headings/labels
- Use of section headings

Predictable

The presentation of content should be in a predictable order to help users with disabilities use the content provided. Implementing all pages in the application to appear and operate in predictable ways will help the user have control and not get confused. A good presentation can be done by implementing consistent navigation and place the content in the same places on all pages. Success criteria (WAI) [30]:

- Do not change context when a component get focused
- Do not automatically change context (e.g. input fields)
- Consistent navigation
- Context change happens on requests

Input Assistance

It is always hard to create error-free input, which can be particularly difficult for someone with some disabilities. General error handling may not seem logical for them, and they might not realize that an error has occurred. By following the success criteria provided by WAI [30], this can be prevented by, for example:

- Informing the user what went wrong and be specific
- Labeling input forms precisely
- Importantly, helping users not to make mistakes

2.4.2 Cognitive load theory

A person's mental resources for solving a problem or completing a task are referred to as the cognitive load[31]. Cognitive load theory (CLT) is used to build various alternative instructional interfaces and procedures to help users process the information provided, thus reducing the cognitive load. This theory base on the two major memory systems we have, working memory and long-term memory. Working memory can be seen as consciousness and can only handle a minimal number of novel interacting elements (two or three). Working memory alone only involves the most trivial human cognitive activities. On the other side, we have long-term memory, which can handle a wider variety of elements or information that correlate with each other. The cognitive load gets divided into three distinct but related categories:

- *Intrinsic cognitive load*

- *Extraneous or ineffective cognitive load*

- *Germane or effective cognitive load.*

Intrinsic cognitive load relates to one specific topic, and extraneous cognitive load is how information or task gets presented to users. These two types of cognitive load are related, where an interface with high intrinsic cognitive load affects the importance of the extraneous cognitive load. A low intrinsic cognitive load will help reduce the total cognitive load, and thus the importance of reducing the extraneous cognitive load may not be that important[32]. Intrinsic cognitive load enables the user to focus on their primary intellectual resources, such as walking, talking, or navigating the road. To support users, decreasing the extraneous cognitive load in the interface will help users focus on their primary task[31].

2.5 Relevant Technology

This project aims to encourage physical activity by using augmented reality. The goal is to create a mobile game that combines the real and virtual worlds. Google and Apple have created frameworks that enable the developer to create such environments. In addition, Unity, a framework for creating games, has created a way to combine both frameworks.

AR Core

AR Core[1] is a software development kit from Google made to build Augmented Reality applications.

AR kit

ARKit[2] is Apples framework for creating Augmented Reality content.

AR Foundation

Unity[3] is a cross-platform game engine platform. Unity provides a high-level library for building Augmented Reality applications for both Android and IOS. It gives the developer an interface for building applications targeting both ARCore and ARKit applications, the primary frameworks from Google and Apple. AR foundation[4] does not implement the AR feature itself. However, it works as an interface between Unity and AR Core/AR kit. Therefore separate packages are needed in order to work on the targeted device. Packages that need to be included for building AR applications on Android and IOS:

- AR Core XR Plugin - Android

- AR Kit XR Plugin - Iphone

Since Google and Apple work on distinct features, the same features are not necessarily available in both platforms. Building AR applications using AR Foundation enables the developer to use features from both platforms in the same project. Using a feature from one of the platforms that are not yet available for the other platforms will disable that feature from being active on that platform. However, the application will still build with the available features for each platform. AR Foundation solves this by using hooks to enable that feature as soon as it is available on the other device. Hooks are a concept that allows for behavior changes without interfering with other parts of the system. The developers only need to update the respective packages, and no rebuilding process is needed to make it work.

1. https://developers.google.com/ar
2. https://developer.apple.com/augmented-reality/
3. https://unity.com
4. https://unity.com/unity/features/arfoundation
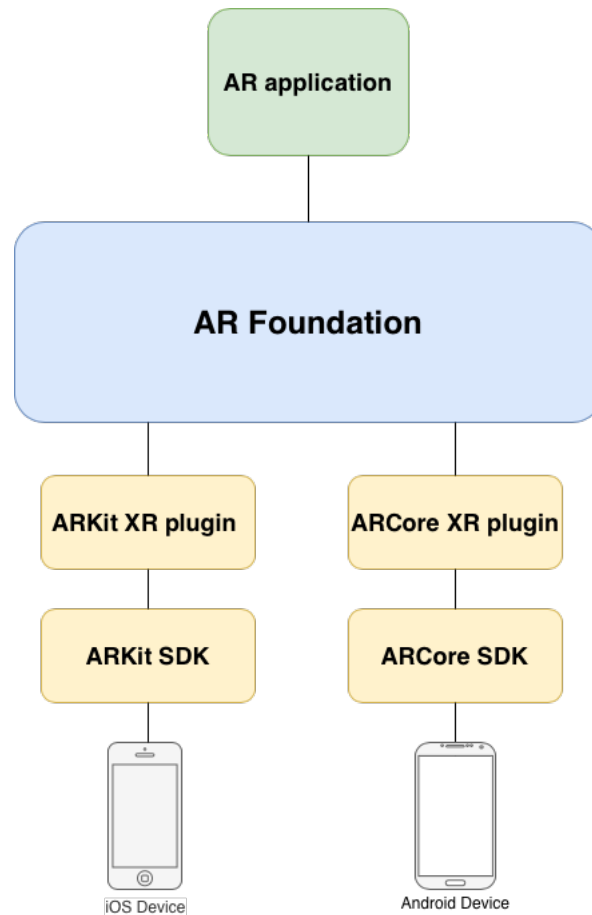
Figure 2.2: AR foundation illustrated

2.6   Mobile games

2.6.1   Augmented Reality Games

Augmented reality creates a mixed reality, where the real world and the virtual world are combined. AR adds more content to the world seen through the mobile camera, such as images, objects, text, and sounds.

This project aims to create an augmented reality game. Hence, a systematic review of augmented reality games was performed. The games selected for review got selected based on the top search results at Google. The search performed as "Augmented Reality Apps 2020". We also included the previous version of this project, *Dyrejakten*. All games were downloaded and tested. Screenshots illustrated in the figures are captured from the author's phone. Pros and cons were mainly evaluated on:

- Encouraging physical activity
- User interface focusing on intellectual disability
- Objective of the game

Pokémon Go (+10 mill downloads)

In Pokémon Go the main objects is to walk around in the real world and catch Pokémons. A long the way users can meet at different locations where you can reload supplies, take over gyms and train your Pokémons.

Pros

- Active game-play which encourage for physical activity
- Fun and rewarding
- Social - meeting new people and can play with friends
- The main objective of the game is clearly defined

Cons

- Game-play is to complicated for people with intellectual disabilities
- User interface is not built to target people with intellectual disabilities
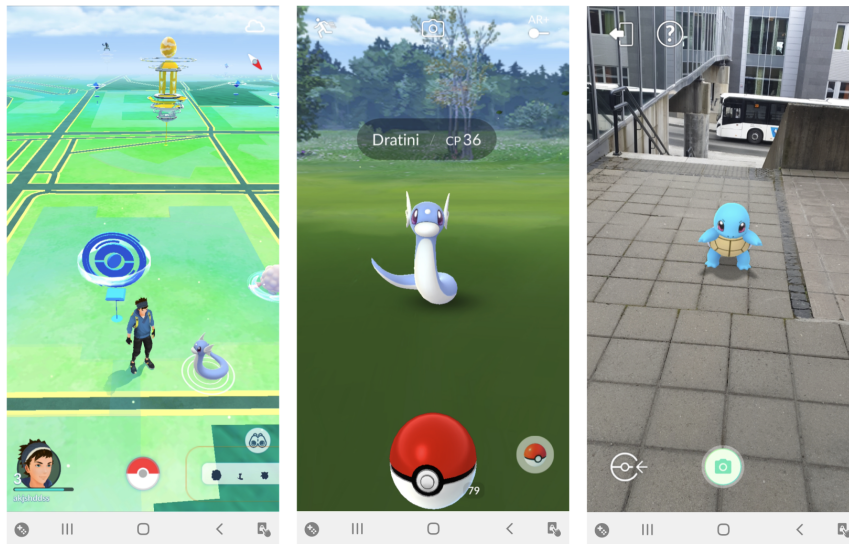
Figure 2.3: Pokemon Go Augmented Reality Game

Ingress (+10 mill downloads)

Uses GPS locations to place out portals which the users interacts with. The main objective of the game is to discover and take over these portals. The game is best suited for playing together with others and collaborate in taking over portals.

Pros

- Active game-play which encourage for physical activity
- Fun missions
- Throughout demonstration of the game
- The main objective of the game is clearly defined

Cons

- A lot of information before starting the game
- Very complicated user interface
- Context changes all the time automatically
- Dark colors make it hard to locate different buttons
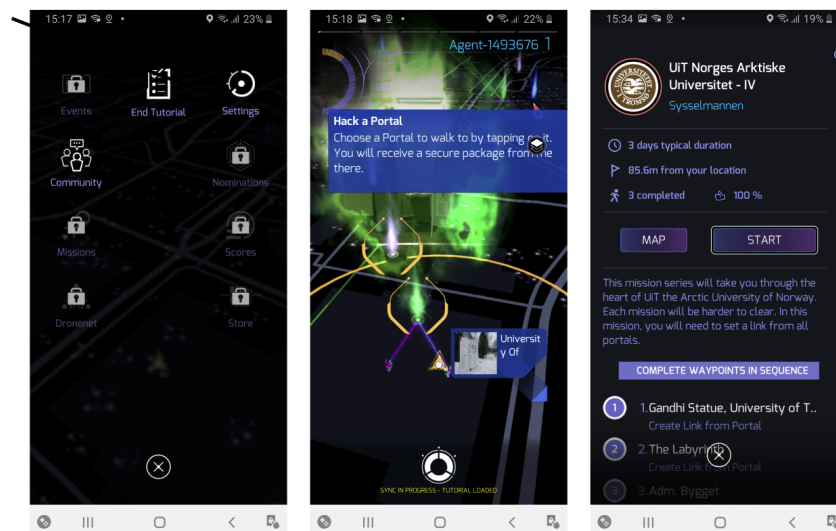
Figure 2.4: Ingress Augmented Reality Game

Jurassic World Alive (+10 mill downloads)

A game similar to Pokémon Go. In Jurassic World Alive players collects dinosaurs that can be used in battles. In order to collect dinosaurs you have to walk around in the world, but the battle itself can happen from home.

Pros

- Fun competing with others
- The rich dinosaur collection can be appealing for someone
- Physical activity is needed to expand the dinosaur collection

Cons

- Not necessary needs to be physical active to play (but recommended)
- Very complicated game-play
- User interface is complicated
- A lot of in-game purchase
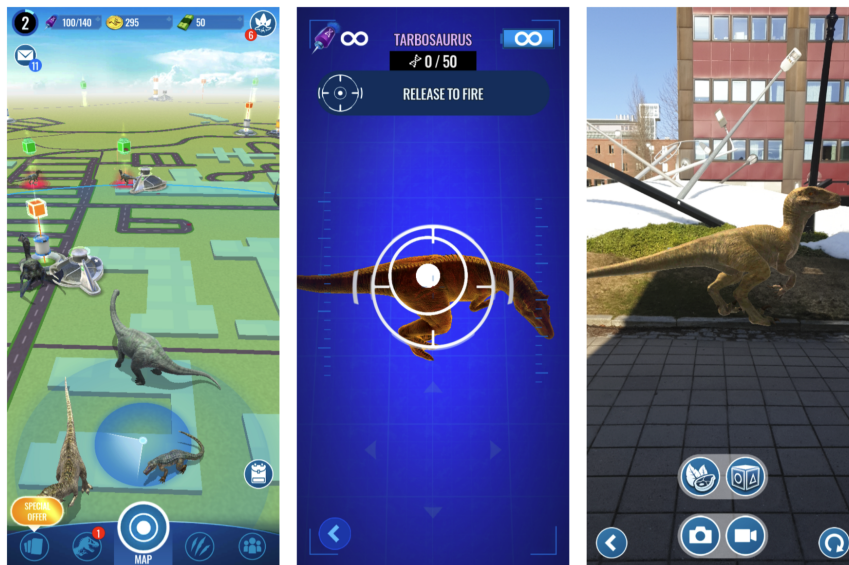
Figure 2.5: Jurassic World Alive

Zombies, Run! (+1 mill downloads)

The game that truly is created for fitness. In Zombies, Run! the objective is
to sample and collect as much supplies as you can to build your base. When
you are out collecting, zombies will come and attack. When zombies' attacks,
players need to outrun them in order to not get caught.

Pros

- Strongly focuses on fitness and physical activity
- A lot of missions
- Fun game-play

Cons

- People with intellectual disabilities may not run fast enough
- Running can be seen as unsafe, especially when holding a phone
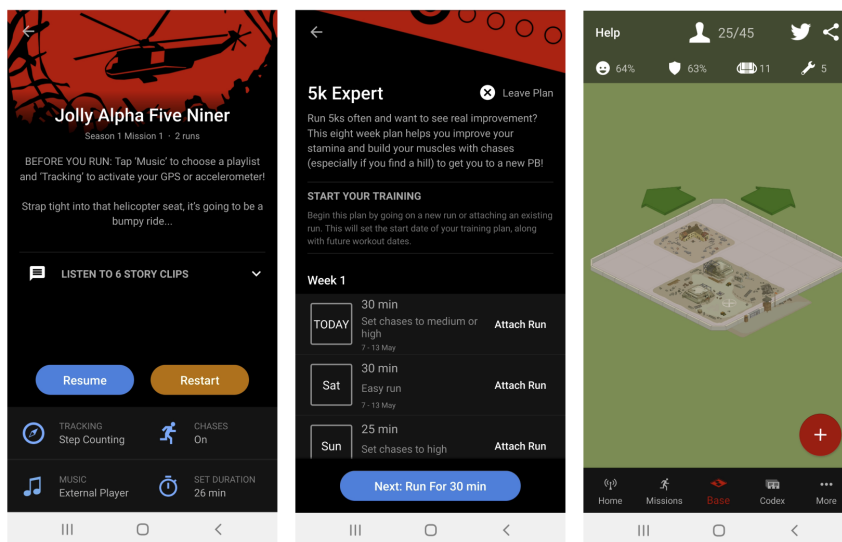
Figure 2.6: Zombies, Run! Augmented Reality Game

Dyrejakten

Dyrejakten is created to engage and motivate people with intellectual disabilities to be physical active. In *Dyrejakten* the users can choose up to four different animals they can go around an collect. Animals are spawned when users tap on the screen, and users are rewarded after each session with a medal and music playing.

Pros

- Created for people with intellectual disabilities
- Focuses on physical activity
- Easy game play

Cons

- No progression is saved
- Buttons and text are placed over the camera view
- Can not adjust difficulty levels
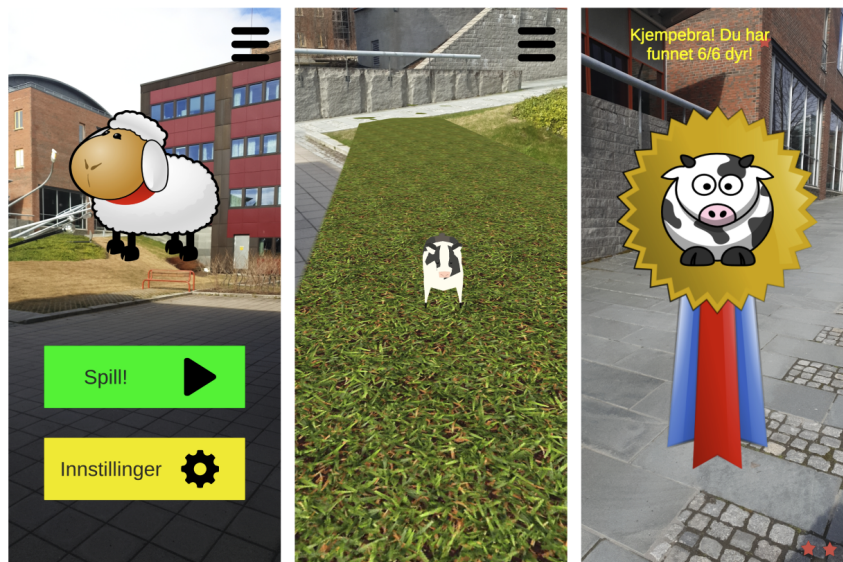
Figure 2.7: Dyrejakten Augmented reality game

2.7   State of the art

Data sources and Exclusion criteria

To form the foundation for the project the following databases was searched:

- PubMed [22]

- ACM Digital Library [0]

- IEEE Xplore [1]

- SCOPUS [1]

- Web of Science [140]

Exclusion criteria

Searching for literature was done using some basic exclusion criteria:

- The paper had to be in English.

- The paper had to involve a gaming perspective.

- The paper had to contain a form of physical exercise or motivational factors.

- Full text had to be available from the university library to be included.

Screening phases

Three screening phases was used:

1. Based on title

2. Based on abstract and introduction

3. Based on the main content

2.7.1　Search Method

> *(intellectual disability OR cognitive disability OR development disability OR downs syndrome OR autism) AND (serious game OR exergame OR video game) AND (activity OR walking OR motivation OR outdoor OR hiking).*

The query listed above was used when performing the literature review. The search was done in October 2020, and had to include at least one of the terms in each section. Each term and section were built using logic operators. The query is listed below for a better overview:

- The first condition involved some sort of intellectual disability.

  - *intellectual disability, cognitive disability, developmental disability, downs syndrome, autism*

- Secondly it had to include some sort of gaming aspect.

  - *serious game, exergame, video game*

- Last it was important that it included ether some sort of activity or motivation factors.

  - *activity, walking, motivation, outdoor, hiking*

Results

After going through the literature search and screening, 6 papers was included. The main content for the included papers were serious games and exercise games. One paper included was a study on brain responses on individuals with ASD. Being diagnosed with ASD is not considered as an intellectual disability. However, a significant percentage of people with ASD also have an intellectual disability. Thus, papers related to ASD combined with the relevant search criteria are argued to be relevant for the literature search in this project.
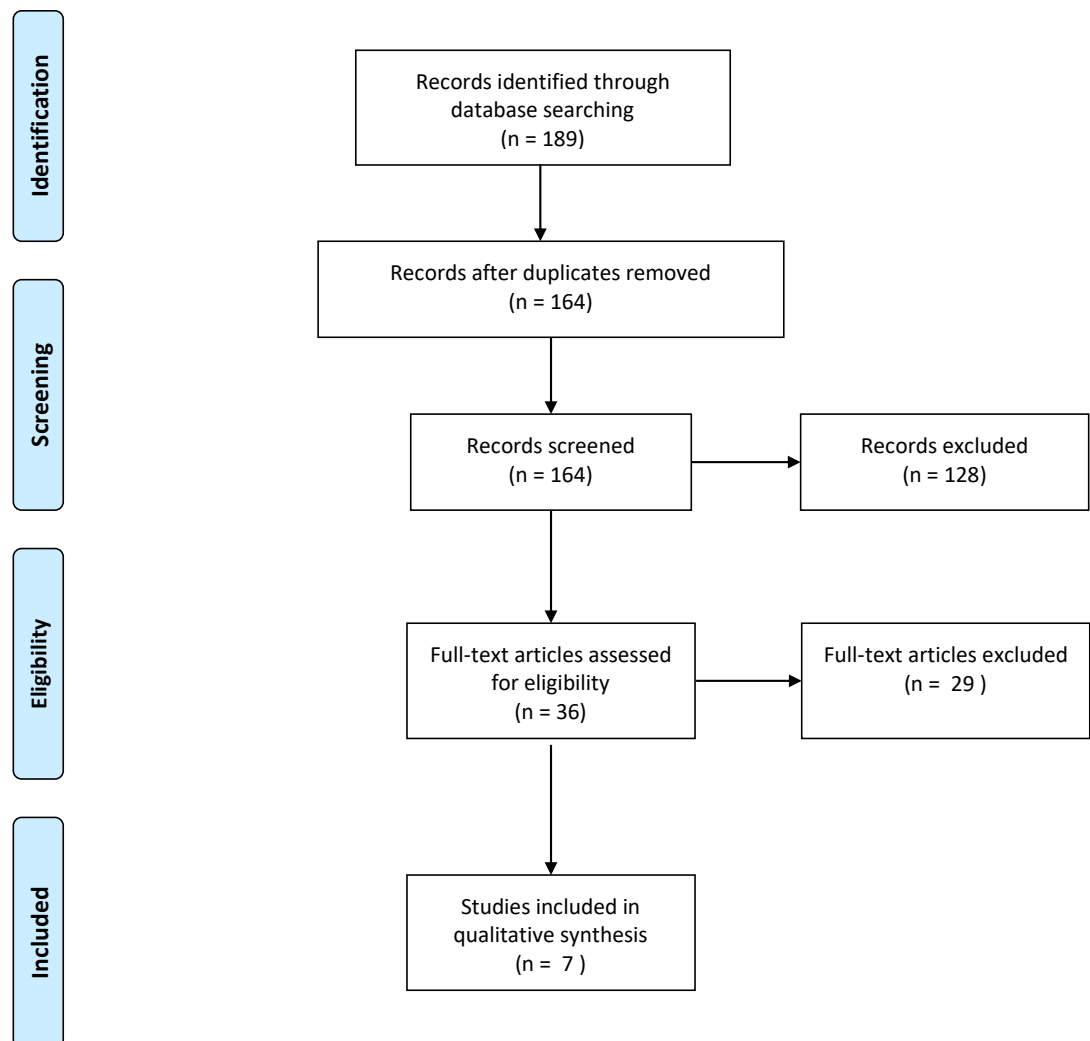
Figure 2.8: PRISMA diagram [33]

Authors	Target Group	Work and Findings
Cunha, P., et al. (2016) [34]	Children with ASD	An AR game designed to help children with ASD recognize facial emotions. The authors claim that this is achieved through the game "GameBook". (Serious game)
Isasi, A. R., et al. (2013). [35]	People with intellectual disabilities, but aimed at children with Down Syndrome	IOs game for improving eating habits for individuals with intellectual disabilities. Through user testing and questionnaires the game was successfully implemented to motivate users while learning about healthy eating habits. All participants wanted to play it again. (Serious game)
Finkelstein, S., et al. (2013) .[36]	Children with ASD	Virtual reality game (Astro-jumper) design to increase PA and motivate. Through questionnaires they were able to conclude that the participants enjoyed the game while also achieving vigorous physical activity. (Exergame).
Dickinson, K. and M. Place. (2016) [37]	Children with ASD	Use an entertainment platform to evaluate social function development. The research shows that the use of a computer based activity program can have a positive impact on the social functioning on individuals with ASD. (Exergame)

Kohls, G., et al. (2018). [38]	People with ASD	Study focusing on interest rewards vs social rewards (social approval) by analysing the brain responses. The study showed an increased satisfaction towards interest rewards, where users showed more positive rewards system responses on Circumscribed interests in non-social realm (e.g. video games). (Reward mechanism)
Fang, Q., et al. (2019). [39]	People with ASD	Investigating the effect of exergaming on people with ASD. Their research indicated a positive impact of increased physical activity level, self-perceived motor skills and executive function. However, no significant effects on emotional control and motor skills.
Cano, A. R., et al. (2018) [40]	Adults with intellectual disabilities	A serious game created for adults to learn train skills in transportation through in a realistic game enviroment. 51 adults tested the game *Downtown, A subway adventure*, and the study suggest that the design of the game was successfully created to target people with intellectual disabilities.

Table 2.2: Literature included from literature review

3

Method

This chapter describes the methods for collecting data, paradigms, materials used, and the methods for testing and evaluating the system developed. At the end of the chapter, criticisms of the methods used are discussed.

3.1 Paradigms used

In the discipline of computing, there are three main paradigms related to the way we approach and define the discipline of computing. The following section discusses these three paradigms[12].

> The first paradigm is the **theory**. Theory, which is rooted in mathematics, consist of four steps:
>
> - Definition - characterize objects of the study
> - Theorem - hypothesize possible relationships between them
> - Proof - is the relationships true
> - Result - interpret results

The second paradigm is the **abstraction**. Abstraction, which is rooted in scientific methods, consist of the following four steps:

- Hypothesis - form a hypothesis
- Model - make predictions based on a constructed model
- Design and collect - experiment
- Analyse - analyse the result

The third and last paradigm is the **Design**. Design, which is rooted in engineering, consist of the following four steps:

- State the requirements
- State the specifications
- Design and implement the system
- Testing of the system

This project mainly focuses on the engineering approach in the discipline of computing. The three steps listed under *design* are re-entered, and they have effectively turned into a looping activity by re-designing and improving the application. Working on a project rarely consists of just one of the paradigms mentioned[12]. Re-designing is something that we can see from this project. The experimental scientific approach, or the *abstraction* paradigm, was used to form a hypothesis to encourage physical activity through an Augmented Reality application. Having this hypothesis, we created a model that features the peculiarities of the application and the game itself, which contributed to achieving the final goal. We also designed an experiment and analyzed the results. The whole foundation of the project lies closest to the *theory* paradigm, and this is where we developed the fundamental aspects of the implementation of this project.
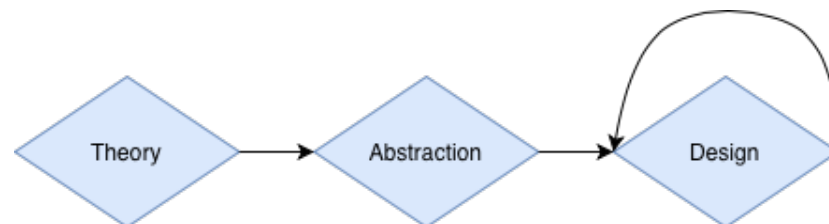
Figure 3.1: Computing as a discipline approach for this project

3.2   Tools

In this project we used several tools to create the proposed solution. The following tools and hardware were used in the development stage:

Development

When starting this project, we wanted to create a cross-platform augmented reality game. The choice went to the **Unity**[1] game engine for several reasons. Unity is a powerful game engine for creating cross-platform games and includes a wide range of features for creating games. Secondly, as the choice went on to creating a cross-platform AR game, Unity has released **AR Foundation**[2]. As mentioned in the previous chapter, AR Foundation includes core features from Google's AR Core and Apple's AR Kit. Further, Unity is highly integrated with Visual Studio and provides a **C#** scripting API. For this project, **Visual Studio 2019 for Mac (Version 8.8.10)**[3] is used for scripting. Compiling the iOS verions is done using **Xcode (Version 12.4)**[4].

Before starting the implementation of the application, **Figma**[5] was used to sketch out an early mockup of the application. Even though this design was not wholly how the final product ended, it was a valuable tool for further development. Figma is an online tool for designing UI/UX and prototyping. Figma can be used to design components, websites, mobile applications, and interfaces.

Hardware

Application development was first targeted towards the Samsung Galaxy S9. However, since Samsung A20e was used in the projects, development was later changed to target this device. The application was also compiled and tested for iPhone 11 and iPhone XR.

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1. https://unity.com
2. https://unity.com/unity/features/arfoundation
3. https://visualstudio.microsoft.com
4. https://developer.apple.com/xcode/
5. https://figma.com

3.3   Data Collection

3.3.1   Literature review

After searching databases from the range 2010 to 2020, the result only included seven final papers. Results indicate that limited research has been conducted on AR technology, physical activity, and intellectual disabilities. Through the literature search, we did, however, find that:

> **Designing applications should focus on accessibility for people with intellectual disabilities.**

> **Serious games and exergames can be used to motivate people with intellectual disabilities.**

> **Real life objects are exciting and can draw attention.**

3.3.2   Discussions with professionals

Chief physician and professor Audny Anke and psychologist Henriette Michalsen have made a significant contribution to this project's development and testing stages. Together, they are in charge of the project *Effects of Physical Activity with e-health support in Individuals with Intellectual Disabilities*. Their expertise has been highly valued in the process of state requirements.

Dr. Audny Anke was the primary source for these requirements in the early stages of planning and development. Her knowledge became important when deciding on colors that complement each other in high contrasts and adjusting the size of fonts and buttons.

Henriette Michalsen came into this project when the development started, but her perspective has impacted the final product. Through conversations and meetings, she tried the app and helped design the dialogue inside the app. Her knowledge become useful when formulating missions and including a mascot which is the primary source for text-to-speech in the application. She also helped to add more requirements and to avoid adding too complex tasks in the game.

3.3.3 Interviews with special education teachers

In the process of implementing the application, Prestvannet elementary school was involved. At Prestvannet, they have an area in the school where people with various kinds of disabilities go. Each individual, regardless of the degree of disability, is also highly integrated with the class. They use tablets, music, and games to help students learn, play, and interact with each other.

Through interviews with the leader of this institution and special education teachers, they helped shape the application's idea. Together we went through the previous installment of game implemented by Haugland and looked at the application's initial design. Their contribution became significant when deciding on the main contents of the game land further for deciding game objects.

3.4 Experiments and evaluation methods

This section discusses how the game was evaluated. This includes the setup and evaluation methods done in order to measure the actual value of the game.

3.4.1 System Usability Scale

The purpose of System Usability Scale (SUS) is to give feedback on the subjective aspects of usability[41]. SUS is developed as a *Likert scale* with ten items grading from "*Strongly disagree* to "*Strongly agree*" (1-5).

The ten items included used are implemented to remove biases on the questions. Alternating positive and negative items prevent questions that the respondents do not have to think through. Examples of a positive and negative item:

> Q1: *I found the system easy to use*

> Q2: *I found the system very cumbersome to use*

Because of this approach to the *Likert scale*, a respondent will have to rate 50% of the question as "*strongly agree*" and the remaining 50% of the questions to "*strongly disagree*" to rate the system as extremely good.
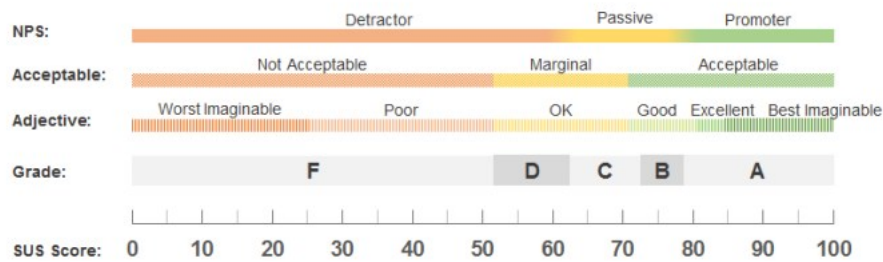
Figure 3.2: SUS-scale grading [42]

3.4.2 Evaluation Setup

For testing purposes, we gathered people with relevant backgrounds or experts in intellectual disabilities. This test aimed to test the application's usability, as this was an essential goal while working on this project. The first phase of testing took place in a local school where different field experts were gathered. Testing was conducted by teachers and the leader of ambulatory community services for individuals with intellectual disabilities.

Due to covid-19 restrictions, only professionals in the field and care workers tested the application. We did not include actual users with intellectual disabilities. Testing was carried out by first giving a summary of the project. Introducing the application focused on the parts where parents and assistants can personalize steps, goals, and rewards. Since the application's primary focus is simplicity, we did not want to provide in-depth introductions to menus and gameplay.

Phase two of the testing involved using the application. All participants was provided hardware (phones) with the application installed. After walking around the area, we gathered together and discussed how they experienced the game. We wanted to discover if anything was missing, weaknesses, the value of personalized goals, and general feedback from interviews. All participants also filled out a System Usability Scale, where they answered questions focusing on usability for people with mild to moderate intellectual disabilities.

3.4.3 Critique

As the game was only tested on experts and professionals in the field, we only received their perspectives. Their point of view of the game is important, as they have the expertise needed to point out the weaknesses and the strengths of the application. On the other hand, actual testing on users would have been

beneficial. Not testing the application on actual users was a limitation, but it was out of the authors' control due to time and COVID-19 restrictions.

More frequent meetings with psychologists and people working in the project *Effects of Physical Activity with e-health support in Individuals with Intellectual Disabilities* might also have improved the quality of the entire application and the requirement specification. However, frequent tests were carried out in the final phase of the project.

Another point of critique is also the regular feedback on the gameplay. Covid-19 restrictions and lockdowns required to schedule all meetings online, and the main feedback became on menus and organization of the game. Showing how the gameplay works in Augmented Reality is challenging this way and has been mostly described orally. Another, and possibly better approach, would have been to do more regular video recording of game play action sequences. From there, get more detailed feedback from supervisors and co-supervisors. Recorded videos could also have been distributed to other professionals in the field.

Lastly, the literature mainly included children/young adults with intellectual disabilities. Five of the seven papers included people with Autism Spectrum Disorder, and only one of the seven targets adults with intellectual disabilities. Even though most of the research included was related to ASD and children, the research conducted in these papers was argued to include information relevant to people with intellectual disability.

3.4.4   Summary

This chapter has described the methods used during application development. Also, describing the research paradigms and discussed the reasons for choosing Unity for implementing the application. The development stages consisted of an engineering approach and looped feedback. Iterative feedback loop enabled re-designing the user interface and features efficiently to fit people with intellectual disabilities. Further, the chapter described how we collected data and briefly discussed the main findings of the literature. For evaluating the application usability, special education teachers and professionals were included in the project. The chapter ends with some critiques of the methods used and suggesting better approaches.

/4

Requirements Specification

This chapter describes the establishment of functional and non-functional requirements. First, the chapter describes the source and how requirements were defined, followed by requirement specifications.

4.1 Defining requirements

In this project, we started by examining the previous application implemented by Haugland [7]. It became evident from using the app and analyzing the test feedback that some core functionalities were missing. The previous version lacked to track physical activity, reward users, motivate them to come back, and have different difficulty levels. All the features mentioned were considered essential to be successful in the development of the new application. Uploading data for the science group in the main project was also something that was missing from the previous version.

Another great source of information when forming requirements was weekly meetings with supervisors, meetings with caretakers, and literature related to intellectual disabilities and user interface. The authors' previous experience working with intellectual disabilities and system development is another source of information used when forming requirements.

4.2   Scenarios

Creating user scenarios is a common technique used to illustrate how a product can come into use and serve its purpose. We have created two user scenarios to illustrate how the game's context of *Sorterius* can be a good option for outdoor hiking.

Scenario 1

Arne is nineteen years old and was born with down syndrome. He lives with his parents in Tromsø, and in the daytime, he goes to school and plays with his friends. When Arne comes home from school, he likes to play video games, play on his mobile phone and watch TV. There is not much that motivates him to go outside for hikes, except when he can go to his grandmother. Arne likes walking there to give her something he has made at school or deliver her food supplies that his parents have bought. Arne does not get any motivation from the exercise, but he likes that there is always something funny happening when he comes to his grandmother. His grandmother is now moving out of town, and he can not walk there anymore. His parents are now concerned about how to get Arne out doing physical activity on a regular basis.

Scenario 2

Ingrid is twenty-three years old and was born with Autism Spectrum Disorder. She lives alone but has care takers and parents that can help her daily. She works for a local business where she helps to deliver fruit to companies in the city. She likes her job, but she is mainly interested in her mobile phone, watching YouTube, and listening to music when she comes home. When she was younger, she enjoyed going to the beach to collect shells. She now lives far away from the sea, and she does not like to go for hikes outside. She thinks it is boring to walk around, and her parents and care workers are struggling to encourage her to do physical activity.

4.3   Functional requirements

Functional requirements for the system development describe the components needed to achieve its purpose. Functional requirements need to be implemented in the end product, and resulting functions must be accessible by the users.

The functional requirements are documented using Volere Requirements Spec-
ification Template[43]. This project uses an adapted version of the Volere
template. Customer satisfaction and dissatisfaction are changed out to include
a priority level. The items used to form the functional requirements are:

- **Requirement #:** Unique identifier

- **Description:** The intention of the requirement

- **Rationale:** Describes why the requirement is considered important

- **Source:** Who stated the requirement?

- **Fit-Criterion:** The criterion for evaluating if a solution fits the require-
  ment

- **Priority:** The importance of the requirement on a scale from 1 to 5

- **Dependencies:** Other requirements that have an impact on the require-
  ment (if any)

Prioritizing each requirement is done partly through the author's previous
knowledge around system development. Because this application is developed
for people with intellectual disabilities, prioritizing each requirement is also
done by asking special education teachers and psychologists. Together we
prioritized each task on a scale from 1 to 5.

The following table describes the functional requirements for the game *Sor-
terius*, and the reason for its existence:

#	Description	Rationale	Source	Fit-Criteria	Prio.	Dep.
1	The application must be able to start	If the system can not start its useless	Author	Users can reach the content of the application	5	
2	The application must include difficulty levels	Include people with different level of understanding and add a progression layer to the game	Author	Before starting a game, users can choose the difficulty level	4	1

3	The application must track physical activity	Provide information on the amount of PA achieved through the application	Author, advisors, experts	The systems count steps using the internal step counter	4	1
4	The application must display the amount of activity visually	If users do not see progression it can motivate to keep on playing to reach the main goal	Author	When users are done with an activity, they are rewarded with stars based on the total activity done	5	1, 11, 19
5	The application must include text-to-speech	If users having trouble reading, they should also be able to play	Author, experts	Users with bad vision or reading abilities can understand the content	5	1
6	Users must be able to share their achievements	If users can share their activities, the game can turn out more competitive	Advisors	When users finish a session, they can share their activity to other people using the application	2	1
7	The gameplay must give the users tasks when playing	Users get an easy task to complete when reaching each sub-goal	Author	When users pick up a 3D object, they are asked to put it in the trash	5	1, 2, 15
8	The users must be able to restart the game they have completed	Users can play again with a minimum amount of effort	Author	After completing a game session, users can choose to play again with the same settings	3	1
9	The users must be able to quit the game without losing amount of PA achieved to that point	If a user need to quit a session, the current amount of PA is stored - even though they did not complete	Author	Quitting an already started session will store the PA achieved to the point of quitting	5	1, 11

10	The application must upload health data to an external database	Enable evaluation of the physical activity data for project-leaders	Experts	Anonymous activity data is stored in a safe data storage	3	1, 3
11	The users must be able to **not** share health data	If users want to play without sharing their activity data, they should still be able to play	Author	Through the settings menu, users can choose to play without uploading data	2	
12	Users must be able to start a game session with a minimum amount of effort	If users are getting to much choices and task before starting a game, they can get frustrated and do not want to play	Author, experts	Users are only given the option regarding difficulty levels and number of objects(medium/hard). No input boxes are used, everything relies on buttons (max 3).	4	1
13	Users must be able to choose the length of the session	If a user wants to play for a shorter/longer time	Author, experts	Before starting the game, users can choose how many objects they want to discover	3	1, 3
14	Users must not see the ground planes	Make ground planes transparent to make the world as realistic as possible	Author, experts, advisors	If users look through the screen while walking, they will still be able to see where they walk	4	1
15	The application must be able to place 3D objects on the ground	Users get goals to reach when playing	Author	The user can tap on the screen to place 3D objects, or choose to have them placed automatically	5	1, 13, 14

16	The system must reward the users when doing correct choices or completing tasks	The user get excited when given a visual feedback when interacting with 3D objects	Author	Adding bursting stars when adding trash in the correct garbage bin, completing sessions or reaching their weekly goal	3	
17	Users must be given instruction when playing	The user is provided instructions when playing	Author, experts	When a user is walking around, they are given instructions on what to do	3	1, 5, 16
18	Parents/assistants must be able to adjust daily and weekly activity goals	The user activity levels can be tailored towards specific users	Author, experts	Through a menu designed for parents/assistants they can adjust daily steps, weekly goals and add rewards	4	1

Table 4.1: Functional requirements

4.4 Non-Functional requirements

Non-functional requirements describes properties the system must have. While functional requirements are something the product be able to perform, non-functional requirements are a more qualitative view of properties the product must have. Non-functional requirements describe the qualities the application must have, for example, to be secure, safe, usable and maintainable.

Below are the non-functional requirements stated in the game *Sorterius*:

Safety

The application must be safe to use when players walk around looking for objects. Paying the game must not put the users in physical danger.

User Interface

The user interface must be accessible for users with intellectual disabilities. People with intellectual disabilities can have bad reading abilities and impaired visual acuity. The designed interface should follow guidelines created for people with intellectual disabilities.

Application Localization

The content of the game must be in Norwegian. The targeted user group is Norwegian, and they must be able to understand messages and instructions.

Security

Data stored in the application must not include any information that could identify the user. Sharing physical activity data must be done on secure channels and anonymously.

4.5   Summary

This chapter described the requirement specification stages. Together with supervisors, experts, and looking at the old game developed for this project, and other games available for people with intellectual disabilities, we defined functional and non-functional requirements for this project. User scenarios illustrate in what context this application could help users engage in physical activity.

/5

Design

This chapter will describe the design choices made when implementing this project. An overview of the entire design and a detailed description related to all different views in the app is the main content of this chapter.

5.1 Game Scenario

The game scenario includes the phone's camera and the real world. Detection of the ground is done through the camera lens, while the users orientate around the real world. Users will see the world as it is, and a transparent texture covers the detected ground. Transparent textures' role in the game is to attach and anchor objects to the real world and make them look as realistic as possible through the phone's camera. Having transparent texture covering the ground is an answer to requirement #14 in chapter 4.3.

Sorterius is a game created to encourage users to be physically active while picking up garbage while walking. The game's main content is to help the game mascot, Sorterius, to clean the world. Players are rewarded with stars daily and weekly, based on their number of steps or meters. While the users progress through the game, the phone uses the camera lens to detect the ground. When the users walk around in the real world, 3D objects will spawn in front of them. Before users can see any garbage (objects), they need to walk a certain number of steps or meters. As soon as users locate new garbage, they need to pick it

up and throw it in the garbage bin. Depending on the difficulty level, they will need to make the correct choice on which kind of trash to throw in which garbage bin.

Locating objects

The game's main intention is to encourage users to go outside and, at the same time, get physical activity. Thus, objects spawn randomly and are not bound to any predefined geolocations. Having predefined positions of the objects would increase the dependency needed from parents/assistants before sessions. Adding automatic spawning based on the phone's orientation in the world, users can choose where to go without following a predefined route. Based on the device's current position, the automatic placement of objects is related to functional requirement #15. The next chapter describes the implementation of automatic placement. Figure 5.1 illustrates a placed object in the virtual world from the users' perspective.
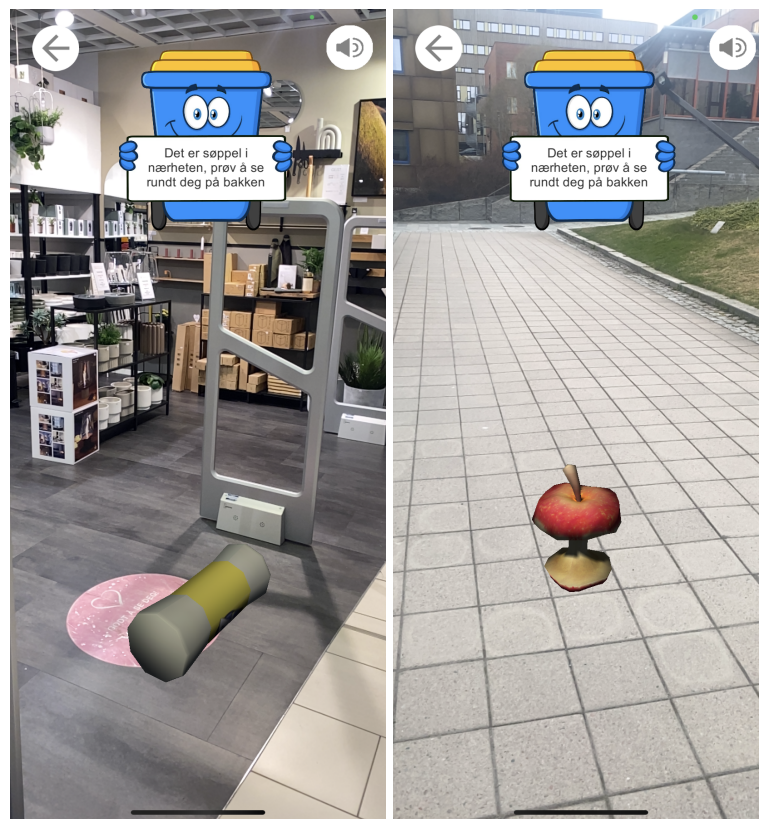
Figure 5.1: Locating an empty Zalo bottle and an eaten apple

Picking up objects and interact with garbage bins

Figure 5.2 shows how the 3D object and garbage bins are presented on the screen when picking up trash. When users have located trash, they need to tap the screen to pick it up. After locating and picking up the trash, it is no longer attached to the ground. When looking at picked up trash, it is attached to the screen center with rotation around the vertical axis. Having the object rotate gives the users a full view of the object they picked, and they can investigate it from all angles.

Under the rotating object, different types of garbage bins appear. The number and types of garbage bins are related to the current difficulty level. The garbage bins are buttons, and throwing trash is done by tapping the correct trash button. If users are mistaken, the mascot will tell the users that they need to try again. Having several tries enables users to learn the correct sorting system, even though they are making mistakes. By allowing users to make mistakes, we hope to encourage them to move on and try to make the correct choice on the first try next time they see the same object. Placing garbage in different garbage bins is related to requirement #7, stating that players must be given tasks while playing.

Figure 5.2: Picking up an empty Zalo bottle and an eaten apple

5.1.1   Before transparent background and automatic placement

In the beginning phase of this project, we had difficulties getting automatic placement implemented correctly. As a result, another approach was tested out. This approach involved both changing out the transparent background and add the placement of objects manually.

Before ending up with the automatic placement, we tried out another angle on using the standard way of placing objects - by using the touch screen. The goal was to use grass texture to cover the ground while users walked around, and when the user had walked enough steps, the grass would turn yellow, indicating that the grass had dried out because of the trash. The main reason for doing this was to give users better visual feedback when they needed to touch the screen. This implementation worked well, and the toggling between textures happened as soon as users had walked enough steps. However, as this did not fulfill requirements #14, this was only considered a good second option if we did not make automatic placement work and was later changed out.

5.2   Figures and 3D objects

In this project, we have focused on having 3D object that users can relate to from everyday life situations. A mascot is included for helping users and giving instructions while playing.

5.2.1   Game Mascot

For each view in the game, there will be a mascot. The mascots' primary object of the game is to help users and display or read out instructions. Figure 5.3 shows the mascot used to give feedback in the main menu and in-game view and relates to requirement #7 stating that players should get instructions when playing. Figure 5.4 shows the rest of the mascots used inside the applications for various situations.

All instructions and information the mascot presents are read out load to assist users. For every star the users receives, the mascot holds a sign telling the users their current status for the daily activity - this is also pointed out by the voice.

Inside the game view, the voice assist the players and guide them through the game. When they do mistakes, for example putting the trash in the wrong

garbage bin, this is also pointed out by the voice. Users can choose to deactivate this voice when playing.

Having a voice assistant covers requirement #5 in the requirement specification.
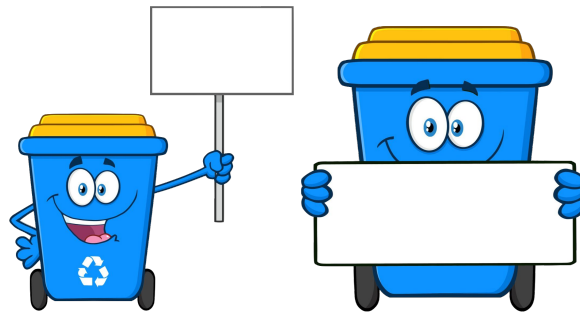
Figure 5.3: The mascot used to display information

Figure 5.4: The mascot used in different views of the applications

5.2.2   3D objects

Unity Asset Store

Searching though Unity Asset store[1], we managed to find some good 3D objects that would serve its purpose in this game. 3D objects included from Unity Asset store covers food trash, glass, and paper.

Special designed 3D-objects

Through the included literature and interviews with experts on the field, it became clear that real life objects is something that is exciting and an important aspects for getting the users attention. Having this in mind, it became clear that we needed more than just the assets that Unity Asset store could provide. After meetings with experts and caretaker workers we decided to get some special designed 3D objects. Objects created are objects that people usually see and hold/interact with daily. Objects decided upon are objects that are regularly on commercials and strongly connected to daily life. Together with supervisors and experts, we decided to get the objects illustrated in figure 5.5:

Figure 5.5: 3D objects design for the project

Another reason for having these objects created, and not food/glass/paper trash is the difficulties of differentiating plastic trash from regular or paper trash when looking at 3D objects.

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1. https://assetstore.unity.com

5.3   User Interface Design

In this project, four different scenes are used when building the game. Figure 5.6 shows the content of all views inside the menu scene and how different views work together. Figure 5.7 illustrates the views used inside the game view scene. Game views are separated but similarly designed.

Menu scene

Figure 5.6 shows how the menu scene are connected. Each box represents the main objective of the view together with the content represented inside the view.
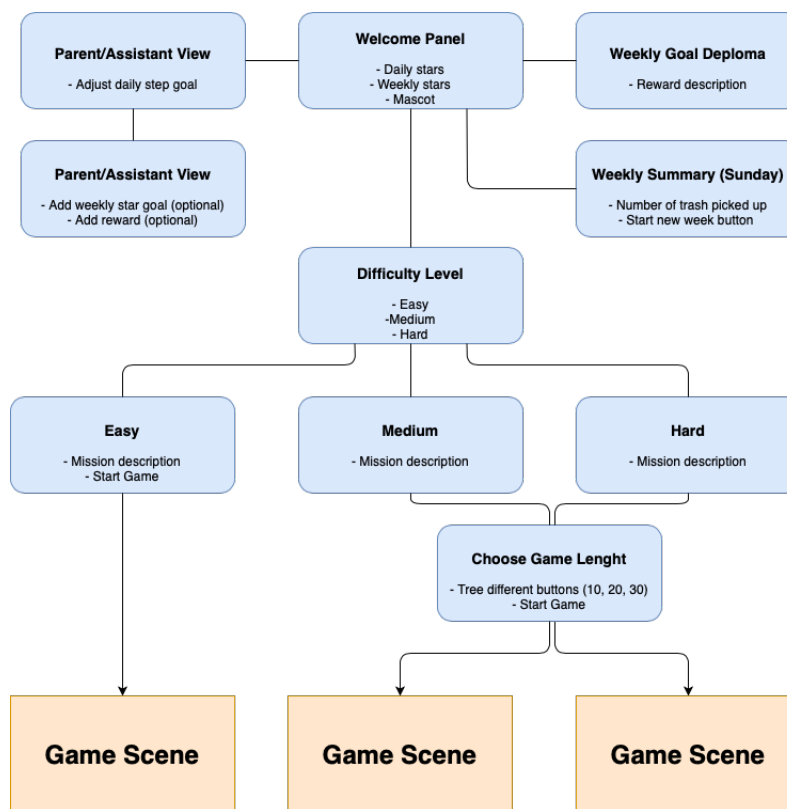
Figure 5.6: Menu scene - structure over views

Game Scene

Figure 5.7 shows how the game scene is designed. Distinguishing between the scenes happens through the garbage bins attached to the view. The green box represents the content of the view when a player picks up an object. After placing trash in the correct garbage bin, it goes back to the blue box attached to it.
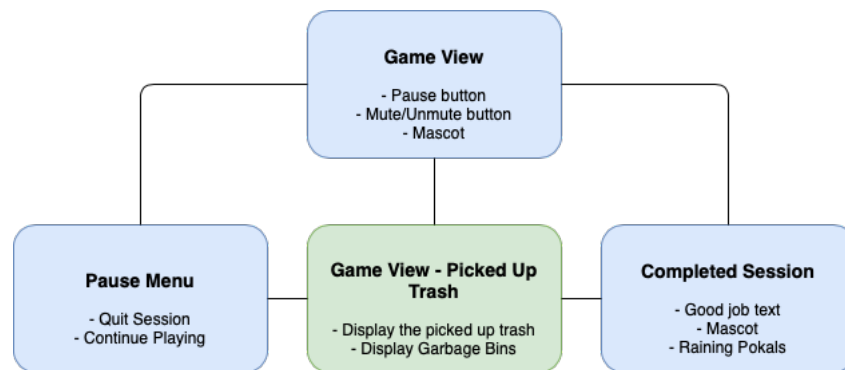
Figure 5.7: Game scene - structure

5.4   User Interface

This section describes the user interface. The user interface is implemented in its own scene, and all objects are statically attached to the screen. Objects used to form the user interface scale with the screen size. The main reason for scaling with the screen size is to enable users with low visual acuity to play the game using a tablet, which has a bigger screen size than a phone.

The guidelines discussed in section 2.5.1 are the primary literature used for developing the user interface. The entire user interface focuses on having a consistent representation of buttons and colors, Arial font style, and large font sizes. Colors are chosen to have high contrast (dark on light) to achieve better readability. We have also chosen not to include any input boxes for the users (except in the parent/assistant view) and no context change without the user actively tries to navigate forward. Removing input boxes and direct navigation is done to help users not to make mistakes.

5.4.1   Welcome view

The welcome view shown in figure 5.8, includes the daily and weekly stars received. Here, the mascot sign will update the progress throughout the day, and short and concise messages tell the users their current status or achievement. Updating of stars happens when users reach a certain number of steps/meters throughout the day. Receiving the second and third stars relates to the daily goal. Users get their first star after walking 50 steps, giving users instant feedback after only one game session. Users receive the second star after walking 40% of the daily targeted goal and the third when they complete. Displaying stars reflects the requirement #4 from the requirement specification about visualizing activity data.

There are only three interactable items on the view:

- Navigate to parent/assistant view (three vertical lines)

- Quit the application

- Navigate forward

As the user progress throughout the week, the weekly star goal gets updated. While this is persistent throughout the week, the daily stars reset every day. Daily stars take up most of the view, as the primary focus is to motivate daily activity. When a user reaches a weekly goal, the three daily stars get replaced by the reward button (figure 5.8). Reaching a weekly goal also activates a particle effect, where trophies are shot out from the mascot.

5.4.2   Parent/assistant view

This section of the application focuses on tailoring activity goals to the users. By including people who know the users, they can help them set a reachable activity goal and add rewards they want to accomplish. For each editable setting, there is a description related to it. Because this view is for parents and assistants only, they must navigate through a small icon in the top right corner in the welcome panel. The focus on the welcome panel is the mascot, stars, and forward button. The parent/assistant view directly translate to the requirement #19. The parent/assistant view are illustrated in figure 5.9

Figure 5.8: Welcome screen in different states
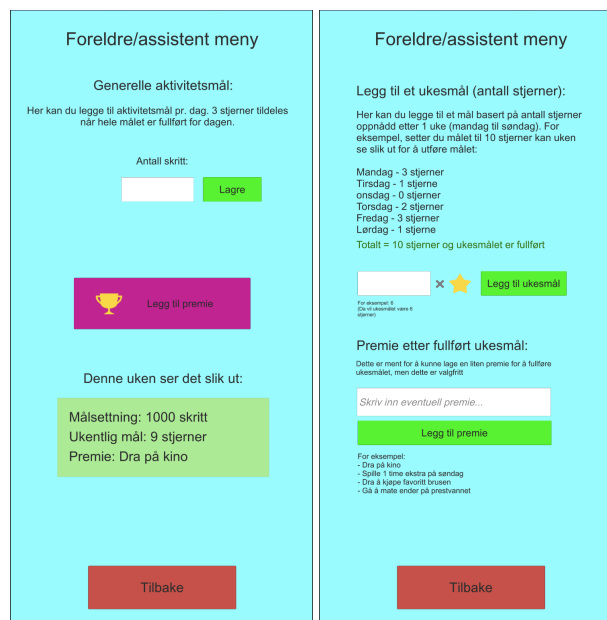
Figure 5.9: Add daily goals, weekly goals and rewards in the parent/assistant view

5.4.3   Choose level menu

This view relates to requirement #2 in the requirement specifications. After navigating from the welcome panel, the users need to choose a difficulty level. We also tried to describe how difficult a level is by adding one to three garbage bins at the buttons. To prevent users from pressing the wrong buttons, which can further put them on the wrong level, they must first choose difficulty level, then press the green button to go forward. If a user tries to go forward before selecting difficulty, a voice is activated and tells the users to do an action before moving forward. Users have three actions that they can do in this view:

- Choose difficulty

- Move forward

- Go back to the welcome panel

Figure 5.10 shows how the selection of difficulty levels:

Figure 5.10: Before and after choosing difficulty level

5.4.4 Different levels

Different game levels are created to have the same initial gameplay but with more complicated sorting options when collecting trash. The easy game mode has an initial state regarding how much trash users will pick up in one session. When users get more comfortable playing and want to advance to medium/hard difficulty, they will choose the length of the session based on how many objects they want to collect. The number of objects they can choose from is predefined to help users not make mistakes when interacting with an input field. Verbal presentation of the mission helps users with bad reading skills before starting the game or choosing the number of objects.

The content of each mission has changed throughout the project, and the initial idea was to have two different sorting options playing in the easy game mode. The initial idea of the medium and hard game mode was to have four different sorting options. Also, the hard game mode would have a time limit for putting it in the correct garbage bin. After playing the game with a psychologist, we decided that this could be too complicated for some users who wanted to play the easy and medium level. Further, this led to the change of each mission's content to include one garbage bin to easy game mode, two garbage bins to medium, and four garbage bins to hard game mode. We also argued that a time limit on hard game mode could make the game more stressful. The view displaying missions is displayed in figure 5.11 and choosing objects in figure 5.12

Figure 5.11: Different missions in the game
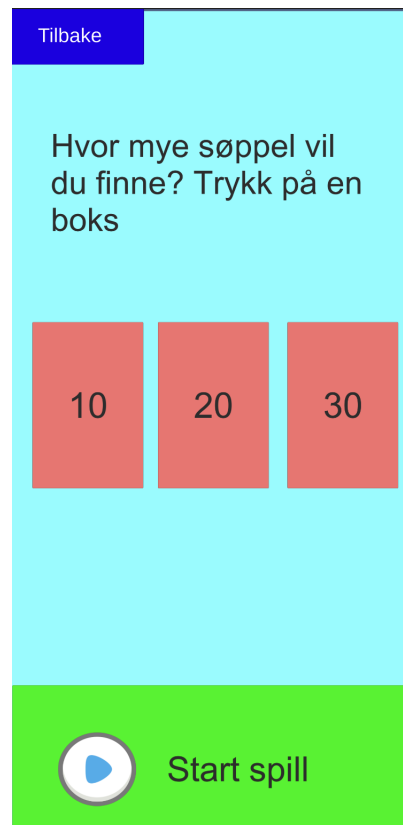
Figure 5.12: Before starting the game at medium or hard difficulty

5.4.5   End of the week and reward screen

After completing a weekly goal, players receive a diploma with a description of their reward. In the welcome view, stars disappear, and a big purple button is displayed. Clicking this button leads the users to the reward page and gives the players something to present to their parents/assistants, and hopefully, this encourages them to continue to play for more stars and rewards.

Each Sunday, a simple summary view is displayed when opening the application. If they do not open the application on that particular Sunday, this view will be displayed the next time they open the application. The goal behind presenting a summary page before resetting the week is to give the users a chance to see how well they did before deleting the weekly data stored.
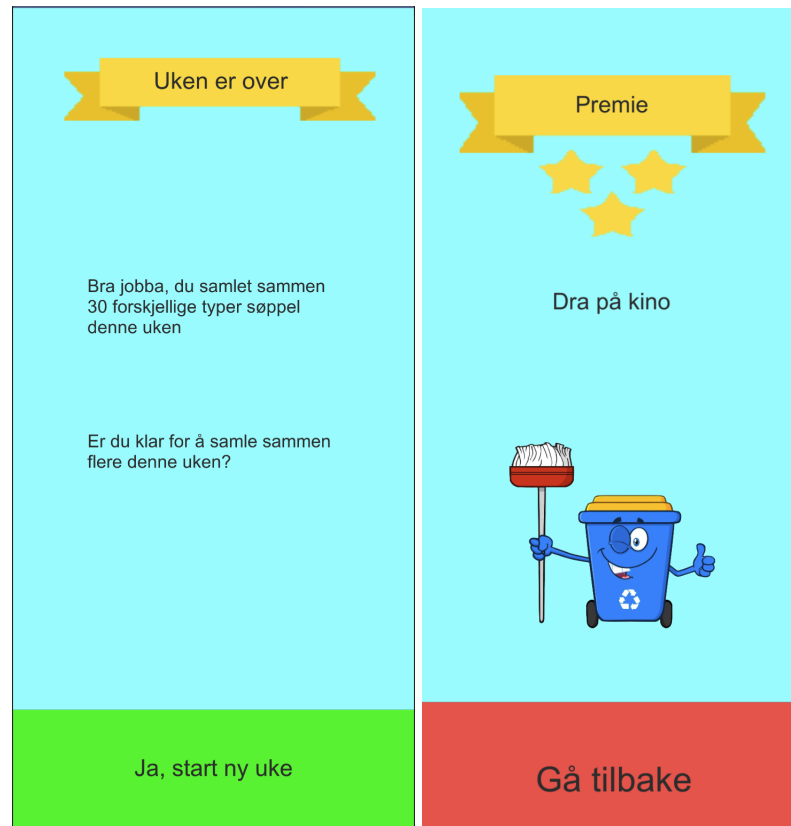
Figure 5.13: End of the week view and displaying of rewards

5.4.6   Visual Embellishments

Visual feedback, or Visual embellishments (VEs), is a concept referred to as juiciness in games[44]. Visual embellishments are not related to the functionality but rather a non-functional aspect of the polishing of player experience. Adding visual feedback is related to functional requirements #16, stating that the application must reward users when making correct choices or completing tasks.

Improving user experience is done by adding visual feedback when users collect trash, complete sessions, and reach weekly goals. When a user puts the collected trash in the correct garbage bin, the trash disappears from the screen, and stars burst out from the position where the trash is displayed. This star bursting is illustrated in figure 5.14

Users who complete a session will also see medals dropping down from the screen for five seconds. Animated medals are also added to the welcome view when users reach the weekly goal. Figure 5.15 shows the medals displayed

when completing a session or weekly goal.
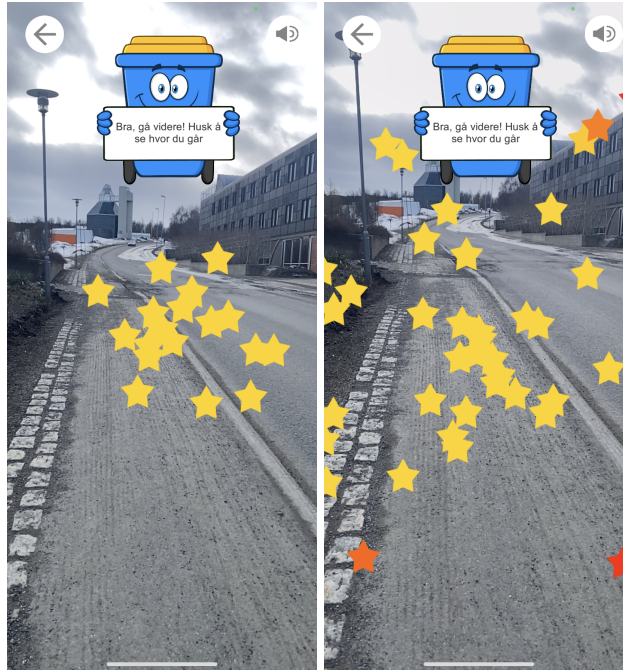
Figure 5.14: Starburst activated when trash is added to the garbage bin

Figure 5.15: Different trophy effects used

5.4.7   Color palette
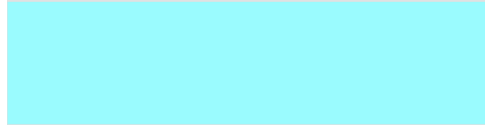
Figure 5.16: Background color

Figure 5.17: Button colors

The application uses colors to make buttons visible and a background that compliments the colors. As blue is one of the primary colors, it is ideally suited for backgrounds [45].

Choosing colors is done by looking at the meaning of colors, such that users can make the correct association. The three most essential colors of the buttons are:

Green - Navigate forward
Green is the most visible color of the primary colors. Navigating forward in the menus and starting a game is therefore done by using big green buttons. Green also indicates "all systems go" which is a phrase used for indicating that the system is ready to move forward [45].

Yellow - make a choice
Because of its high visibility, yellow is often used for warning and indicating caution [45]. Using yellow when choosing difficulty levels is therefore used to get users' attention. When users have chosen a level, it turns green, indicating that it is ready to go forward.

Red - Quit
Quitting a game session or closing the application, the buttons are colored red. Red indicated danger and is an aggressive color that is easy to notice [45]. Quitting a game session is therefore colored red to help users not quitting it accidentally.

Using a high contrast color on top of the light blue background is created for users to see that they have received an award. The purple color also symbolizes royalty and luxury.

5.5   Summary

This chapter described the different views and all objects used within the application. Illustrating each view is done using text and figures, and the chapter starts by describing the game scenario.

6

Implementation

In this chapter, the important implementation aspects, and structure of Sorterius is described. The implementation is a cross-platform Augmented Reality application, where the final product will be used in a pilot study, running on an iPhone. Through the implementation of the project, testing was mostly done on Android devices due to hardware availability. Devices used had to support ARCore [46] or ARKit [47].

6.1 Creating views and game objects

Different views are created using Unity's drag-and-drop functionality and do not include any programming. Initialization of the views and their properties happens at compilation time. As the game objects have several properties, these properties can be altered and changed by the developer at run-time through attached scripts.

Game objects are the central concept in Unity. A game object is not anything on its own but a container with components. Adding different combinations of components makes them different. Examples of different game objects in this application are 3D objects, views, special effects, and the texture used on the horizontal plane.

6.2 Augmented Reality

As mentioned earlier in this thesis, Augmented reality mixes the real world and the virtual world. It describes the technique of bringing three-dimensional virtual objects into a real three-dimensional environment [48]. Using Augmented reality, users can sense the real world around them while the device combines the real and virtual world. The environment is in three dimensions and is interactive in real-time [48].

6.2.1 Augmented Reality technology used in Development

This project uses AR Foundation to enable cross-platform Augmented Reality gameplay. There are three main concepts used to form the three-dimensional interactive gameplay:

AR Session Origin

The AR Session Origin must be attached to one of the game objects to enable AR to the Unity scene. This component aims to track trackable features, such as the trackable surfaces, and keep track of the final position and orientation in the real world. AR provides data in an unscaled space relative to the beginning of the AR session. This component performs the transformation of this "session space" to Unity space.

AR session origin also allows the scaling of virtual objects and applies an offset to the device camera.
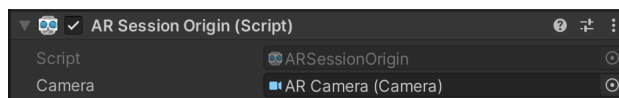
Figure 6.1: Ar Session Origin enables Augmented Reality gameplay

AR Plane Manager

This project places 3D objects on the ground. However, the ground is not a known element through the camera lens. Placing objects to the ground happens with AR Plane Manager. This component detects flat surfaces represented by position, orientation, dimensions, and boundary points. The plane manager creates game objects for all detected planes. Transparent plane detection is achieved by adding a transparent game object and use horizontal detection mode.

AR plane manager keeps track of all planes added, updated, and removed. Once per frame, the list of all planes are updated, and programmers can react to these changes. In this project, the plane manager is responsible for removing old planes and update new planes.
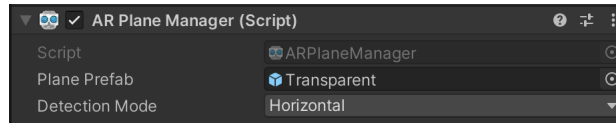
Figure 6.2: Ar Plane Manager enables horizontal plane detection

AR Raycast Manager

The AR Raycast manager provides an application programming interface (API) to perform single ray casts, known as hit testing. Ray casts detect intersection points of a ray (straight line from origin) and a trackable. The process of automatic placement uses ray cast to place objects and is described in section 6.4.
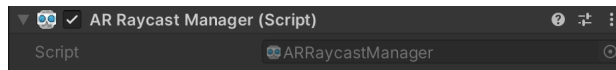
Figure 6.3: Ar Raycast Manager enables ray casting in this project

6.3   Structuring the project

One of the goals of this project is to create a user interface that is easy to use. We want to create more views and lower the amount of content for each view. Lowering the amount of information in each view is done to lower the intrinsic cognitive load. Inside each scene, there are several game objects created to present different views.

The project consists of four different scenes. Splitting scenes make the project decoupled, organized, and well structured. Having all in one scene would significantly increase complexity and lead to a coupled system.

Figure 6.4 shows the organization of the menu scene. As shown, the parent object, navigation, hold several views related to the main user interface. Different views are activated or deactivated as the user navigates. Inside each view are buttons, text, and images used to present the content. Figure 6.4 includes an example of the content of a view.

Game scenes are also built to have several views. Two of the views include a background color. The background enables buttons and text easier to read. Figure 6.5 shows the organization of game scenes.

Figure 6.6 displays available assets in this project. Every image, icon, 3D object, materials, texture, and script used within the project is in this folder.
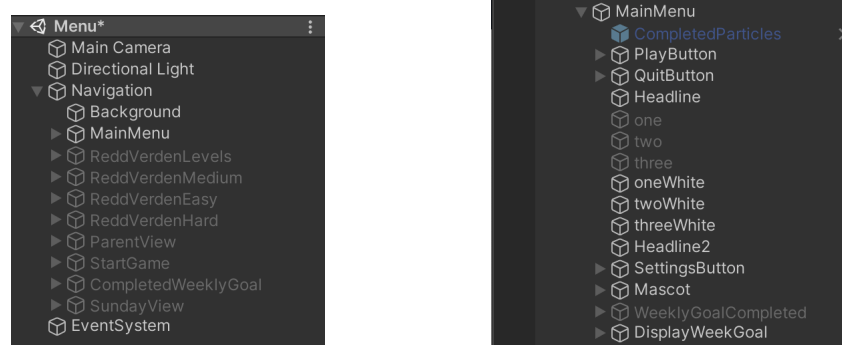
Figure 6.4: How game objects are used to build scenes and views
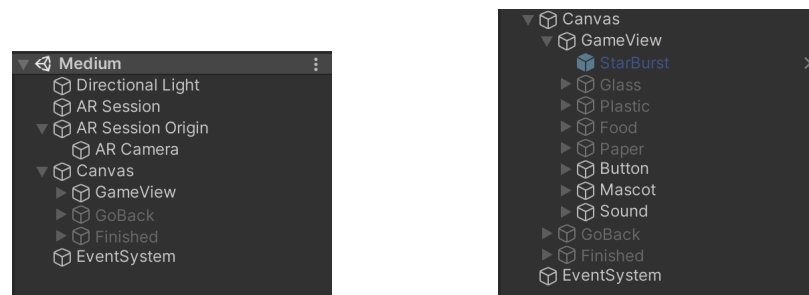
Figure 6.5: Structure of the game scene and the game view
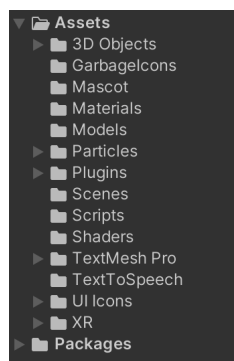
Figure 6.6: Assets folder

6.4   Run-time Execution

Some game objects, such as the objects in the menu or part of the game view described, are initialized at compile time. The instantiating of other game objects happens at run-time.

By adding a public reference to game objects, they can be altered and initialized during run-time. These public references are created through a script and can further initialize at run-time. Figure 6.5 displays the game objects used to implement one of the game modes. All visible fields are components made public and therefore accessible from the Unity Editor.

From the public fields are the various kinds of trash that the user will find during the game. The different types of trash are not initialized during compile time but get instantiated while the player walks around in the world. Thus, they are made publicly available through the script, which is responsible for the instantiating and placement of the objects.

Another component not initialized during compile time is the voices (TTS Sounds). As the voice activation happens depending on the various situations, we do not want all voices to get instantiated during compilation time. The voice activation is therefore instantiated and controlled by the script.

Some game objects are statically attached to the screen and only present during defined phases of the game, such as when players pick up trash. Garbage bins and the bursting stars are initialized during compile time but are further activated/deactivated using the script when the users progress through the game.

6.5   Placement of objects

Working with the placement of objects and anchoring them to the horizontal plane, it became apparent that the standard and easiest way is to place objects by tapping the screen. Using the tapped position, AR Foundation will, through ray casts, determine if the tapped areas are intersecting the horizontal plane. As this application focuses on simplicity, manually adding objects can be seen as another layer of confusion, especially when the horizontal plane is transparent. To prevent users from having trouble placing objects, we implemented an automatic system for placing 3D objects to the horizontal plane.

Implementing automatic placement of objects is done using ray casting, also referred to as hit testing. When the user has walked a certain number of steps,

the phone sends out a ray. The ray is an infinite line that starts at origin (the phone) and shoots forward. In this implementation, the origin from where the ray is cast is in the mobile device screen center. The reason for doing this is to check where that line intersects and if it does not hit a trackable plane (horizontal plane/ground plane). If it hits a horizontal plane, the 3-dimensional position of where the ray hits are temporarily stored and further used to anchor the 3D object to where the ray intersected with the plane. If the ray cast does not intersect with the horizontal plane, this could mean that the phone's angle is facing forward, or the horizontal plane is not yet detected in front of the player. If this happens, players are instructed to hold their phones to face the ground. Facing the phone to the ground enables the AR manager to update and detect the horizontal planes and further anchor the 3D objects. After anchoring objects, ray casting is disabled until new objects are ready to be added to the scene. Figure 6.7 illustrate how we use ray casting.
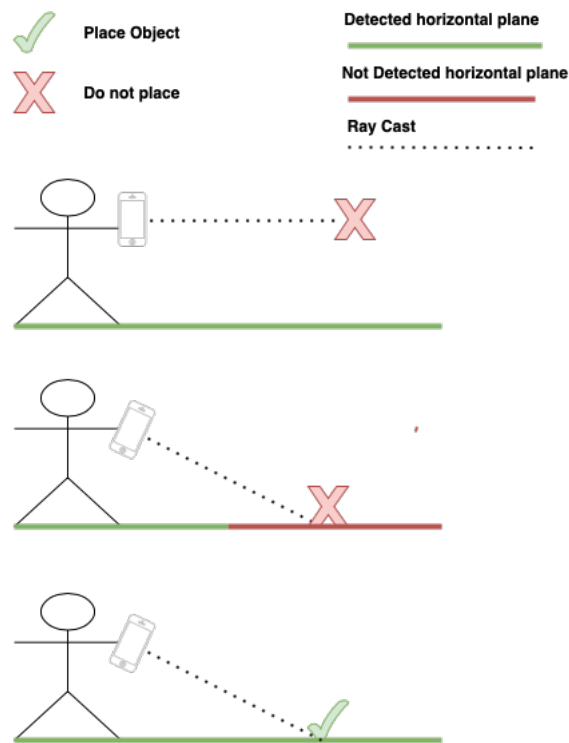
Figure 6.7: Using ray cast to automatic place objects

6.6 Storing game data

Unity's local storage handles progression data and in-game settings. Progression data is related to daily and weekly physical activity.

Storing progress and player settings through the local storage is done using key-value pairs. Because of this system's simple progression system, this is a reliable way of storing data. The local storage is created only to store simple key-value pairs as integers, floating numbers, and strings. This is not a good choice for games where we need to store the game state

The application includes a simple interface for storing the data, which further utilizes the local storage. Creating an interface for storing data also enables the system to integrate into other storing options in the future. For now, local storage is enough due to the small amount of progression data stored. Each game session starts initially, and no in-game progression is stored.

Decoupling data between all parts of the application makes it straightforward to integrate and upload data between sessions and add more components to the system to utilize the data stored. Updating a key-value pair stays consistent throughout the application. Figure 6.8 shows an overview of stored data. The data represented in the boxes labeled daily or weekly are reset daily or weekly, respectively. How data flows through the application is illustrated in figure ??.

Daily	Weekly	Settings (stored until changed)
Step Count / Meeters Walked	Total Stars collected	User Identification
Daily Stars	Weekly Goal	Token (for uploading of activity data)
Todays date	Weekly Reward	Daily activity goals (steps/meters)
	Total trash picked up	Sound (on/off)
	End of the week date	

Figure 6.8: Data stored in local storage

6.7 Measuring activity data

When first starting implementation, the goal was to access the device step counter from the sensor data. During development, this turned out to be more challenging than first anticipated. Early in the project, the only available devices was Samsung phones, which was the main focus area at the time.

Deciding to place objects after a certain number of steps is considered an important aspect of the application. Thus, a considerable amount of time was

spent on trying out different solutions.

Unity Sensor Class

Unity provides a class for reading sensor data. After enabling sensor data, we failed in retrieving step counts. Other sensor data, such as the accelerometer, was successfully retrieved. Being able to read step counts from Android devices requires Activity recognition permission. Trying to open Androids Activity Recognition was failed on the Samsung A20e. Not being able to read data is most likely related to the problem described below (i.e., the Samsung Health partner program). Not discovering the issue related to Samsung Health caused this process to take up much time.

Samsung Health

Samsung Health SDK[1] enables sharing of activity data between the Samsung Health system and other applications. Sharing data from Samsung Health would work as a tool for testing this project. However, enabling sharing of data between Samsung Health and other applications is restricted and requires access to the Samsung partner program. Currently, this program is closed for registration, and we had to look for other solutions.

Google Fit

Google Fit has an open API for accessing health data. Reading data can be done either directly from the device or through Google Fitness Storage. Google Fit work both for iOS and Android (not only Samsung). The only criteria for doing this is that users must authenticate themself using their google account. As the main focus for this project is simplicity and making the application accessible for people with intellectual disabilities, this authentication would add a layer of complexity and dependency to the application. First, all users would need to have a Google account. Second, they would need to log on to this account to read their health data. After some discussions with supervisors and professionals, we decided that this was not the option we wanted in this application.

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1. https://developer.samsung.com/health/android/overview.html

Workarounds

Workaround 1: The Haversine formula

The first workaround relied on meters walked. As global position systems (GPS) is present on many modern smartphones, this application uses coordinates to calculate the distance by combining the .Net Frameworks location service and Haversine formula. The haversine formula uses latitude and longitude to calculate a straight line between two coordinates[49]. To reach this project purpose, it relies on frequent position updates. A frequent update on the position is needed to minimize wrong measurements when players are not walking in a straight line. Also, not having frequent updates makes players walk long distances before objects appear. Thus, coordinates try to update every meter the users walk. Receiving frequency gets configured using the .Net Frameworks location service.

The .Net Framework implements this feature but is not accessible through Unity's C# library. However, the .Net Framework was the inspiration for choosing Havarsine to calculate distance.

After receiving coordinates, their decimal numbers get converted to radians. Applying the latitude and longitude radians in the Haversine formula is done by the equation:

$$haversine(\theta) = sin^2(\theta/2)$$

$$a = sin^2\left(\frac{\Delta lat}{2}\right) + \cos(lat1) x \cos(lat2) \ x \ sin^2(\frac{\Delta long}{2}) \qquad (1)$$

$$c = 2 \ a \ \tan 2(\sqrt{a} * \sqrt{1-a}) \qquad (2)$$

$$d = EquatoralEarthRadius * c \qquad (3)$$

In step (1) values of latitude and longitude are calculated. Step (2) calculated the axis intersection point, followed by step 3) calculating the distance [49].

The formula works well when connected to the internet. However, not fetching coordinates frequently enough without constant internet access became a

problem. User testing happened without the internet, and we had to move on to a second workaround.

Workaround 2: The lightweight step counter

The implementation is considered a lightweight step counter that detects when the phone tilts in different directions.

The magnitude of each acceleration sample is calculated using the Pythagorean theorem. Calculating the magnitude of vectors gives the length of each sample. Using the Pythagorean theorem for a 3-dimensional vector is given by:

$$\sqrt{x^2 + y^2 + z^2}$$

Steps are detected when the length of the vector reaches a constant. To remove high-frequency noise, i.e., when not moving, a low-pass filter is applied. Steps are detected by looking at peaks in the filtered output. Implementing the low-pass filter is done using Unity's example on filtering acceleration inputs.

The lightweight step counter consists of four steps:

1. Apply low-pass filter to the input

2. Calculate the magnitude of low-pass filtered output

3. Compare it with the previous output

4. Check for peaks in the signal against a constant x

Implementing a step counter using the accelerometer is entirely considered a workaround. There are still many false-positive signals picked up and registered as steps. Users can, for example, shake their phones to manipulate the algorithm to detect steps. It was, however, argued that this was a good solution for testing purposes.

6.8   Storing health data

This project includes external storage for physical activity data after sessions. All methods for sending and receiving data are added to mSpiders REST API. However, the final integration between the application and mSpider was not finalized.. The benefit of REST APIs is the use of existing protocols for

transmitting data, such as HTTP (hypertext transfer protocol), which is the foundation for data exchange on the internet. Using HTTP benefits from no additional software or libraries must be installed for communicating with the API. REST APIs also benefit from a stateless, client-server architecture. Meaning that clients and servers can evolve individually, and each request is holding all data needed to complete independently.

There are two methods for data transmission in this project. We are getting resources from the server and adding data to the database. Getting resources is done through an HTTP GET request. The REST APIs GET method takes in a participant user identification and application name. When the GET method receives valid user identification, it sends a response back, including a token. Users that are part of the pilot RCT project receive a participant identification. In the parent/assistant view, they can add the users' participant identification and enable the uploading of activity data. Sending GET request is made when there is no token stored or changing user identification.

After completing a session, an HTTP POST method takes the activity data. For the REST API to store data, the HTTP POST request must include a valid token. With a valid token included, data gets stored in the database.
HTTP GET: User identification and application name
HTTP POST: Token and activity data

After every session, the application sends a HTTP POST request to mSpider. Figure 6.9 illustrates a user that completing a session.
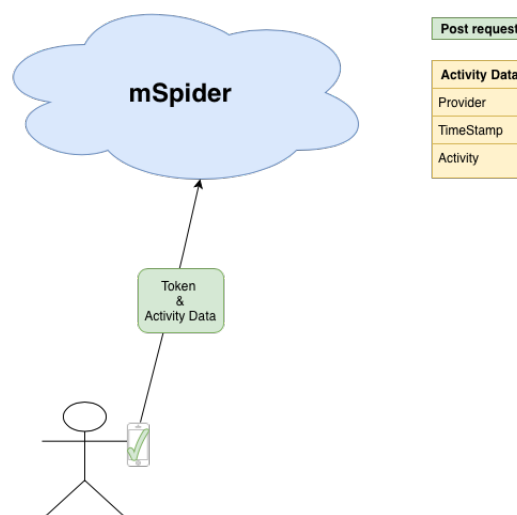
Figure 6.9: After each session, activity data is uploaded

6.9   Architecture of the application

Overview of the application architecture illustrated in figure 6.10. Views connected with a line can navigate forward and backward to the corresponding view. All blue boxes are scripts that are running the code related to the particular views. The menu scripts handle all interactions from the welcome view to starting a game. Arrows indicate read or read/write to the local storage.
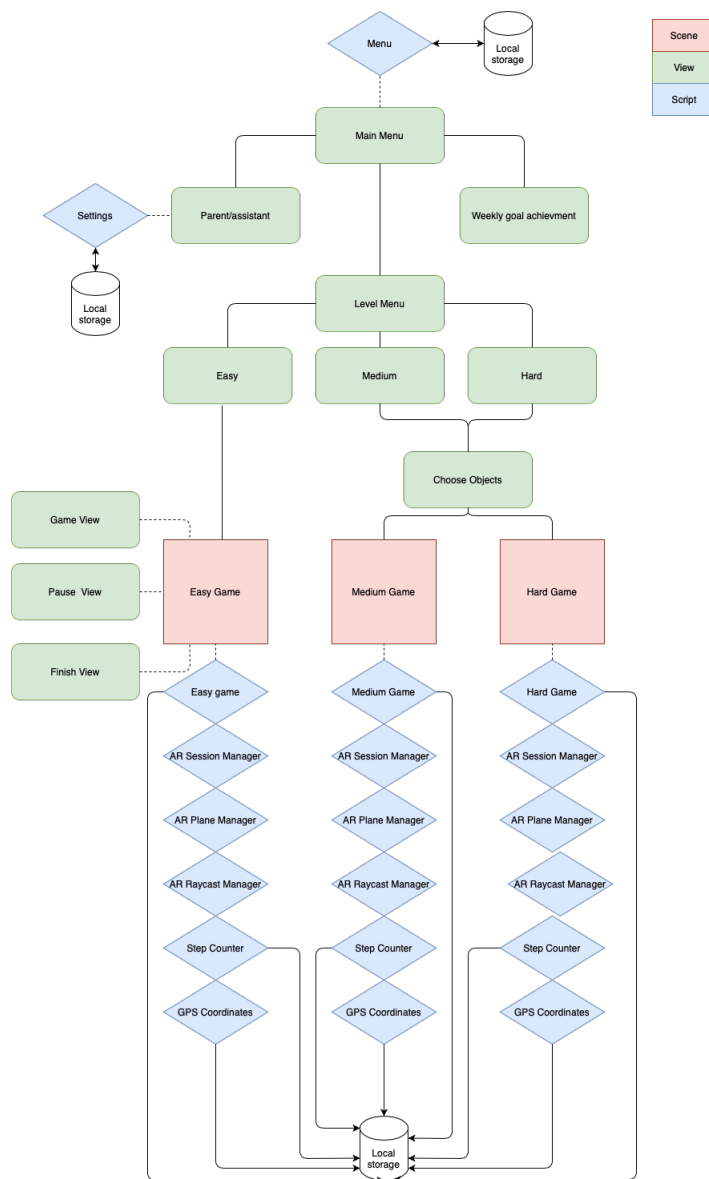
Figure 6.10: Overview over Sorterius - scenes, panels, scripts and storage

6.10   Summary

This chapter describes the core functionalities of developing augmented reality applications and how this project has solved problems related to the automatic placement of 3D objects. This chapter also describes the structuring of the application and how this project uses run-time and compile-time execution of different game objects. Also, by discussing the problems related to integrating a step counter, two workarounds are presented. Lastly, this chapter illustrates the overall architecture and how different views and scripts are connected.

/7

Test and Results

This chapter presents test results from interviews and the final SUS score of the application.

7.1   Test Participants

Participants were people working directly with people with intellectual disabilities. In total, eight different people tested and evaluated the application. Because of COVID-19 restrictions and regulations, user testing could not happen with actual users. The solution was to test the application on people who worked closely with people with intellectual disabilities. People attending testing had experience from the following fields:

- Teachers
- Special educational teachers
- Assistants
- Psychologists

Evaluating the test results in the previous project developed by Haugland[7], the system was evaluated to F on the grade scale. However, the application showed promising results related to engagement. Improving usability has been the primary focus of the current thesis. To evaluate the system usability, all participants were handed out a system usability scale after testing the

application.

7.2   Scoring SUS

Participants rates all ten questions on a scale from 1 to 5. Each question is not considered meaningful on its own. The final results rely on the overall accumulation. Interpreting the final result is done by subtracting one point from all odd questions (1, 3, 5, 7, 9). For even numbers, the final grading gets subtracted from five [41]. Thus, each SUS item can get a maximum score of 4. The lowest score possible is 0.

Figure 7.1 shows the accumulated results on each statement from all eight participants. Each color in the graph represents an individual respondent. Summing the score from all questions and respondents results in (195 * 2.5) / 8 = **61**.
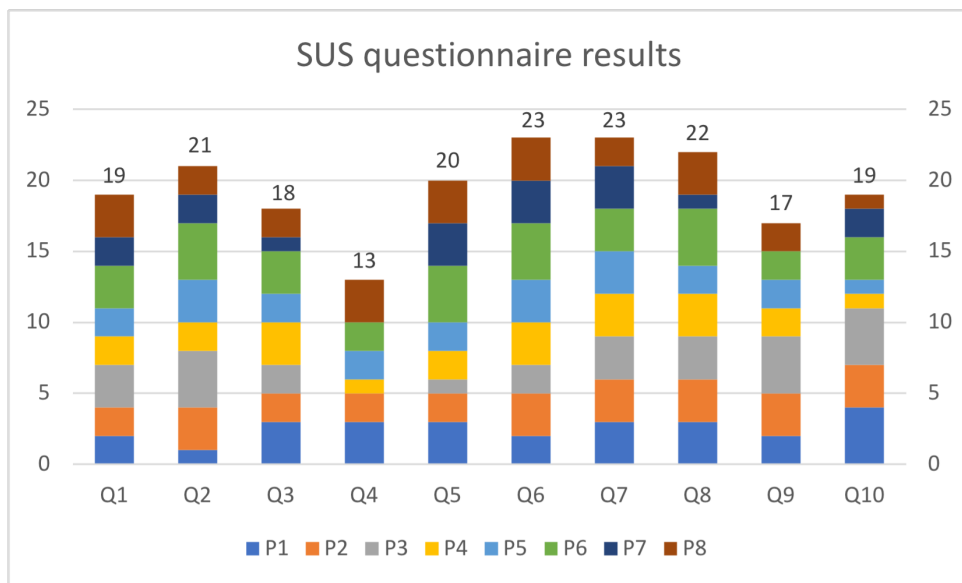
Figure 7.1: SUS questionnaire results.

Figure 7.2 shows the accumulated score for each participant.

7.2.1   Results

SUS scores range from 0 to 100. Scoring under 25 is considered "not acceptable," and a score of 100 is best imaginable. This application achieved 61, which
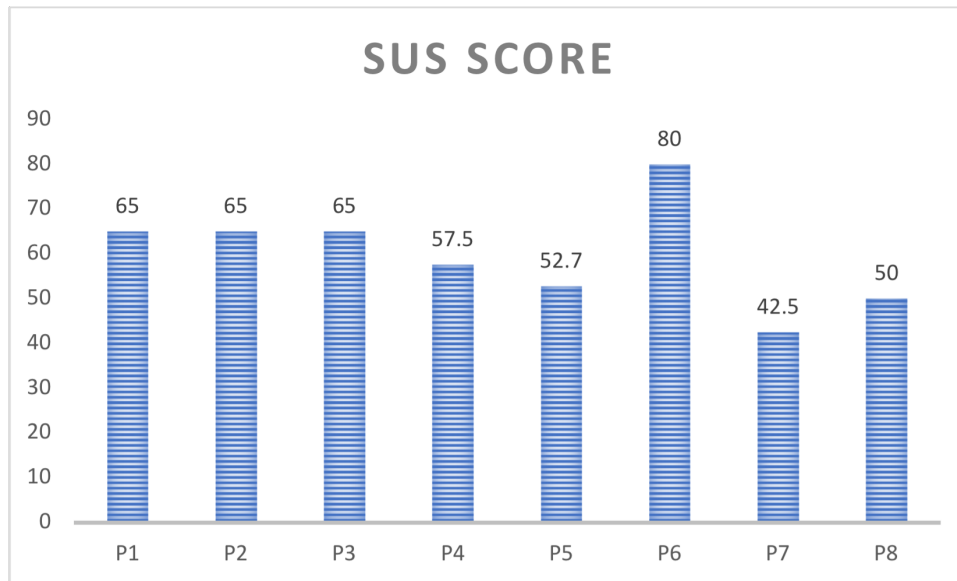
Figure 7.2: Final SUS score for each participant.

gives:

- Grade D.

- Acceptability score in the high end of marginal, between not acceptable and acceptable.

- It rated a between "OK" and "good" and marginally towards "good".

The grading implicates that the system marginally goes towards an acceptable level, but it falls in the marginal level between acceptable and not acceptable. Scoring 61 is borderline C, which starts between 60-65.

As we can we from the results in figure 7.2, the individual SUS score varies from the highest score of 80 to the lowest at 42.5. Almost half of the participants scored the application to 65. The variety of individual results is discussed further in the next chapter.

7.3   General Feedback

Before, during, and after testing, participants were able to ask questions and give general feedback related to the application. Some participants wanted

the application on a larger device. They thought the small screen size could be difficult for many users. Larger devices are possible in the application, but we only had small mobile phones at the testing. Some participants had issues during testing. Several users had problems with objects getting stuck, and they could not pick them up. One participant walked around the entire school and only located one object. Discussing problems related to the gameplay is described and discussed in the next chapter.

One of the participants wanted to log trash not thrown in the correct garbage bin. Using the error data, the participant thought the application could have an extra value related to learning. Using this type of logging could also benefit if the application expands to not only sort trash.

Even though some problems occurred, the general feedback from testing was good. Two of the participants from Kvaløya VGS showed an extra interest in using the application. They wanted to use the application on users during the summer but wanted some minor changes related to the issues mentioned.

7.4   Summary

This chapter presented the test result from usability testing of this application. General feedback implied that the application could have a potential value for people with intellectual disabilities. Looking at the SUS-score of 61, the application still has room for improvement. Chapter 8 discusses the test results and limitations related to testing.

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Discussion

This chapter starts by discussing usability testing results and answering the research questions stated in the first chapter. Also, limitations of the application and future work are described at the end of the chapter.

8.1 Evaluating Test Results

While the feedback from testing was promising, testing it on actual users would give more precise feedback on the usability and value of the game. However, looking at the results from the SUS questionnaire and feedback from testing shows that aspects of this application could benefit people with intellectual disabilities. All participants answered that they thought people with intellectual disabilities would learn how to use the application and use it regularly.

By looking at the results, there is one question that affects the overall score negatively. Interestingly, this same question sticks out negatively in the previous project[7].

> Q4: "I think a person with intellectual disabilities would need support to use the application."

Even though one question is not considered meaningful on its own, this particular question is worth addressing. The target group for this application is a user group where some have access to support every day. However, generalizing the user group is problematic because the level of support needed is very individual. Relying on support from assistants and family members is not necessarily bad when it comes to the usability of this application. Scoring low on this question can also indicate that augmented reality is too challenging for this user group. Testing it on actual users is required to conclude if this is true.

There is also a big difference between the highest individual score and the lowest. Participant seven (P7) and participant eight (P8) scored 42.5 and 50. While filling out the questionnaire, they said it was difficult for them to answer these questions precisely. They thought it was difficult to generalize because they worked with various severities of intellectual disabilities. However, one participant awarded the application a SUS-score of 80, meaning that they thought it was highly usable. Diversity in SUS-questionnaires is not unusual, but the gap between scores was significant in this usability test.

This SUS-questionnaire may be hard to evaluate precisely without testing the application on actual users. While one participant thought the application was usable for people with moderate to severe intellectual disabilities (with support), some thought it could be too difficult for persons with severity level moderate.

8.1.1   Research Limitations

The SUS questionnaire itself was translated to Norwegian and somewhat modified to target users with mild to moderate intellectual disabilities. Translating the questionnaire can affect the meaning of the question and make the text somewhat inaccurate. However, we took great care not to make it inaccurate and translate it as precisely as possible.

Comparing the results to the previous project is hard to conduct. The present project entirely relied on feedback project entirely relied on feedback from teachers, special education teachers, psychologists, and assistants. The previous project performed testing on actual users. Even though the staff members filled out the SUS-questionnaire, they were able to observe how users could interact with the application.

Another limitation is related to the hardware used when testing. The only available hardware was Samsung A20e, and running the application on this particular device is known to have minor bugs. Those bugs are further described later in this chapter, but all participants that experienced this got a somewhat

worse impression of the application. Experiencing a bug while testing an application can make people doubt the value of the system. How this impacted the overall score is hard to tell. However, most of the participants were concerned about this when evaluating the application. I was able to resolve these bugs when compiling the application for iPhone, and these bugs are not present on this device. We will therefore use the iPhone version in the upcoming pilot study.

Doing the necessary research and development, combined with a limited time-frame, made long-term testing difficult. However, as this is part of a bigger research project, long-time testing is meant to occur in the upcoming months. The physical activity pilot study is currently recruiting participants, and the Sorterius application will be used in this pilot as a mHealth intervention tool.

8.2 Cross-Platform implementation

In order to reach more people, we wanted the application to run on multiple mobile platforms. Looking at the recent development in the Augmented Reality industry and the upgrading of AR Foundation 2.2 in Unity, it became evident that this was something we wanted for this project. As the previous project only works on Android, this was a step towards making a valuable product.

Android phones (ARCore) were the primary device used for feature testing. During testing, it became evident that the product worked very well on both platforms.

However, there are some differences between the two platforms regarding performance. The Android version faced some problems with picking up objects. Problems occur when players walk too fast or move the phone too fast when placing objects. Fast movements causes objects to miss the detected horizontal plane, and objects do not get correctly placed.

Testing the exact implementation on an iPhone does not give the same problems. The application perfectly places objects, even if players walk fast or move their phones around quickly. Testing the application on an iPhone XR did not occur until the last weeks of the project. Two group members of the project performed testing over seven days. They did not experience any bugs with the application during testing. They also tested the version on a Samsung A20e before we had iPhones available.

Problems that arose are not related to the implementation but are related to how

the different frameworks, or platforms, handle rapid movements. Comparing the two frameworks, ARKit is proven to handle rapid movements better than ARCore[50]. One of the reasons for handling rapid movements better is that ARKit devices handle twice as many frames per second (fps). In addition, ARKit includes the accelerometer data, which enables planes and object to remain the same, even when covering the camera lens[50].

In this project, Samsung A20e and iPhone XR/11 are the primary testing devices. All iPhones that run Augmented Reality can handle 60 fps, while the Samsung A20e only handles 30fps.

8.3   Research Problems

8.3.1   Sub-Problems

In the following section the research questions are discussed and answered.

Sub-Problem 1

> RP1: *How can we personalize the application to fit users with different severities of intellectual disabilities?*

In this project we wanted to include people with different severities of intellectual disability. Having a "one solution fits all" was not wanted, and players can choose three different difficulty levels.

With help from the psychologist, we designed three different levels. The main content for each level stays consistent, but players need more knowledge around sorting trash on each level. Progressing up a level will challenge the users by adding more garbage bins. Having different levels does not only challenge the users, but also teaches them how to sort trash while progressing in the game.

A player who plays on the medium or hard game mode can adjust the length of the session. Before the game starts, they can choose between 10, 20, or 30 objects. As spawning objects happen every ten steps, this also relates to how far they must walk to complete that session.

To target users with different severities of intellectual disabilities, the applica-

tion also focuses on adjusting the complexity of starting a game session. When players want an easy challenge, they do not have to choose how many objects they want to find during the game. Removing this view also prevents users who want an easy challenge from making any choices before starting the game. They only must choose the easy game mode and then press start. Easy game modes consist of ten items, making it a short game session.

Sub-Problem 2

> RP2: *How can we improve the application to encourage users to use it throughout the week?*

Physical activity is not a one-time thing, and encouraging users throughout the week is vital to achieving the primary purpose of the application. Maintaining physical activity over time is a crucial aspect of improving health. This application aims to encourage users to to return to the game by using short-term, long-term, and instant feedback.

Maintaining physical activity is done by encouraging users through daily and weekly goals. Designing the welcome page is done entirely to give users feedback about how well they have done the current day and their progression towards the weekly goal. Handing out stars is a tool used for visualizing the progression, and receiving the first stars requires users to walk 50 steps. Users get instant rewards after playing one session, and each session contains at least ten objects. Because every object appears after ten steps, they will always have one star after the first session each day. As mentioned, this is to give positive feedback with a minimum of effort.

Adding visual feedback when adding trash to the correct garbage bins is another tool to encourage users during the game session. As shown in chapter 5, objects disappear from the screen, and a starburst appears while the mascot encourages feedback. Adding visual feedback is a tool used to encourage users when they make correct choices, completing sessions and completing a weekly goal.

Sub-Problem 3

> RP3: *How can we design the application using user interface guidelines for supporting people with intellectual disabilities?*

Through discussions with experts, literature, and what was addressed in section 2.5, this thesis have shown that there are many considerations when designing an application for people with intellectual disabilities. Applying this knowledge resulted in a simplified interface, focus on error-free inputs, clear contrasting colors, and consistency throughout the application.

Uncovering the importance of an intuitive and straightforward user interface was done through discussions with healthcare workers, psychologists, and intellectual disability professionals. They also helped point out the value of easy and understandable gameplay with precise instructions.

This application includes several views with few elements and a clear purpose for each view. Choosing to add several views enables each view to include only a few interactable elements simultaneously. For most of the views, there is a maximum of three interactable buttons. These design choices are considered an essential aspect of this application.

Using the Web Accessibility Initiative (WAI), designing the application follows guidelines for developing a user-friendly interface to support individuals with intellectual disabilities. The guidelines provided valuable insights when developing the application.

Focusing on simplicity and help users through the menu have been a big focus area when designing. From the guidelines (WAI) and discussions, this project has introduced some valuable techniques to achieve this.

- Limited information on each view

- Consistent color and placement on buttons

- No input fields

- Context change on the same button in each view

- Text-to-speech

- Simple language

- Using icons to convey the meaning behind buttons

It was revealed through testing that using several views with a limited amount of information, together with text-to-speech, was a valuable feature.

Sub-Problem 4

> RP4: *How can we encourage increased physical activity through person-alised goals?*

Through discussions with psychologists and special education teachers, combined with the authors' previous knowledge working with people with intellectual disabilities, it was found that the application should include parents and care staff. A good dialog between individuals with intellectual disabilities and parents or care staff is considered the primary encouragement factor for physical activity.

Tailoring physical activity goals to specific users is considered necessary to encourage users. Having a pre-defined number of steps to reach three daily stars causes some users to have a too easy challenge, while some may struggle to reach those goals. Some of the barriers people with intellectual disabilities face are self-efficacy and lack of personal interest[5]. Using the parents' or care staff's knowledge, they can create reachable goals for specific users. To increase the interest in reaching goals, they can add a reward to the end of the week.

It was revealed through testing that including parents and care staff was a valuable feature. Adding small rewards tailored to specific users was a feature all participants liked. Also, some users only needed to walk 500 steps extra to make an impact, while others would benefit from walking 1000 steps.

8.3.2   Main research problem

> RP: *How can we design and implement a mobile game for people with mild to moderate intellectual disability that encourages physical activity?*

The goal was to develop a game that helps people with intellectual disabilities reach the recommended amount of physical activity. The solution provided is an augmented reality game, using exergame and serious games as the central concept. By combining physical activity and cleaning the environment, the application aims to encourage users to learn while playing the game.

By creating an exergame, the goal was to make the application fun so they would not think about the fact that they were doing physical activity. Taking

the focus away from physical activity was done by adding practical chores when users were walking. Through discussions with intellectual disability professionals, the application's content is designed around a real-life scenario, including objects included in everyday life.

While the game itself focuses on physical activity through practical chores, its application is not considered usable without a simple design. Thus, the application includes a simplistic design developed through literature and discussions with professionals with intellectual disabilities.

Testing revealed that combining parents/assistants, rewards, practical chores, and a game scenario based on everyday life could be valuable for encouraging users to physical activity. However, if augmented reality is a suitable technology for this particular user group was addressed as a potential problem.

8.4   Augmented Reality for people with intellectual disabilities

As described earlier in the thesis, augmented reality mixes the real world and the virtual world. The concept of interacting with objects present in a particular place in the virtual world, but not when you look at the same position in the real world, can be hard to understand. As individuals with intellectual disabilities can struggle with abstraction, augmented reality may not the optimal solution for this user group. Taking an advanced concept and making it easy and understandable is not an easy task.

Developing this application has focused on making the augmented reality game play simple by removing most of the interactions related to 3D objects. The most significant contribution to simplicity in AR is automatic placement after walking a certain number of steps. The previous version added an object to the world by tapping the screen and then walking close to the object to pick it up. In this project, this interaction is turned around. When users see an object, they press the screen to pick it up. Doing this enables users to walk around without focusing on touching the correct place on the screen. Placing an object by touching the screen relies on two things. First, users need to touch the part of the screen where the ground is detected. Second, they must focus entirely on the screen. By removing this functionality, users can focus on walking while the software detects and place objects. After placing objects, the application will tell the users that something is nearby.

8.5 Application Limitations

The Lightweight step counter

The most significant limitation in this application is the usage of the lightweight step counter. The implementation works well during testing but also counts steps when users shake the phone. This way, users can manipulate the step count and achieve their weekly and daily goals by not walking the correct number of steps. However, to prevent users from taking advantage of this, the step counting number is not displayed when users walk. Hiding the step count prevents users from exploiting this bug. It is, however, an area that needs improvement in the future.

Calibrating the step counter was done by the author and other testing persons. Testing the application on several people revealed that some persons held their phones in a very firm grip. A firm grip, combined with walking carefully, prevented the accelerometer from picking up signals high enough to detect steps.

Android issues

Another limitation in this project is the diverse performance on Android phones. While the overall functionality is present on both phones, the phone is not perfectly usable on Android. Doing steady movements and stopping up when objects are places will make it usable. However, making the application working by depending on user movements is not wanted. Some users may think they are the problem, not the application, and making them annoyed. Thus, not wanting to play anymore. One teacher even said that this particular issue could make someone throw the phone away.

8.6 Future Work

This section describes future work that can be used to enhance the application. As some of the requirements were not implemented, they are also listed here.

8.6.1 Add more content

In this project, five 3D objects were created to make the game content relatable to everyday life. Having more objects created to target everyday life should be

considered in the future. Making the game as realistic as possible should be the focus area when creating a game that focuses on real-life scenarios. Also, by increasing the number of trash users can find, the game can be more fun and engaging in the long run.

8.6.2   Add different Game modes

For the benefit of the project, we wanted to create a decoupled system. Creating a system that does not rely on every part makes it easy to integrate new solutions. As for all games, there is no solution that everyone likes. Implementation of this system relies on four different scenes. Splitting the distinct part of the application in different modules enables the game scenes to be changed easily. Changing out scenes does not impact the overall implementation. Step counter, GPS tracker, and scripts are not depending on the actual game and their system modules. Placing objects and interacting with the game is implemented in the scripts, and it is only needed to change out 3D objects.

Future work should focus on implementing more game modes to target a wider specter of people or purposes. During testing, one of the participants said this could be a great tool in the school system by adding other tasks.

One game mode suggested included animals. By changing the trash with animals and garbage bins with ocean, sky, and forest, users can place the animal where they belong. Finding a fish would lead the user to push the button with an ocean on it.

8.6.3   Integrate with Apple Health Kit

At the beginning of this project, the only available hardware was Samsung phones (S9 and A20e). This led to spending much time looking into a suitable solution for detecting steps using these particular phones. However, in the late stages of the project, new iPhones were provided. Using iPhones introduced the possibility of integrating Apple HealthKit for detecting steps. As this is an open solution for developers, and the current application uses a workaround for counting steps, this is an area that could be improved.

Using the Apple health kit also enables developers to access wheelchair data for users wearing Apple Watch. By tracking pushes rather than steps, the application can reach out to more people. This feature requires the users to wear Apple Watch.

8.6.4   Support for people in wheelchair

As mentioned, the Apple Health kit can read pushes rather than steps. As this requires users to wear an Apple Watch, there should also be options for people who do not have access to Apple Watch or playing on Android phones. When creating a step counter, one of the workarounds consists of a GPS-based solution that measures steps. Even though the solution did not work for testing purposes, the solution still exists in the project. Measuring distance alternatively to steps can include people in wheelchairs to use the application. Future work should test this solution extensively and make the application adaptable for people in wheelchairs.

8.6.5   Persistent storage

This implementation relies on Unity's local storage. All data are deleted daily and weekly, which removes the possibility of keeping track of previous achieved activities and goals reached. Future work should focus on adding a persisting storage system, which will enable the opportunity to add even more features. Storing data on a remote server also allows requirement #6 to be implemented, stating that users must be able to share their achievements.

Make it Competitive

Adding persistent storage will create a way of making it competitive between players. Storing user data on a remote server enables the application to take advantage of other user's data and create a layer of competitive features. Creating scoreboards and share physical activities in the application could add another layer of motivational factors to the application.

Final integration with mSpider

Because of the upcoming pilot study, the final integration with mSpider was not finalized. The last weeks of the project went on refining solutions that would benefit the pilot study, and full integration with mSpider was concluded not to benefit the pilot study at this point. Before uploading data between sessions, more comprehensive testing would be needed. As all the data is stored within the application, there is no need to establish the connection to mSpider. Future work should focus on establishing this connection, do comprehensive testing and error handling. This integration enables the completion of requirements #10 and #11 related to the uploading of data.

8.7   Pilot study

In the upcoming weeks, the iPhone version of the application will be used in a pilot study. In the study, several people will have the possibility to try out the application in a study conducted by the University hospital of North Norway (UNN), in collaboration with UiT The Arctic University of Norway. The study aims to improve health-related activities for people with intellectual disabilities.
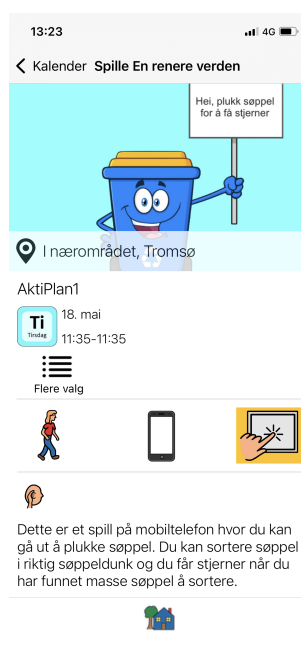
Figure 8.1: The application ready for Pilot Study.

8.8   Summary

This chapter discussed the test results and limitations of the research. Throughout the chapter, the weaknesses and limitations of the application are described. Also, research problems are answered and discussed.

The application got positive feedback related to usability and value for people with intellectual disabilities. However, a final conclusion is dependent on testing of actual users.

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Conclusion

Based on findings from relevant literature, discussions with experts in the field and special education teachers, and the author's previous experience with intellectual disabilities, this project has designed an application with special focus on providing a user interface for people with intellectual disabilities. Evaluating the test results shows that we have created a suitable user interface for the targeted user group. The techniques applied can contribute to future projects wanting to design user-friendly applications for people with intellectual disabilities.

The main contribution of this project is a cross-platform augmented reality application combining physical activity and learning. The application combines two critical topics in our society, physical activity and environmental problems. While playing the game, players will gain experience sorting garbage and, at the same time, be physically active (walking). The application includes goalsetting, thereby involving the support persons around the individual with intellectual disability, which previously is shown to improve motivation towards physical activity in this user group.

The application has primarily been tested on experts in intellectual disability research and with social workers, health care workers, and teachers working with people with intellectual disability. This means that this application so far has not been tested on the actual reference user, people with intellectual disability. However, experts and people working with those who have an intellectual disability diagnosis can provide valuable information. They know how

well the application fits the user and will often be involved when used. Future testing of the application should include users with intellectual disabilities to ensure the generalizability of this research and usability of the application. So far, all participants in the study have been positive, and long-term testing will start this month.

The author feels confident that the solution developed can be expanded to target a broader range of users and projects. Using augmented reality to address meaningful societal aspects, such as the environment, can be a helpful tool in raising awareness while at the same time strengthening the knowledge towards serious topics in an engaging digital environment. By changing the game objects used in the application, the learning aspects of the application can fit different purposes. Expanding can also happen on an international scale. Changing the Norwegian products and language in the application can contribute to encouraging physical activity participation internationally.

The final product has received exciting feedback from experts and testing participants. In addition, the chief physician, and leader of the project, are impressed by the process and the final solution and have decided to use it in the upcoming pilot study. With many years of experience working with intellectual disabilities, this feedback has been a quality assurance towards deployment in the upcoming pilot study.

Sorterius will be available for users in a pilot study conducted by the University Hospital of North Norway (UNN), in collaboration with UiT The Arctic University of Norway. The result from the pilot study will be published in scientific journals.

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Appendix A - SUS questionnaire

Spørsmål - tilfredshet

Disse spørsmålene er laget for å høre hvordan du tror denne mobil appen er å bruke for personer med mild/moderat grad av psykisk utviklingshemming.

	Veldig uenig				Veldig enig
1. Jeg tror appen kan bli brukt jevnlig av personer med psykisk utviklingshemming.	1	2	3	4	5
2. Jeg tror appen er for komplisert for personer med psykisk utviklingshemming.	1	2	3	4	5
3. Jeg tror appen er lett å bruke for personer med psykisk utviklinghemming.	1	2	3	4	5
4. Jeg tror en person med psykisk utviklinghemming vil trenge støtte for å bruke appen.	1	2	3	4	5
5. Jeg tror en person med psykisk utviklingshemming vil synes de forskjellige delene av appen henger godt sammen.	1	2	3	4	5
6. Jeg tror en person med psykisk utviklingshemming vil synes det er for mye inkonsistens i appen. (Det virker ulogisk)	1	2	3	4	5
7. Jeg tror en person med psykisk utviklingshemming vil kunne lære seg å bruke denne appen.	1	2	3	4	5
8. Jeg tror appen er for vanskelig å bruke for en person med psykisk utviklingshemming.	1	2	3	4	5
9. Jeg tror en person med psykisk utviklingshemming vil være komfortabel med å bruke denne appen alene.	1	2	3	4	5
10. Jeg tror det vil kreve omfattende opplæring før appen kan brukes.	1	2	3	4	5

Figure 1: Appendix - SUS questionnaire