



Lowering barriers for mathematics

Key considerations for designing an introductory game for mathematics exhibitions at science centers

Master's thesis in Computer science and engineering

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Cover: Picture from mathrix, Figure from Universeum's web page.

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Abstract

Science centers are known for presenting science related subjects in an engaging way. Visitors have the opportunity to familiarize themselves with ideas and concepts in science through interactive installations. Mathematics is a subject students have been shown to have a complicated relationship with [4]. A negative emotional response to learning math is not uncommon among teenagers. This may result in a certain threshold for visiting an exhibition focusing on mathematics in a science center. In this project, we have used a research through design approach to investigate how an introductory digital game can be designed to lower the threshold.

The project has a design thinking approach and utilizes a 5-step iterative process. The steps being, empathizing and understanding the context, defining user requirements, ideating, prototyping and testing. The research was carried out at Mathrix, an interactive mathematics exhibition at Universeum, and led to the development of two digital games. The games aims to lower the visitors entry barrier towards the exhibition. Feedback from user tests indicates that visitors recognized elements from the games in Mathrix which helped facilitated the visit.

During the design process of both prototypes, a number of key considerations for designing an introductory interactive game for a mathematics exhibition were identified. These included considerations regarding connection between the game and exhibiton, incorporation of mathematics and different aspects of the nature of the game. The findings provides valuable insights regarding lowering entry barriers for mathematics exhibitons and the knowledge can be utilized for research on introductory games for a mathematics exhibiton.

Keywords: Interaction Design, Research Through Design, Game design, Science centers, Mathematics, Design Thinking.

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1

Introduction

Learning is often perceived to be limited to the confines of the school environment; however, students are known to acquire knowledge outside of the school setting in more informal learning settings. It is shown that learning in informal environments benefits science learning [1]. A prominent example of an informal setting that benefits learning is science centers, where visitors can interact with exhibition pieces and explore various subjects within the realm of science.

Science centers provide an ideal platform for experimenting with interactive design. These museums offer user experiences that focus on understanding, entertainment, and exploration. Ideally, a science center is both fun, exploratory, and educational for the visitors. However, learning is a byproduct of attention and since learning is the ultimate goal of an exhibition, the exhibition should strive to keep the visitors' attention [2]. In order to do so the exhibition has to be understandable and intriguing. Achieving this is a major challenge for the exhibition designer.

Sweden's national science center, Universeum, provides many exhibitions with interactive features to inspire and educate people in the field of science [3]. Science centers are naturally a tangible environment in the sense that the visitors' expect to be able to interact with the installations through tangible interaction. A science center is an environment where various elements of interaction design are present. First off, visiting a science center is a clear user experience with a beginning and an end. The installations often incorporate tangible interaction in some form. Screens with an interactive user interface are also common. This makes Universeums' science centers a clear forum for interaction design.

Mathematics is an indispensable and fundamental subject and it is a tool for developing all other sciences. However, many students find the subject difficult and it can evoke fear and anxiety [4]. There are three things that make mathematics difficult for students, and one of these is the environment. Therefore, it is particularly interesting to investigate if it is possible to create an environment where young people can explore their knowledge in mathematics. Currently, Universeum has an exhibition in place that pertains to the subject of mathematics, where this study will be conducted.

1.1 Background

Universeum has developed exhibitions for visitors to learn more about theoretical subjects in an interactive environment. Vislab, one exhibition which gives the visitor the opportunity to explore science, opened 2021. A previous master thesis report *Designing interactive digital guides to increase teenagers' engagement at science centers* investigated if teenagers' engagement in a Vislab exhibition could be increased by using a digital interactive guide [5]. The project focused on the following four categories:

- Making it easier for visitors to understand how to interact with the exhibits
- Making the content of the exhibits more interesting
- Contributing to an exploratory experience for teenage visitors.
- The text in the entries may be of any length.

The results showed that despite that the visitors who used the interactive guide stayed longer at the exhibition the understandability of content between users and non-users was slightly lower for users and that the guide did not make the contents of the exhibits at Vislab more interesting.

User experiences can be measured over different time spans into different time spans [6]. Anticipated UX, which takes place before the experience and is formed by expectations. Momentary UX, which is the actual experience. Episodic UX takes place after the experience and is formed by reflecting. Lastly, cumulative UX is described as the experience summarized after several uses over a longer period of time. Since the previous master thesis with the interactive guide was used while experiencing the exhibition, we argue that the focus was on momentary UX, implementing an interactive guide as an extra layer to the experience at the moment.

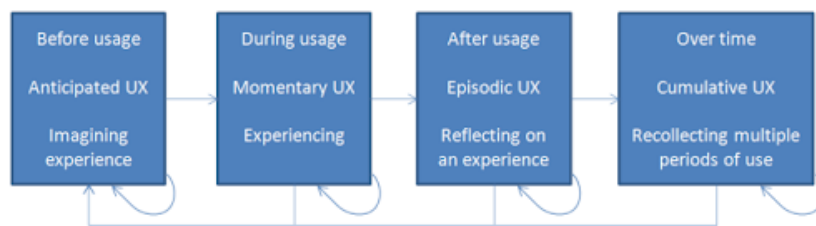


Figure 1.1: The different time spans of UX[6]

1.2 Purpose and Aim

Mathrix is a newly opened exhibition with focus on mathematics. School classes are common to visit Universeums various exhibition centers and this will be the case for Mathrix as well. During a school classes visit to Universeums exhibition center, students are given self-guided tasks on cards that direct them to a particular installation, prompt them to answer a question, and encourage discussion. The aim

is to investigate what aspects should be considered while designing and developing a game with the intention to affect the anticipation on an exhibition visit at a science center. More specifically within the context of a school class visit with self-guided tasks. Our hypothesis is that an introductory game can lower the visitor's threshold via recognition.

In recent years, the implementation of games in educational purposes has increased [14]. It is shown that games have beneficial impacts on individuals' motivation, engagement and learning skills. Therefore, an interactive game, with focus on introducing visitors to the mathematics exhibition, will be employed.

1.3 Research Question

Mathematics is shown to be a generally underappreciated subject among teenagers but science centers can help change this and Universeums goal with Mathrix is to spark an interest in mathematics. However, attending the exhibition only involves momentary user experience and the expectations on the visit are also a part of the whole experience. Games have been shown to have a positive effect on motivation for learning and it is interesting to investigate what aspects should be considered while designing a game with the purpose of lowering the visitors' threshold for visiting a mathematics exhibition. Based on this background the thesis aims to use interaction design methods to investigate the following research question:

What are key considerations for developing an introductory interactive game intending to lower the visitors' entry barrier for a mathematics exhibition at a science center?

This is a design project that contains development of an interactive game designed to affect the visitors' expectations on Mathrix at Universeum. The visitors are supposed to play the game before entering the exhibition, affecting the anticipated user experience. Therefore, based on the MDA-framework (see 3.3.2), a design challenge for how the game will be designed is also stated:

What mechanics, dynamics and aesthetics are important to consider while designing an introductory interactive game for the Mathrix exhibition at Universeum?

1.4 Scope and limitations

This project focuses on lowering entry barriers for an exhibition, meaning that the games will not aim to teach math but rather spark an interest for and help facilitate an exhibition visit. Mathrix in itself aims to spark an interest in math and could be described as an environment that lowers the entry barrier for the subject. Our game will in turn aim to lower the entry barrier for Mathrix.

The scope of this study will not include investigations into the effects on learning,

although it is an interesting aspect. Since the study implements research through design and focuses on interaction design, pedagogy will not be focused on.

The project does not aim to make a fully implemented design, but rather to make an installation with the purpose of researching the effect the installation has on its environment. The project employs design strategies for the purpose of conducting research rather than focusing on the quality of the final solution.

Since the installation will be exclusively evaluated within the confines of Universeum the user target group will specifically be teenagers visiting Universeum. The context being limited to Universeum also brings another limitation, as testing the installation in other science centers could generate better results. However, general conclusions may be drawn from the study.

1.5 Ethical concerns

Given that the objective is to involve users in the design process, it is essential that the principle of informed consent is followed and that all participants are fully informed about the nature of the study and participation is entirely voluntary. Participants have the option to discontinue their involvement at any time and request the deletion of their data.

Data collected is anonymous, and any data gathering is conducted with the prior consent of the participant, who is also informed about how their data will be utilized.

Accessibility is also of utmost consideration, as failing to take accessibility into account can result in the exclusion of a portion of the target group and limit the usability of the designed product. Our goal is to involve a wide range of users throughout the project to avoid limiting the accessibility of the installation.

2

Theory

This chapter introduces the underlying theory integrated in this thesis. Interaction design as a whole is described. However, interaction design is a large subject and the divisions that are prominent in this thesis will be described more in depth. Research on science centers and the behavior of its visitors will be presented as well as research regarding informal learning and teens' relation to mathematics.

2.1 Interaction Design

Interaction design is described as “the creation of a dialogue between a person and a product service or system” [7]. In a similar way, the term is described as “it is about creating user experiences that enhance and augment the way people work, communicate, and interact” [8]. Numerous terms are used to accentuate the various facets of interaction design, such as user interface design, software design, user-centered design, product design, web design, user experience design, and interactive system design [8]. Interaction design is typically utilized as a comprehensive term to describe the field and its approaches, theories, and methods. Some aspects of interaction design will be used more than others in this thesis, these subjects will be described more in-depth.

2.1.1 Designing user experience

The most prominent category of interaction design used in this project is design of user experiences as the goal is to affect the experience of the science centers' visitors. The term “user experience” is described as a comprehensive assessment of an individual's or a group's encounter with a system, which encompasses both the beginning and the end of the interaction [6]. Visiting a website or playing a game are brought up as examples of a user's experiences. Both examples have a clear beginning and end and include an interaction between users and a system.

2.1.2 Information visualization

Visualization is the act of creating a mental representation of information. In modern times, visualization has developed into a specialized field that utilizes the capabilities of computers to convert complex data into visual forms that can be easily understood and communicated [9].

The process of information visualization follows four stages [10], an illustration of the four stages is shown in Figure 2.1. The stages are as follows:

- The collection and storage of data.
- A pre-processing stage designed to transform the data into something that is easier to manipulate. Usually there is some form of data reduction to reveal selected aspects. Data exploration is the process of changing the subset that is currently being viewed.
- Mapping from the selected data to a visual representation, which is accomplished through computer algorithms that produce an image on the screen. User input can transform the mappings, highlight subsets, or transform the view. Generally this is done on the user's own computer.
- The human perceptual and cognitive system (the perceiver).

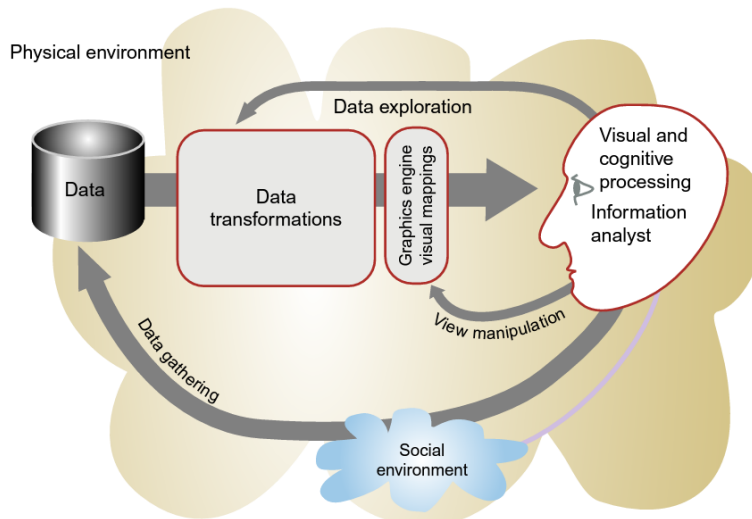


Figure 2.1: The different time spans of UX[10]

It is further stated that proper information visualization can help discover problems with the data and data collection. Visualization can also be useful in identifying patterns that can be difficult to discern when looking at the data in a raw form.

2.2 Informal learning

As mentioned in the introduction, informal learning, i.e learning outside of conventional learning environments, is shown to have a positive effect on science learning [1]. There are various forms of informal learning, this section will focus on the forms of informal learning prominent in this thesis.

2.2.1 Exhibition centers

A study was conducted at the Tom Tits Experiment, where an exhibition installation was redesigned to incorporate elements of gamification, by incorporating a point system to the installations [11]. The aim of this redesign was to increase the attractiveness of the exhibit to a generation that is used to stimulation through computer games, as well as to provide additional opportunities for family engagement, and to reduce the risk of "museum fatigue". The study's findings indicate that the incorporation of gamification can enhance visitor engagement, however, there is a risk that the game elements may become the primary focus, thus detracting from the educational objectives of the exhibition.

2.2.1.1 Visitor engagement

A study is presented of visitor engagement at a science center [12]. Visitor engagement is defined as "the observed degree to which the visitor pays attention to the exhibit and participates". The study observed 9 exhibits with 200 visitors each and analyzed their behavior. The study's result showed a declining interest over time, [12] discusses possible explanations for this, one being the various options of activities a science center offers. They state the fact that the exhibition pieces are competing for the visitors' engagement may lead to oversaturation and lower the engagement towards the installation the visitor is currently engaging with. In addition, the visitors don't know if they will be rewarded for maintaining focus which might also be a reason for the declining attention.

A study is executed aiming to find out how specific independent variables individually contribute to learning outcomes from a science center visit [13]. The study observed 217 visitors at California Science Center's World of Life exhibition. The study result showed that no single factor could explain the learning outcomes for all visitors. It did however conclude that a number of various factors had an impact on the learning outcomes, examples of such factors was prior knowledge, motivation, and expectations.

2.2.2 Learning through games

Games and simulations for training have long held the potential for individuals to rehearse skills and for groups to practice coordinated actions. This has given rise to initiatives such as Montessori games, which have been considered by some in the educational community as an effective form of learning [14].

A study made by [15] explored the difference in learning outcomes based on conventional education as opposed to learning by playing computer games. The findings revealed that a majority of the experiments yielded superior learning outcomes when utilizing game-based education. Additionally, participants demonstrated a higher level of enjoyment in the game-based learning approach as opposed to conventional methods. The most significant disparities were observed among middle-school students.

2.2.2.1 Gamification

Gamification is explained as game elements included in non-game devices or services [16]. Examples of such elements are points, levels, and challenges. Data collected with the “keyword” gamification shows that gamification is increasingly accepted as a learning tool and is shown to have a positive effect on students’ motivation. Additionally, it highlights points, leaderboards, badges, and levels as the most significant game elements.

2.2.2.2 Serious games

There is a difference in definition of gamification and serious games [17]. Gamification is described as using gaming elements in a non-gaming environment whilst serious games are complete games with the purpose to educate.

2.3 Learning through repetition

Learning involves many elements, but repetition is a crucial one. Scientists have studied repetition learning through the Hebb repetition paradigm and they have found that we remember things better if we repeat it, than if we only see it once [19]. Previously they thought learning through repetition happened without us even noticing. However, they have found that we actually are aware of the repetition, and this awareness helps us learn faster. The paper gives two predictions: The time when people start learning should be correlated with the time they become aware of the repetition. The time of awareness should come before, or at the same time as, the start of learning.

2.4 Teen’s relation to mathematics

Various studies have been made on the subject of mathematics anxiety and how it affects learning. Increased mathematical anxiety correlates with decreasing results [20] and [21]. Inadequate mathematics proficiency can be negative for an individual’s professional prospects in STEM fields, which requires advanced mathematical competency [21].

A negative emotional attitude towards learning mathematics is established, but what can be done to counteract such attitudes? [22] explains how engagement is required to achieve learning. The study explores how serious games can be used to enhance the learning of mathematics. The study concludes that engagement is a multifaceted and individualized concept; various components of a game are capable of captivating different people, thus suggesting that a serious game should incorporate a wide array of engagement factors and the ability to give players the freedom to discover their own individual journey through the game.

3

Methodology

This project use primarily a Research through Design approach(RtD), where the design is a part of the research [23]. RtD is a term often used in interaction design(IxD) and human computer interaction (HCI). However, the definition of RtD can vary, since both HCI and IxD are young fields. The common core is that design activities such as ideation, developing prototypes, measure and analyzing its effect is in itself contributing to the research and generate new knowledge and insights about the context. In this chapter, the methods used in this project are described as well as some relevant methods that were not selected.

Design thinking is a way for designers to approach wicked problems and goes on to describe the term as a five-stage process [24].

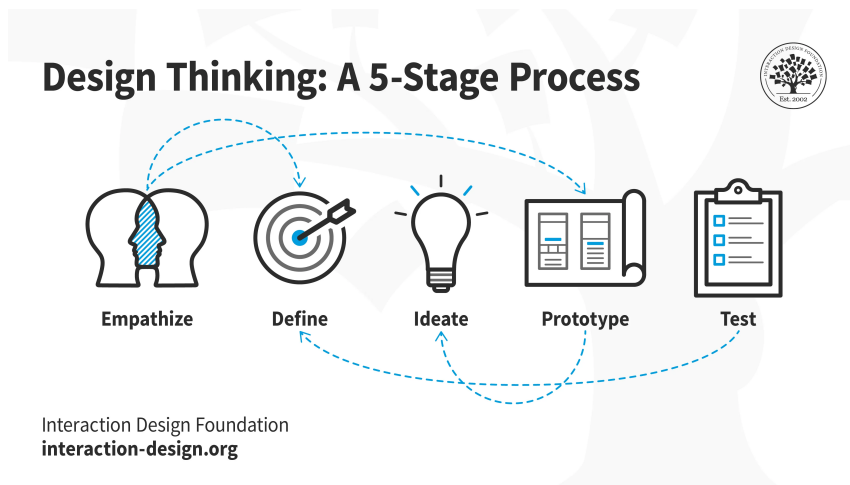


Figure 3.1: The double diamond process

Another framework, quite similar to design thinking is double diamond [25]. This framework divides the design process into two stages, problem space and solution space. The designer explore the problem in the problem space and ends up with a clear definition of the problem which is brought into the solution space that focuses on solving the problem.

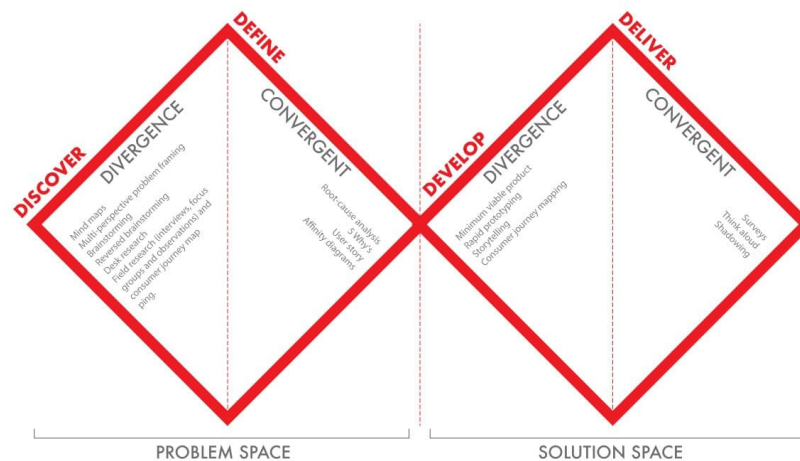


Figure 3.2: The double diamond process

However, in this thesis, Design thinking is used as a foundation as it is a bit more iterative and lets us as designers to work a bit more freely which suits this project. The methods used in the thesis are divided into the frameworks three categories.

3.1 Empathize

This step is about understanding the context. This allows the designer to gather insights about the users needs, behaviour, experience and values.

Three categories of tools and techniques used to understand and empathize with the user are presented [26]:

- What people say
- What people do
- What people make

Letting users express their emotions and needs in these different ways lets the designer paint a holistic picture. Examples of how to gather information in these ways are to listen to what users **say** in interviews, observe what people **do**, letting users **make** in a co-creation workshop or by letting them draw UX curves.

3.1.1 Fly on the wall observations

The fly on the wall method, described by [27], involves the researcher observing the interactions and behaviors of individuals within a specific space. Fly on the wall observations, as articulated by [28], aims to capture the most authentic behavior of the individuals being observed. This is achieved by maintaining a distance between the observer and the individuals, thus avoiding the phenomenon known as the Hawthorne effect, which refers to the alteration of behavior that occurs when people are aware they are being observed.

3.1.2 Interviews

Interviews are a commonly utilized method for collecting qualitative research data and are often considered to be most effective when conducted in person, as it allows for the recognition of facial expressions and body language of the interviewee [28]. They can provide valuable insights into an individual's motivations and experiences, making them an effective tool for gaining a deeper understanding of human behavior [29]. Interviews can take various forms, such as structured, unstructured, or semi-structured. An unstructured interview is characterized by its informal and conversational nature, where the interviewer guides the discussion without a set list of questions. On the other hand, a structured interview is more rigid and the interviewee is asked a predetermined set of questions. A semi-structured interview is a hybrid of the two, where pre-written questions serve as the foundation of the interview, but the interviewee is also given the opportunity to expand on the topic beyond the predetermined questions.

3.1.3 UX curve

UX curve is a method for evaluating user experience over time [30]. The user gets to reflect upon their experience by drawing a curve. Time is displayed on the x-axis and satisfaction is displayed on the y-axis. An example of a UX curve is shown in Fig 3.3.

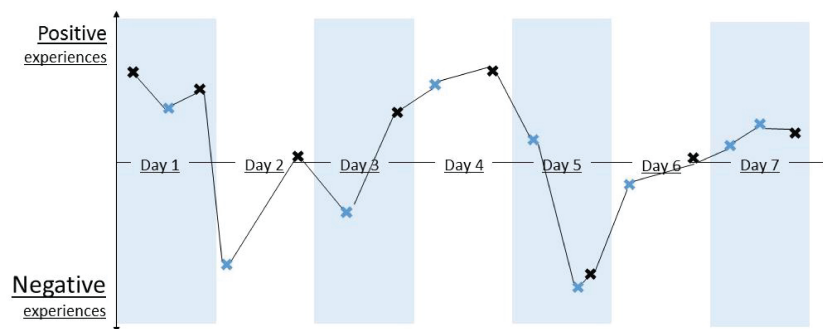


Figure 3.3: Example of UX curve

3.1.4 Co-Creation Workshop

Co-creation is described as collaboration with other stakeholders to collect a broader range of insights [31]. The idea is that the other stakeholders interact with the designers and each other to widen the designers' perspective.

3.2 Define

In this step, the findings gathered in the empathize phase are analyzed and the designer define the key insights that have been identified. These analyzes will result in problem statements that are used in *Ideate* phase [24].

3.2.1 Affinity diagramming

Affinity diagramming, also known as the KJ-method, is a technique employed for externalizing, comprehending, and organizing large quantities of unstructured, varied, and seemingly dissimilar qualitative data [32]. This method has been adopted and utilized by practitioners in the fields of Human-Computer Interaction and interaction design for various purposes. The technique operates as follows: information is recorded on post-it notes and affixed to paper or a wall [33]. The post-it notes are then rearranged and grouped based on their connections to one another. The process is grounded on a creative and intuitive approach rather than logical reasoning.

3.2.2 Scenarios

Scenario-building is a valuable technique to envision feasible future scenarios, including the associated problems and opportunities. The process of designing scenarios is a means of exploring potential future outcomes. Furthermore, the creation and implementation of a scenario can enhance understanding of the business environment in which the designer operates. It is described as a narrative that illustrates the interactions and experiences of an individual, often represented by a persona, with a product or service [28]. Typically, scenarios begin with the introduction of a problem and end with the resolution of that problem through the use of the product or service.

3.2.3 Personas

A persona is a fictional person who represents the intended target group [34]. The personas are based on research on how the real user acts in the context. The information will help the researcher understand the needs, behaviors, experiences, and goals of the users. Since there might be multiple target groups, the designer might benefit from creating multiple personas. The details that should be included for the personas are:

- A picture
- Values and behaviors
- Education, interests and lifestyle
- Attitudes and goals

3.3 Ideate

Based on the problem statements identified in the *Define* phase, multiple ideas are generated to explore different solutions and alternatives [24].

3.3.1 Brainstorming

Brainstorming is a method traditionally utilized to promote group creativity and generate concepts and ideas. It is governed by several widely accepted principles. These include a focus on generating a large quantity of ideas, rather than a select few of high quality, as well as the withholding of judgment and criticism, the encouragement of building upon the ideas of others, and the acceptance of unconventional and unique ideas. The goal of these guidelines is to establish a safe and conducive environment for the free expression and association of creative ideas, thus eliminating any inhibitions among the participants and facilitating the exploration of new and innovative concepts [28].

3.3.2 MDA-framework

The MDA-framework is commonly used when developing games. MDA is a method where a game is analyzed by breaking it down into components [35]. The components are categorized into three categories, mechanics, dynamics, and aesthetics. Mechanics are concrete aspects of the game that the player interacts with, for example drawing cards or throwing dice. Dynamics are elements of the game that are consequences of the mechanics and are part of the playing style. Examples of dynamics are teamwork or randomness. Aesthetics are more abstract elements and can be described as emotions that arise in the player, for example, desperation or surprise. The MDA-framework can be used to analyze an already existing game but is also useful while developing a game from scratch as it helps the designer keep track of the purpose and constituents of the game.

3.3.3 Morphological matrix

A morphological matrix is a technique in which a design problem is decomposed into smaller, more manageable sub-problems that require individual solutions [36]. These sub-problems are then independently addressed, and the resulting solutions are subsequently integrated in various combinations to generate a variety of potential solutions for the overarching design challenge. The method lets the designer reach the best possible design solution by combining the partial design solutions.

3.4 Prototyping

In this step, the ideas that have been generated takes shapes in form of different levels of prototypes. Early in the process, low fidelity prototypes will be created to make changes more easily. When the solutions are more identified, high fidelity prototypes will be created to give users a more correct picture of the final design [24].

3.4.1 Low-fidelity prototyping

Low-fidelity prototyping is a way where the designer quickly and simply creates tangible representations of a digital concept. The goal with low-fidelity prototypes is to test the usability of the concept in an early stage. However, it is important to know that low-fidelity prototypes have some imitations, as they are mostly not clickable. Examples of this type of prototypes are sketching and paper prototyping [37].

3.4.1.1 Sketching

Sketching is a way for the designers to communicate and explore their ideas by making drawings on paper [38]. By using sketching, the designers can in an easy way create and iterate their ideas, and it is a tool to eliminate misunderstandings. The goal with sketching is to communicate ideas, not to create art. There are some characteristics to think of when using sketching as a tool in the design process:

- The sketches should be made in a quick way and not take a long time to produce
- The sketches should be plentiful and show different aspect of the interaction
- The sketches should be minimalistic and contain the most important qualities

3.4.1.2 Paper prototyping

Paper prototyping is a process when the designer realizes a digital product with use of paper representations [39]. This process is an easy way to shape concepts and to study how the users interact with the concept and what their reactions are. Paper prototyping is useful in brainstorming and the designers can at an early stage eliminate ideas that do not work. This method is suitable when the project contains graphical user interfaces.

3.4.2 Mid- and high-fidelity prototyping

The more advanced version of a prototype is mid- and high-fidelity prototyping. They show a more correct version of the functionality and are more aesthetically pleasing. This prototypes require longer time to develop and are therefore used further along in the design process. [37].

3.4.2.1 Throwaway prototyping

This method is a way to creating a prototype to demonstrate the feasibility of a new concept. This is especially helpful when resources are limited, and it allows us to use languages and tools that may have limitations. The most obvious disadvantage of creating a throw-away prototype is that the time and resources spent on building it will not directly contribute to the final product [40].

3.4.2.2 Digital prototypes

Digital prototypes are forms of prototypes that are interactive and animated. A digital prototype shows a more accurate representation of the final design and how the user interacts with it [37]. Digital prototypes are easier and faster to test and they contain higher levels of visual design and content [41].

3.5 Test

In the *Test* phase, the prototypes are evaluated. The outcome from the tests will give insights about improvements for further iterations [24].

3.5.1 PMI

PMI stands for Plus, Minus, and Interesting and is a concept evaluation method where the designer evaluates which aspect of the concept should be worked on further. All the positive and negative aspects of each concept are listed in a table, as well as the features which are interesting to develop more. Based on this list, decisions can be made about the elimination, modification, and further development of each concept. [46]

3.5.2 Pugh Matrix

Pugh matrix is an evaluation method to select one of several alternatives by using criteria scoring [47]. The designer identifies relevant user criteria or requirements and then develops weights for each of these requirements. One of the concept alternatives is then used as a baseline for the current state, and the remaining alternatives are evaluated against the baseline. They are graded according to each requirement as positive, negative or equal. In the next iteration, a new concept is set as the baseline, and the best elements of each alternative are combined for an optimal solution.

3.5.3 Prioritization matrix

A prioritization matrix is a tool to evaluate information based on objective, relevant criteria instead of subjective opinions [48]. The tool help teams to prioritize tasks or goals and to identify that the most important items are given priority.

3.5.4 Controlled user testing

Controlled user testing is a way to evaluate the concept in controlled conditions, e.g. a controlled laboratory environment, and let representative users perform a series of tasks with it while the researcher observes [49]. The goal with this evaluating method is to gather data about the users performance and thoughts while using the concept. If further information is needed, the researcher can ask questions while testing. The main benefit of controlled user testing is that the concept will be tested in an environment which is similar to the “real” context. This method requires careful planning and pilot testing.

3.5.5 A/B Testing

A/B Testing is a method where two different versions of a design is tested [28]. This method enables the designer to measure *which* one of the versions presented the best results. However, the method will not give the answer of *why* one of the versions was preferred. In order to generate a deeper understanding of the outcome from the A/B Testing, it can be paired with a method that provides more qualitative data.

3.5.6 Satisfaction questionnaires

In a user test where participants interacts with a designed prototype, Satisfaction questionnaires can be used to understand the users' experience [49]. One example of a questionnaire is SUMI, which provides information about perceived efficiency, likeability, control, learnability and helpfulness [50].

3.5.7 Thinking aloud

Thinking aloud is a method that involves verbalizing one's thoughts and actions while interacting with a product [51]. In this technique, participants are asked to express their thoughts and concerns aloud as they perform a set of predetermined tasks. The goal of this method is to understand how users approach a task, the difficulties they might have, and the thought process they go through while using and interacting with the product. It is a valuable tool in evaluating the usability of a product and identifying areas of improvement. By using this technique, it is possible to obtain valuable insights into users' behaviors, thought processes, and pain points, which can help improve the design and usability of a product.

3.5.8 Expert review

Expert review is a method to find usability problems and bugs in the design and implementation, which can be done in early project stages [52]. This method is both effective and cost-efficient, since the expert is well known about the user's perspective. However, it is important to remember that this method does not include any end users, and some problem might only be encountered with end users involvement [53].

3.6 Digital tools

In this step, the tools used in this project are described. This includes both tools for organisations, making illustrations and programming.

3.6.1 Figma

Figma is a free online web application for interface design [42]. It allows for real-time collaboration and focuses on user interface and user experience design. The program is often used for creating interactive mock-ups and prototypes, as well as

for being a helpful tool in the ideation phase. Figma is an effective tool for designers and teams to work together in the design process.

3.6.2 Unity

Unity is a cross-platform game engine and development tool used to create video games, virtual reality experiences, and other interactive content [43]. The platform lets the user model game elements in both 2D and 3D. The game logic can then be implemented either by visual scripting or writing code in C#.

3.6.3 Miro

Miro is a collaborative tool for organizing ideas and data. The main feature is a digital whiteboard for collaboration where users can organize and structure projects [44].

3.6.4 Itch.io

Itch.io is a website that allows users to distribute games online. The games can either be uploaded as downloadable files or played directly in the browser. [45]

4

Planning

The project begins with a literature review for gathering data and providing an academic background about interactive exhibitions and informal learning. Further, the project contains a pre-study and analysis phase, where the focus is to understand the context and the users' experiences. The last phase is the development process, which is divided into three iterations. Miro will be used to organize documents throughout the project. An overview of the time plan can be seen in the Gantt scheme in Figure 4.1.

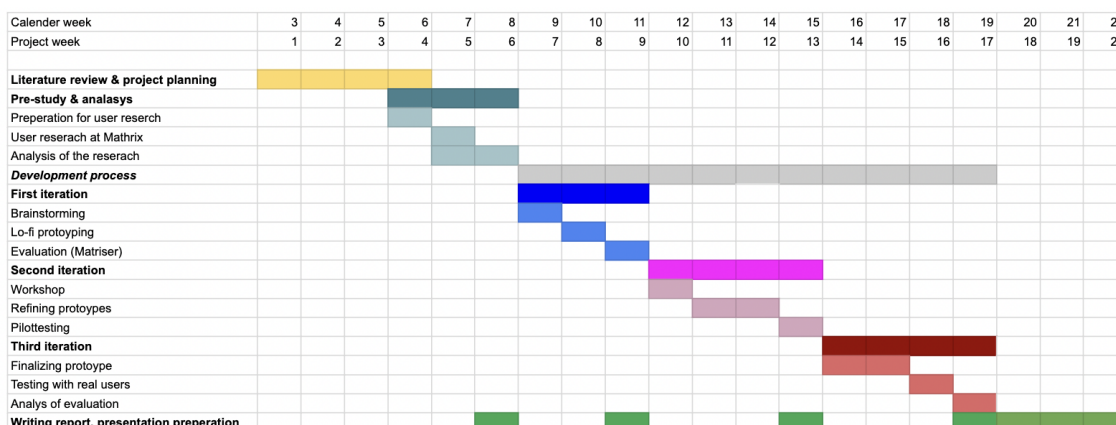


Figure 4.1: An overview of the Gantt-scheme

4.1 Literature review and project planning

The first phase contains a literature review to get an overview of the subject, planning, and structuring of the project. The findings in the literature review contribute to identifying relevant topics and stating the scope and problem statements of the project. Previous scientific literature work is found through the research database Google Scholar and the search words are in the theme of interaction design, informal learning, and mathematics.

4.2 Pre-study and analysis

In the pre-study phase, visits to Mathrix at Universeum are made to get valuable insights about the context and the target group. The visits provide an understanding

of the environment, how the exhibitions are designed, and insights into how an introductory interactive game can contribute to the visitors' experience. In the pre-study, observations and interviews are performed. Observations will be the main focus since it lets us recognize visitors' behavioral patterns and draw inspiration from their reactions to the exhibit. Short interviews will be carried out if some visitors show an interesting behavior that we want to explore further. We also plan to set up a station at the entrance where visitors are asked to write their expectations on a piece of paper before entering the exhibition. In this stage, UX curves could have been a relevant method to use to track the visitor's emotions and experience during the visit. However, we argue that the findings from the observations, interviews, and the question about expectations would gather more sufficient data and that the UX curves would be redundant. The findings from the pre-study will be analyzed through affinity diagramming and be the base for the development process.

4.3 Development process

This project will contain three iterations, the first planned over three weeks and the remaining two planned over four weeks. The iterative process gives room for multiple tests and possibilities to refine the prototype.

4.3.1 First iteration

The first iteration is planned to generate ideas based on the insights found in the pre-study. Personas will be constructed based on the findings, since a persona provides a comprehensive understanding of the user's behavior and actions within the context. However, we contend that a scenario will not be constructed, since the scenario method does not do justice to the various way the visitors can experience the exhibition. For generating a broad range of ideas, a brainstorming session will be conducted as well as a morphological matrix. An MDA framework will be used to better understand what concrete mechanics can be used to achieve the desired aesthetics that can influence the users' expectations. In this first iteration, low-fidelity prototypes will be constructed to further develop and visualize the ideas. These prototypes will be sketched and made out of paper, since that allow us to easy shape the concepts. Paper prototypes are also useful in this stage since ideas that do not work quickly can be eliminated. In the end of this phase, the ideas will be evaluated using the established frameworks PMI and Pugh's-matrix. The methods provides us with an overview of both the positive and negative aspects of the elements, as well as insights of what aspect can be further developed.

4.3.2 Second iteration

The second iteration is planned to refine the ideas from the first iteration. The plan is to arrange a co-creation workshop with the user group to generate new ideas. The reason behind holding a co-creation workshop as opposed to continuing brainstorming on our own is that we want to involve the target group in the process. In this stage of the process, feedback from the target group will be valuable as we

can test our initial ideas at the same time as we take inspiration for refining the concept. The data gathered from the workshop will be analyzed using an affinity diagram. The findings, as well as the low-fidelity prototypes from the first iteration, will then be taken into account while creating a mid-fidelity prototype. The mid-fidelity prototype will be digital and made in either Figma or Unity, depending on the solution. The idea is that the final prototype will be made in Unity but if its possible to make a mid-fidelity prototype in Figma, we aim to do so. Since we both have greater knowledge in Figma, prototyping in this software will help us save time and make our work more efficient. The prototype will then be evaluated in a controlled user test. We find a controlled user test fitting in this stage of the process as it lets us test the features of our game and make changes before testing it with the actual user group. It will also prepare us for the final user testing.

4.3.3 Third iteration

The findings from the controlled user test will then be used as a foundation for making a final high-fidelity prototype in Unity. This prototype will then be tested at Mathrix. A final evaluation with end users will be conducted. The test will begin with letting the participants play test the games in the classroom a few days before their visits at Mathrix. After the play test, the participants will answer a satisfaction questionnaires where they can express their thoughts about their experience. During their visit at Mathrix, observations will be held to recognize the participants behaviour. The final evaluation will end with the participants answering a questionnaire with open-text questions regarding their experience in Mathrix. The results from the open questions will be analyzed using an affinity diagram. A decision was made to not conduct an A/B test since the research question benefits from having qualitative rather than quantitative answers. It also requires more participants to be able to get statistically significant responses from an A/B test, which will not be achievable within the time frame.

5

Process

This chapter describes how the project was carried out. First, a context analysis was made to understand the environment and get inspiration for the development of the product. The rest of the process is divided into three iterations, all containing ideation, prototyping, and testing but with varied methods for each iteration.

5.1 Context analysis

The first stage in context analysis was a literature review with the goal of exploring relevant theory. Then an interview with one of the developers of Mathrix, Håkan Sigurdsson was conducted. The interview was semi-structured and followed a template with questions (see Appendix A). The purpose of the interview was to gain information regarding the thought process behind Mathrix, their goals for the exhibition and the intended target group. The inspiration behind the exhibition pieces was discussed, as well as what previous knowledge in mathematics is expected from the visitors. Further discussions were about what they thought about an introductory element before entering Mathrix, and if they have previously had something similar at another exhibition.

The second stage in gathering data an understanding the context was observations. The observations were held in Mathrix at Universeum during one week. These observations were made during sports holiday in Gothenburg, since Universeum has many visitors that week. For the observations, we used two different approaches. First, we were focusing on one piece at the time, where we looked into how much time they spent with that piece and how they interacted with it. We also followed groups of people from their entry to the time they left, to see how they went through the exhibition and for how long they stayed.

The same week we set up a station at the entrance to Mathrix, where we let the visitors anonymously write down their expectations for the visit on a sticky note. The week after, a similar station was set up, where we instead asked the visitors what piece they liked the most and why. Appendix A shows a picture of how the station was set up.

The answer from the interview with Håkan, the findings from the observations and the answers from the visitors were compiled on sticky notes in Miro. All the notes was then discussed and analysed to see patterns (see Appendix A). A summary of

the most important findings was compiled in a list which can be seen below.

The game might benefit from:

- align with Mathrix's goal of displaying that mathematics is used in everyday life
- being digital
- including different levels
- having a clear start and end
- including a competitive element, either against yourself or others
- preventing the user from being disturbed by others
- including everyday tasks
- open up for discussions
- providing a toolbox of mathematical tips and tricks
- involving yourself
- avoid grading the users for their skills in mathematics
- being understandable without an explanatory text

5.2 First iteration

The first iteration was about coming up with ideas based on the findings from the pre-study. This iteration includes a trend analysis, an initial brainstorming session, low-fidelity prototypes to concrete and visualize the ideas, and evaluation matrices to get insights about which concepts to further develop. In this iteration, we also began to work in Unity, where we started off with throwaway prototyping and then continued with mid-fidelity prototyping. The following section describes the process as well as the methods used. This iteration concludes with a presentation of three digital game prototypes: "Maze", "Number sequence" and "Bingo". In contrast to the planning phase, personas were not created in this iteration. They were instead created in the next phase since we wanted more data to use as a foundation for developing the personas. The same applies to the creation of MDA-frameworks. These were also made in the second iteration when we had more developed prototypes. Figma was not used for prototyping as intended. We decided to do all mid-fidelity prototypes in Unity instead. The reasoning was that a Figma prototype would be too dissimilar to a final prototype and therefore not do justice to the idea.

5.2.1 Trend analysis

We began this iteration with a trend analysis (See appendix B). We examined various websites for other games that involved mathematics and analyzed their mechanics, dynamics, and aesthetics as well as how the math was incorporated into the game.

We observed that a significant proportion of these games consisted of a limited number of mechanics, typically involving questions related to mathematics and a set of answer choices. Players would then select the correct answer, which does not differ

significantly in terms of interaction from answering questions in a mathematics textbook. We identified three categories that distinguished these games from each other.

The first category is games where the primary distinction between the game and a textbook is that the answer choices were visualized in various ways to make the game more engaging. One example of such a game featured fish as the answer choices, and when the player selected the correct answer, a fishing rod was thrown into the water and the fish was caught. Selecting the wrong answer instead caused the fish to swim away.

The next category of games involved math but as a completely separate element. Math questions were answered at the beginning of each round and then a completely different game was presented and the results from the math questions did not affect any parameters of the following game. An example of this was a mini-golf game where the player had to solve five equations before each hole.

The third category is games that were initiated by math questions but where answering right gave you an advantage in the actual game. An example of this was a game where the player was supposed to launch a lama as far as possible and the number of right answers determined the power of the launch.

We concluded that none of these games fulfilled Universeum's desire to place mathematics within a different context than a mathematics textbook, as their overall format too closely resembled a standard mathematical exercise. We had in mind to avoid this type of game while brainstorming later on.

Another common feature was math used as an obstacle. We found various endless runner versions with obstacles where the player had to collide with the right answer to keep running. We also saw this element in other contexts. In one example, the player navigated through a maze and picked up coins. In order to pick up a coin the player first had to get to the coin and then a separate window with a math question appeared which the player had to get right. The use of math as an obstacle was also something we wanted to avoid and had in mind later on while brainstorming.

We also identified elements that we appreciated and brought them with us to the brainstorming session. For instance, we found that games that offered exploratory features generally succeeded in presenting mathematics as a tool rather than an obstacle, which is a goal we aspire to achieve. An example of such a game is Mathbreakers, in which the player employs mathematics to navigate an open-world environment and explore and solve problems.

5.2.2 Initial brainstorming

Based on the findings from the pre-study and from the trend analysis, a brainstorming session was conducted. Before the brainstorming, in a meeting with our supervisor it was concluded that the best results will be obtained if the game is dig-

ital and can be played on a computer. This is mainly because the users should be able to create expectations for the exhibition a couple days before the visit. Another reason is due to the limited space at the entrance of Mathrix, which was found from the observations and the interview with Håkan.

This session resulted in a various range of computer games with different game mechanics, features and mathematical learning methods. After discussing the ideas, another brainstorming session was conducted in order to generate additional ideas. Some of the ideas were similar to each other and after the session, a short analysis session were held to gather similar concepts ideas into different themes. In this stage, a decision was made to not use Morphological matrix unlike how it was schedule in the planning phase, since no specific sub-problems had been identified yet. The working name for the various ideas was as follows: *Music*, *Maze*, *Roll-a-ball*, *Bingo*, *Fill in blank spaces*, *Ping pong*, *Walk around in Mathrix*, *Physics ball*, *Choose life*, *Double trouble*, *Number sequence*, *Monty hall*, *Arrange festival* and *Scenario in everyday life*. A photo of the grouping of ideas can be seen in the figure below (see Figure 5.1).

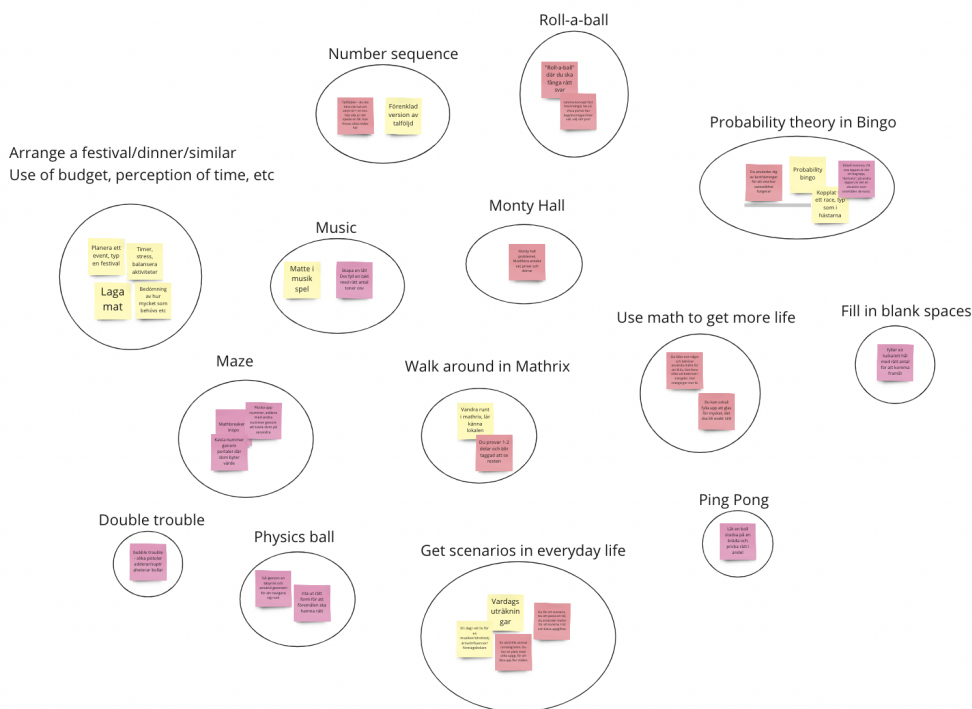


Figure 5.1: The ideas made from the brainstorming sessions grouped together with working names

5.2.3 Low-fidelity prototyping

The first ideas made in the brainstorming session were written down on sticky notes and clustered together in themes. In order to visualize these ideas, low fidelity

prototyping in form of sketching were performed. All ideas were sketched to explain the functionality, game mechanics and the mathematical learning methods. This was made to unify our perception of the ideas. (See Appendix B).

5.2.4 Evaluation of initial concepts

At this stage, we had numerous distinct ideas. A modified version of prioritization matrix with one axis was performed where we evaluated the feasibility of the different ideas based on our previous knowledge in Unity as well as the time schedule of the project (see Appendix B). After the evaluation, some of the ideas were discarded, and we were left with 10 proposed concepts. These remaining 10 concepts were then further evaluated in a Pugh-matrix. The user criteria was decided based on the findings from the interview and observations. All the user criteria were weighted according to a scale of 1-5, where 5 is most important. The Pugh-matrix was performed three times in total. After the first performed matrix, where the concept "Music" acted as reference (see Figure 5.2), none of the concepts were eliminated. Instead, another matrix was carried out where the concept "Maze" acted as reference before decisions were made (see Figure 5.3). After Pugh Matrix 2 was performed, four concepts were eliminated, which were ranked low in both iterations of the method. These four concepts was "Music", "Walk around in Mathrix", "Fill in the blank spaces" and "Ping pong". Unlike the planning phase, a PMI was not performed in this stage. We realized that the Pugh-matrix was a more concrete way of identify positive, negative and interesting aspects when the concepts was compared against each other.

Chalmers												
Pughmatrix (Relativ beslutsmatrix) för												
Utfärdare:										Skapad: 2023-03-03		
										Modifierad: yyyyyy		
Kriterier	Viktning	Alternativ										
		Musiken	Fysikbollen	Vandra i Mathrix	Bingo	Labyrint	Välj liv	Roll a ball	Fyll i hål	Täffögd	Pingis	
Koppling till Utställningen	4	R	-	Plus	0	-	-	-	-	-	-	-
Matematisk svårighetsgrad i nivå med målgruppen och dess kompetenser	3	E	Plus	-	-	Plus	0	0	Plus	Plus	0	
The game is understandable without instructions	1	F	-	plus	-	-	-	plus	-	-	-	
Intriguing mechanics	4	E	plus	0	Plus	0	plus	plus	0	0	plus	
Encourages progress	3	R	plus	0	0	plus	plus	plus	plus	plus	plus	
Encourages discussion	2	E	plus	-	0	plus	plus	-	-	plus	-	
Tydligt start och slut	1	N	plus	0	plus	plus	plus	plus	plus	plus	plus	
Maskerad matte	2	S	-	-	-	-	-	-	-	-	-	
Z+	0	0	13	5	5	9	10	9	7	13	8	
Z 0	0	0	0	0	0	0	0	0	0	0	0	
Z-	0	-7	-7	-7	-6	-7	-7	-8	-9	-3	-9	
Nettovärde	0	6	-2	-1	2	3	-1	-2	10	-1		
Rangerordning	6	2	8	6	7	4	3	5	8	1	7	
Beslut												

Figure 5.2: The first Pugh-matrix

Chalmers												
Pughmatrix (Relativ beslutsmatrix) för												
Utfärdare:										Skapad: 2023-03-06		
										Modifierad: yyyyyy		
Kriterier	Viktning	Alternativ										
		Musiken	Fysikbollen	Vandra i Mathrix	Bingo	Labyrint	Välj liv	Roll a ball	Fyll i hål	Täffögd	Pingis	
Koppling till Utställningen	4	Plus	0	Plus	Plus	R	0	0	0	0	0	
Matematisk svårighetsgrad i nivå med målgruppen och dess kompetenser	3	-	Plus	-	-	E	-	-	0	0	-	
The game is understandable without instructions	1	-	0	Plus	Plus	F	0	Plus	Plus	Plus	-	
Intriguing mechanics	4	-	0	0	0	E	0	-	-	-	Plus	
Encourages progress	3	-	Plus	-	-	R	-	0	0	0	-	
Encourages discussion	2	0	Plus	-	0	E	-	-	0	Plus	-	
Tydligt start och slut	1	-	0	-	0	N	0	0	0	0	0	
Maskerad matte	2	plus	plus	0	0	S	-	0	0	Plus	0	
Z+	6	10	5	5	0	0	1	1	9	4		
Z 0	0	0	0	0	0	0	0	0	0	0		
Z-	-12	0	-9	-6	0	-10	-5	-4	-4	-9		
Nettovärde	-6	10	-4	-1	0	-10	-4	-3	5	-5		
Rangerordning	8	1	6	4	3	9	6	5	2	7		
Rangerordning 1	6	2	8	7	4	9	5	8	1	7		

Figure 5.3: The second Pugh-matrix

After a third iteration of the Pugh Matrix (see Figure 5.4), four concepts remained as those that best met the criteria for the final result. However, due to time limit, we began to focus on 3 of these concept to further develop in Unity. Since the concept "Physics ball" was ranked low in the feasibility matrix, it was de-prioritized for the time being.

Chalmers		Pughmatrix (Relativ beslutsmatrix) för						
Utfördare:	Skapad: 2023-03-06							
	Modifierad: yyyyyy							
Kriterier	Viktning	Fysikbollen	Bingo	Labyrint	Välj liv	Roll a ball	Talföljd	
Koppling till Utställningen	4	0	plus	0	R	0	Plus	
Matematisk svårighetsgrad i nivå med målgruppen och dess kompetenser	3	Plus	0	Plus	E	0	Plus	
The game is understandable without instructions	1	-	0	-	F	0	Plus	
Intriguing mechanics	4	0	Plus	0	E	0	-	
Encourages progress	3	Plus	-	Plus	R	0	0	
Encourages discussion	2	Plus	0	0	E	-	Plus	
Tydligt start och slut	1	0	0	0	N	0	0	
Maskerad matte	2	Plus	Plus	Plus	S	Plus	0	
Σ+		10	10	8	0	2	10	
Σ 0		0	0	0	0	0	0	
Σ -		-1	-3	-1	0	-2	-4	
Nettovärde		9	7	7	0	0	6	
Rangordning		1	2	2	4	4	3	

Figure 5.4: The third Pugh-matrix

5.2.5 Mid-fidelity prototyping

In this phase of the iteration, we began to develop the three remaining concepts: "Maze", "Number sequence" and "Bingo" in Unity. To increase our knowledge in the software, we began to perform the method "throwaway prototyping" where we browsed for tutorial in the field of our ideas. We then created mid-fidelity prototypes of the three ideas. These concepts have the mathematical learning methods and the basic game functionality. However, these prototypes do not have the correct aesthetic style, and more advanced game functionality will be developed for the final prototype. A short explanation of our three mid-fidelity prototypes are described below.

5.2.5.1 Maze

In this concept, the user controls a player and walks around in a maze. The maze contains locked doors that have numbers on them, and to get through these the user needs to walk around the maze to find the correct mathematical operations (see Figure 5.5). The player begins with a player number which changes depending on which mathematical operation he is doing. For example, if the player wears number "4", he must find "+2" to get through the door that has the number "6". The task becomes more difficult the further into the labyrinth you get.



Figure 5.5: The first version of the concept "Maze"

The very first version of "Maze" only included addition. Until the end of the first iteration, subtraction, division, multiplication and square root was added (see Figure 5.6). The maze's layout was also changed and the numbers of doors and pickups were increased so that the prototype had a playable level. When division and square root was added, we discovered that we had to limit the player number to being an integer as having decimal numbers made the game too confusing and complicated. Finally, the visuals of the game were changed, mainly the numbers were put at separate elements hovering over the collectables and doors instead of being mapped onto the 3D objects. This made the numbers easier to see and the game ready for player testing.



Figure 5.6: The second version of the concept "Maze"

5.2.5.2 Number sequence

This concept is inspired by the piece at Mathrix called "Sifferjakten". From the observations, we saw that many visitors explored that piece, and many of these visitors performed multiple levels. In our prototype, the user controls a ball and must use it to find all the correct numbers in a selected number sequence. Like the piece in the exhibition, the user can choose which type of number sequence they

want to do. The game runs on time, and when a correct number is selected it turns green and when all numbers are marked the time stops. If an incorrect number is selected, it turns red and the user will receive a time extension.

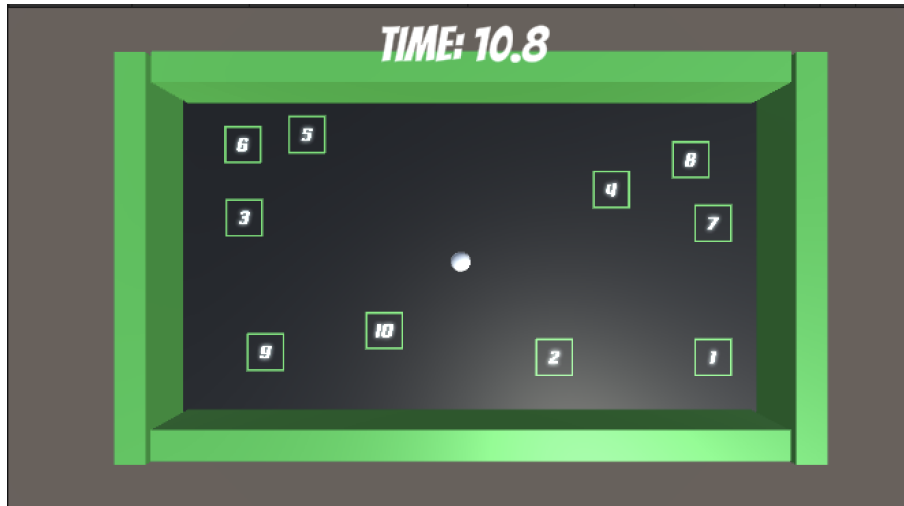


Figure 5.7: The first version of the concept "Number sequence"

5.2.5.3 Bingo

This concept is inspired by the piece "Uppskatta värden" at Mathrix. The user is asked questions about quantity theory, and must connect the correct percentage with the correct fraction. The game is placed on a bingo chart and the goal is to answer correctly to get 5-in-a-row. When a correct tile is marked it becomes green.

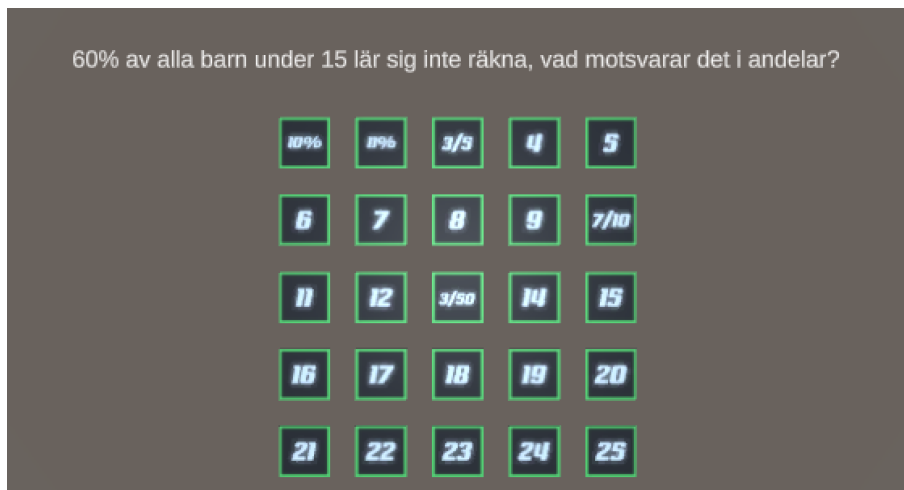


Figure 5.8: The first version of the concept "Bingo"

5.3 Second iteration

The second iteration consisted of testing and development of the three prototypes made in the first iteration. This iteration includes an expert review, a feedback

session, an MDA-framework, a workshop with the target group, personas, refining of the concepts, and a controlled user test for evaluation of the concepts. One of the three prototypes created during the first iteration was eliminated during this iteration. Insights from the final part of this iteration, a controlled user test, resulted in five main categories. These insights feed into the third and final iteration of this work. Unlike the planning phase, the workshop with the target group was not a co-creation workshop including a brainstorming session. The structure of the workshop was instead that we observed when a class performed tasks in Mathrix and qualitative questions was asked at the end of the session.

5.3.1 Expert review

In the beginning of the second iteration, we conducted an expert review to assess the game functionality and the mathematics learning methods in the three prototypes. The expert review was done by Lena Pareto, professor in digitization, IT, and learning, with a focus on promoting children's and young people's learning in technology, science, and mathematics. The expert review began with a short explanation of the process, the target group, and the game's purpose. The expert then played the games to spot bugs and performed thinking aloud while playing. She then recommended changes for improving the prototypes. After the expert review, all feedback was transcribed on sticky notes (see Appendix C). The key takeaways for further development are summarized and listed below:

- Add more competitive elements in "Bingo"
- Adjust the control mechanism of the player in "Maze" and "Number sequence"
- Let the player backtrack to the last move in "Maze"
- Add more sound and visual effects in all games

5.3.2 Feedback session

Halfway through the thesis, a feedback session took place. We discussed the thesis and our game ideas with our supervisor, two other students and their supervisor. The two major takeaways from this session were that "Bingo" needed a lot more work to compare to the other ideas and that "Maze" would benefit from a stronger connection to the exhibition. Therefore, the idea of building the maze so it mimics the exhibition's floor plan got introduced.

The expert review and the feedback session both resulted in the insight that "Bingo" needed development. Mainly, the way math was incorporated into the game was too similar to a standard textbook. Also, the game elements were not as developed and the game would need a lot more work and maybe even a fundamental change in its concept to feel like a game and not just a glorified textbook. Therefore, with regard to the time plan, we decided to stop the development of "Bingo" and focus on the other two games.

5.3.3 MDA-framework

In this stage of the process, we developed an MDA-framework for each of our two prototypes, "Maze" and "Number Sequence" (see Appendix C). The framework is mobile and this is an initial version that changed throughout the development of the prototypes.

5.3.4 Workshop and analysis

At this stage in the process, self-guided tasks (see Appendix C) were tested for Mathrix, Catharina Djurelind conducted a test where two eighth-grade classes visited Mathrix separately with a teacher. The students were divided into groups and performed the tasks one card at a time for one hour. We participated in the test by observing the students and asking questions. From this workshop, we had three major takeaways

- Some visitors expressed a desire to have gained an understanding of certain concepts used in the installations such as Voronoi, Fibonacci sequence, and investment that they did not recognize.
- When some individuals in a group were familiar with Concepts beforehand, it piqued the interest of others in the group to learn more about them.
- Visitors sometimes had difficulty finding their way around the exhibition.

The two first insights combined made us develop a hypothesis that introducing a concept, such as the Fibonacci sequence, in our game would lead to recognition and potentially a larger engagement with that part of the exhibition.

The fact that visitors had difficulty navigating the installation was further motivation for reintroducing the idea of building the maze so it mimics the exhibition's floor plan. We developed a hypothesis that walking around virtually in a room that mimics the exhibition would decrease navigating difficulties in the exhibition.

5.3.5 Further development of the games

Throughout this iteration, further development was made over time. Various changes and improvements were made to all three games but mainly to "Maze" and "Number sequence" since the development of "Bingo" stopped halfway through this iteration.

5.3.5.1 Bingo

Some changes were made to bingo before the concept got eliminated due to the other ones needing less work and therefore they were prioritized. However, before this, feedback from the expert review made us reduce the number of bingo tiles to 3x3 instead of 5x5 to make the rounds shorter and less boring. However, we kept all 25 questions and added a button saying "Svaret finns ej" that the player should press if the correct answers does not match with any of the bingo tiles. A problem with the initial prototype was that the player could just randomly press every tile until they got it right. This change was the first step of fixing this as the player could

potentially skip a question that they actually could answer. However, the issue still remained as the player could press all tiles before pressing the "Svaret finns ej"-button to make sure they would not accidentally skip an answer. Therefore, this would have required further elements as a timer or a tracker of the number of false answers to give the player a consequence for just pressing every button at random.

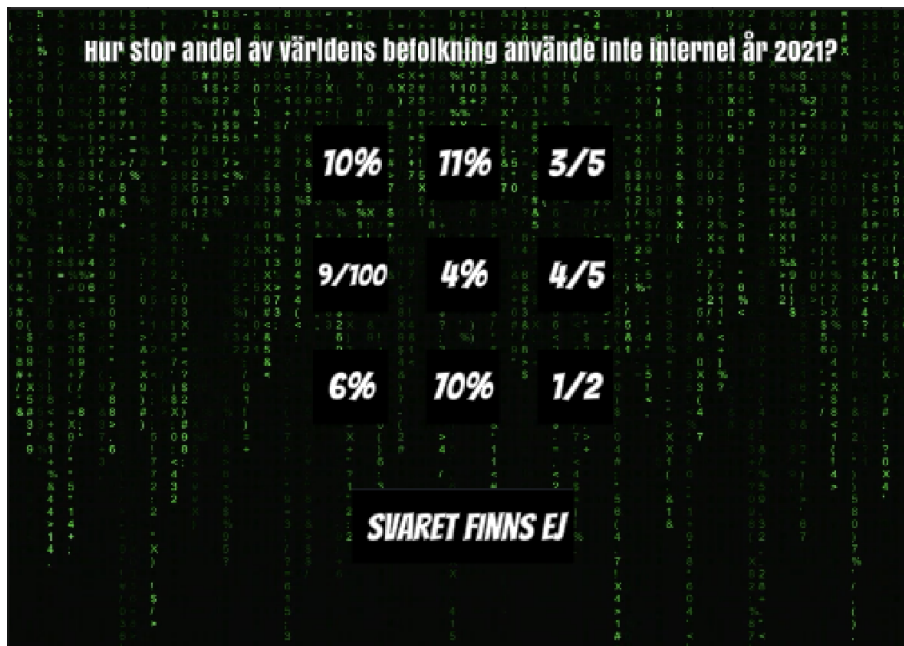


Figure 5.9: The second version of the concept "Bingo"

5.3.5.2 Maze

During the second iteration, a lot of changes were made to "Maze". The first major change made was a reverse button to redo movements. If the player picked up the collectibles in the wrong order, they could get stuck. Therefore we added the possibility to go back. We decided to make each door a checkpoint so that when the player pressed the reverse button, the player position and player number go back to what it was when they passed through the latest door. All collectables needed to pass through the next door also re-spawned so the player can get through to the next step. Secondly, the map was rebuilt to mimic the floor plan of Mathrix. This change led to a lot of changing regarding the game play. For the map to look like Mathrix, the placement of doors and collectables became more complicated which led to the player having the option to choose between different doors to unlock. This enhanced the game's exploratory feature but at the same time, making the math more complicated to set up. It became harder to decide which checkpoints that should re-spawn for which checkpoint as the player could navigate through the map in different ways. This was a trade off, changing a lot of game elements to make the connection between the game and the exhibition more clear.

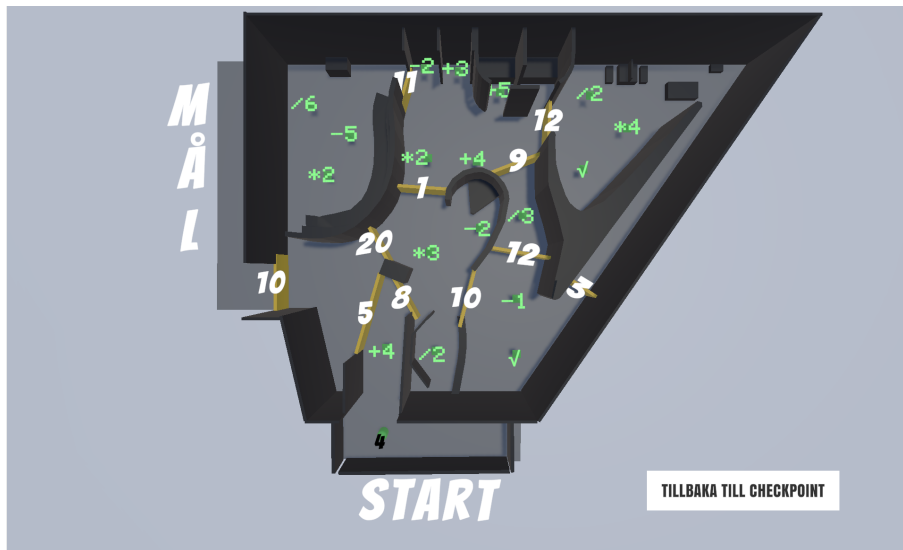


Figure 5.10: The third version of the concept "Maze"

5.3.5.3 Number Sequence

The main change made to "Number Sequence" was changing the player character from a ball to a person to make the steering more smooth. The map was also made bigger so that all the numbers was not visible at the same time which added a memory element to the game. An explanation of the objective was also added to the bottom of the screen. The initial prototype only had one level where the objective was to collect all even numbers in order from one to ten. This new prototype contained three levels: even numbers, the six times table and Fibonacci's number sequence, all ranging from one to thirty.



Figure 5.11: The second version of the concept "Number sequence"

5.3.6 Personas

Two personas were created to represent the intended target group. (see Figure 5.12). These are based on the findings from both the observation from the context analysis and from the workshop with the 8th grade.

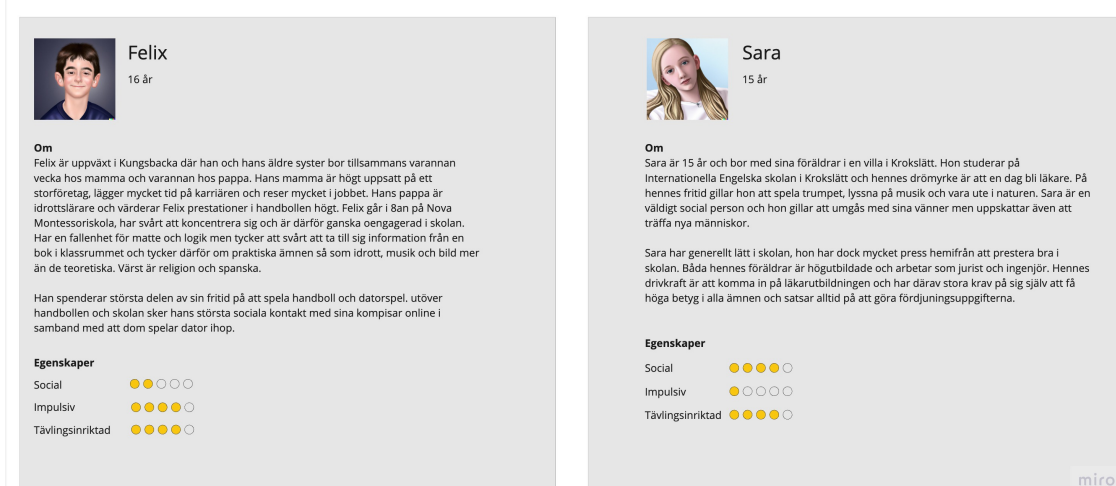


Figure 5.12: A picture of the two personas Felix and Sara

5.3.7 Controlled user testing

A controlled user test was conducted for evaluation of the two game prototypes. Six students aged between 24-34 from Chalmers University of Technology participated in the study. The test was conducted over a period of 2 hours at Universeum. Two of the participants begun with sitting outside Mathrix and playing the digital games, one played "Maze" and one played "Number sequence", while verbally expressing their thoughts through the technique thinking aloud. They were then asked qualitative questions about their experience. Afterwards, they were taken to Mathrix where they received two of the self-guided task. They were asked to perform the task and explore the exhibition further. While these two walked around Mathrix, the same thing started with two new participants. After all six participants played the game and explored the Matrix exhibit, they were individually asked additional qualitative questions about their experience. Performance of the game as well as the interview questions were audio-recorded with the participants' permission. The primary goal of the evaluation was to collect feedback about the understanding and intuitiveness of the game, whether the participants felt that there was any connection between the game and the exhibition and, if so, how this connection expressed itself. The questions about the game and the exhibition can be seen in Appendix C.

5.3.8 Analysis from controlled user testing

The interviews were transcribed together with notes from the thinking aloud. An affinity diagram was made of the data (see Appendix C). Here follow the insights

from the controlled user test:

The connection between the game and the exhibition

In the controlled user test, a difference was observed in how the participants recognized the connection between the game and the exhibition, which was categorized into conceptual and distinct recognition. The distinct perspective on the connection was demonstrated by participants who had played "Number sequence". However, in this group, both positive and negative outcomes were observed from the recognition between the game and the exhibition. The positive outcomes were related to the enjoyment attending the "Sifferjakten" piece at the exhibition, which has the same theme as the game, and the improvement in understanding the Fibonacci number sequence. The negative outcomes were related to the fact that some participants did not pass the Fibonacci number sequence level in the game because it was too difficult which instead resulted in a conflicting feeling towards "Sifferjakten" and the Fibonacci sequence. The conceptual recognition was more related to "Maze". The participants expressed a correlation between the exhibition and "Maze" in the sense that they both presented math in an amusing way. The connection of walking around virtually in a room that mimics the exhibition in the game was not discovered during the controlled user test.

Quantifiable outcome

One insight from the evaluation test was that there was some uncertainty from the participants regarding quantifiable outcome, mainly in "Maze". Some quotes indicated optimism about the opportunity to explore, try and start over if things went wrong. However, there were several participants who expressed a concern about making the wrong moves and getting stuck. Since "Maze" had no quantifiable outcome, the participant began to quantify their experience themselves and create their own goals of how to win the game. This was done in three different ways: completing "Maze" in the shortest time, passing through the fewest doors or running the maze with the least number of resets. These were not goals that were initially established but the participants created them throughout the course of the game. As a result, the participants began to feel a sense of insufficiency about not meeting these self-imposed objectives. In "Number sequence" a timer is initiated when the game starts, which is a clear quantitative result.

Degree of difficulty

Expressions regarding degree of difficulty were related to "Maze" being difficult enough in its current state, and participants not wanting to play more levels if the math in the game had been made more difficult. One possible takeaway from this is to divide "Maze" into multiple levels, having the levels start at an easier difficulty level and then gradually increasing in difficulty.

Negative consequences of memorizing

Another insight that was found was that there were some negative consequences of memorizing. The participants expressed a concern about remembering where the numbers were placed in "Number sequence", and this confusion became a frustration factor. One insights about this is that you might need to play multiple times to actually achieve gratification from memorizing.

Additional insights

Other takeaways from the controlled user test that were found were that some of the previous ideas and choices made in the game were confirmed by the participants as they played. There were also some feedback of specific ways to improve the games and enhance the overall experience. Further insights from the evaluation revealed that the participants had differing perspectives on the purpose of the game. Some viewed it primarily as a tool to learn mathematics, while others saw exploration as the main focus of the game.

5.4 Third iteration

The third iteration was the final one for this project. This iteration includes some final developments of the games based on the feedback from the previous controlled user test as well as a final evaluation test with the end users. The analyzed insights from the final user test is also presented in the section.

5.4.1 Final development of the digital games

From the previous iteration we got feedback of further development of the games. Some of the feedback pertained to making things clearer. For example, a restart button was added to "Number sequence" as well as an option to read the task before the timer starts. We also added a panel at the bottom of the screen in the same game where the user has a visual representation of all the number and receives information about which numbers are already collected. In "Maze" an instruction of how to play the game was added. As part of the development effort, the interfaces in both games were improved to enhance their aesthetic appeal.

5.4.2 User test with target group

A final evaluation was conducted with one seven-grade class from a secondary school in Gothenburg. This user test was divided in two sessions. The first session was conducted in their classroom, where we asked them to test the two digital games and answer a questionnaire. The other session was conducted at Mathrix, where they performed the self-guided tasks, carried out by Catharina Djurelind, and then answered another questionnaire. Below we present how the two session was carried out in more detail.

In the first session we visited their school and conducted the test in their classroom. We started with a short presentation of the study followed by a quick explanation of the prototypes. The games were uploaded to Itch.io and we let all participants play both games on their computer while we walked around in the classroom to observe and help if they had any questions. When they had played both games, after about 25 minutes, the participants were asked to fill in a questionnaire (See Appendix D)

The second session was carried out in a similar way as the workshop in iteration two. Catharina Djurelind explained the visit in short for the class and the teacher before handing the cards with self guided tasks to the teacher. The teacher then divided the students into groups with 3-4 people in each group and handed each group a card with a task. The students then completed the tasks one by one for about 40 minutes. We observed while the participants completed tasks, focusing on "Sifferjakten" since that installation has the strongest connection to our prototypes. Afterwards, the participants were handed a questionnaire with one qualitative question (See Appendix D).

5.4.3 Analysis of the user test with target group

The qualitative data gathered from the final evaluation was analysed in a affinity diagram (See appendix D). Some of the questions in the first session was structure as a likert scale. The quantitative data can be seen in Appendix D. The quantitative data gave a general indication about how easy the games was to understand and if they was fun to play. The qualitative data from each session was first analysed separately and then discussed as a whole to form insights.

Recognition of mathematical concepts

The question asked in the questionnaire was weather or not the games facilitated the exhibition visit in any way. Among the participants that answered yes, the most common explanation to why, was that they learned about Fibonacci's number sequence which they recognized from the game.

Incomprehension towards some installations

Some participants expressed that some installations were hard to understand and caused confusion. Some just stated that they felt confused and did not know what to do at some of the exhibition pieces while other further stated that the confusion was due to the instructions being hard to understand.

Lack of recognition

Among the participants who did not find the games helpful in facilitating their visit, there were different reasons expressed for why this was the case. Some answers simply said that they did not found math interesting and some said that they did not experience any connection between the games and the exhibition. Some answers

mentioned that the difference in difficulty between the games and the exhibition was too big.

Conceptual recognition

Some participants expressed that they felt a conceptual similarity between "In i labyrinthen" and the exhibition. They stated that the exhibition visit reminded them of "In i labyrinthen" since they felt that the exhibition felt like a maze which they explored and solved problems in.

There were also some participants that expressed that the games facilitated their visit in a more vague way. Some expressed that they used the same mathematical mindset in the games and the exhibition. Other just stated that the game and the exhibition had the same vibe.

Expectations on the exhibition

When asked about their expectations on the exhibition, almost every answer was linked to the following three categories; fun, learning and math. A few answers did not fit into any of these three categories, these participants stated that they expected to play more games at the exhibition.

Degree of difficulty

When asked how the games could be improved, both games received answers regarding the degree of difficulty. First off, several answers suggested that more levels could be added. There was also feedback regarding "In i labyrinthen" that the map could be bigger, more complex and that more arithmetic operations could be added. For "Sifferjakten", some answers suggested that more numbers could be added to the map.

Learning

On the question "What did you like most about the game" a majority of the participants answered that it was a fun way of learning math. Some stated that the context of playing a game on a computer was more satisfying than learning math in a more conventional way, by reading a book.

Self explanatory

There were also a lot of answers on the question about what the participants liked most expressing that the game was easy to understand. Some opinions focused on that the game was easy to play, while others expressed that the instructions were easy to understand.

Type of player character

A lot of answers for "In i labyrinthen" said that the character was hard to control, and some even expressed that they wanted a rigged character, as in "Sifferjakten". There were also many answers for "Sifferjakten" showing appreciated for the rigged character used in the game.

Aesthetic elements

There were a substantial part of the opinions regarding the game that focused on the games aesthetic elements. Some participants expressed that "In i labyrinthen" could improve by incorporating forest-like graphic elements such as bushes, stones and trees.

Additional insights

There were some answers highlighting trial and error as a positive element in both games. In "Sifferjakten" there were some mixed answers related to stress. Some that thought the timer was stressful and others liked it and wanted to include an element where the character was being chased. For "In i labyrinthen" many participants said that puzzeling was an element that they enjoyed about the game.

6

Results

This chapter describes the results of the project, including a description of the games (see Section 6.1 and 6.2) and the considerations found during the project (see Section 6.3). The description of the games includes an explanation of the game play, the MDA-framework connected to the each game and the connection between the game and the exhibition. The aim of these games is to provide school classes with a preparatory activity for a school visit at Mathrix at Universeum. Both games must be played on a computer.

6.1 Sifferjakten

The first game, with the working name "Number sequence" is called "Sifferjakten" and this prototype is based on the piece at Mathrix with the same name.

6.1.1 Game play Number sequence

The game starts with the user getting a menu where he can choose which level he wants to start with (see Figure 6.1). In the menu view, the user can choose between "even numbers", "times table of six" or "Fibonacci sequence".



Figure 6.1: The menu view of "Sifferjakten"

When the user clicks on one of the choices, he ends up on a new page with a pop-up window (see Figure 6.2). The user can read about the task, and choose between either start the game or go back to the menu. When he clicks on the start button, a timer starts and the user can walk around as an avatar using the arrow keys (see Figure 6.3). The goal is to collect the numbers in the correct order, either even numbers, the six times table or the Fibonacci number sequence depending on the chosen level.



Figure 6.2: The view of the pop-up window where the user can read about the task



Figure 6.3: The view of the avatar walking around on the board and collecting the numbers

If the user collect a correct number, it turns green and a sound effect is played indicating that you have selected correctly (see Figure 6.4). If an incorrect number

6. Results

is selected, it turns red for a few seconds, another sound effect is played and the user gets 3 seconds added to their time (see Figure 6.5). The user can also see the selected numbers on a panel at the bottom of the screen. If the player wants to restart a game, he can simply click on the restart button in the upper right corner of the screen. When all numbers are collected in the correct order, the time stops and the screen and the games navigates back to the menu view.



Figure 6.4: The view of collecting a correct number



Figure 6.5: The view of collecting an incorrect number

In Fibonacci sequence level, an information button is added in the top left corner that gives a brief description of the Fibonacci sequence (see Figure 6.6).

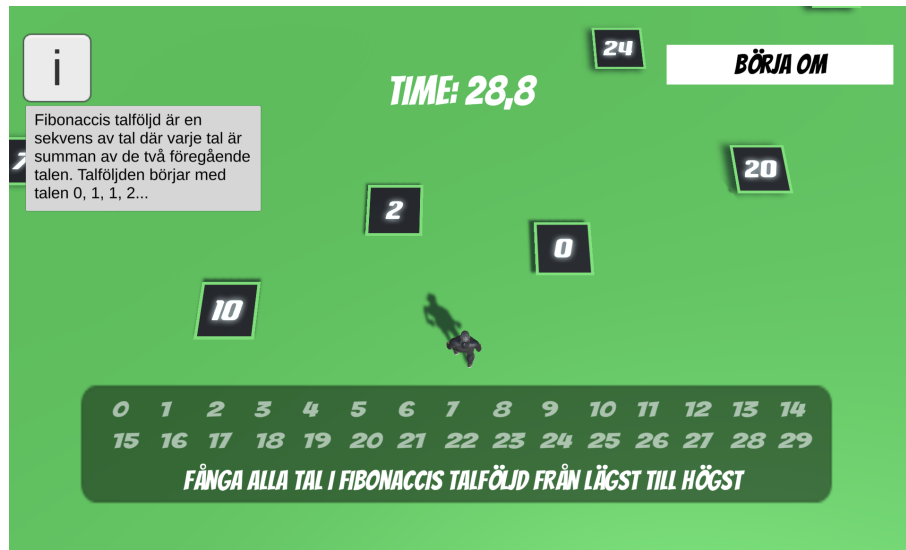


Figure 6.6: The added information button in the Fibonacci sequence

6.1.2 MDA-framweork "Sifferjakten"

The final MDA-framework for "Sifferjakten" (See Appendix D) went through a few changes from the initial state (See Appendix C). The MDA-framework will be explained by stating an aesthetic of the game and then describing what mechanics and dynamics that forms the aesthetic. In this chapter, all mechanics, dynamics and aesthetics will be followed by its first letter of the word in parenthesis for the sake of clarity.

Stress(A)

"Sifferjakten" contains a timer(M) and a leader board(M). These two in combination leads to time pressure(D) which can result in the player feeling stress(A)

Self improvement(A)

The leader board(M) lets the player compare their results which allows for replayability(D). This in combination with the time pressure can result in self improvement(A) as the player always can improve from their previous results.

Engagement (A)

"Sifferjakten" incorporates different levels(M) with different difficulty, this leads to a difficulty increase(D) which in turn leads to progression(D). This in combination with time pressure(D) can result in the feeling of engagement(A).

Frustration (A)

Two staple mechanics in the game are running(M) and collecting(M) as the player

are running around the map, collecting the numbers in the right order. However, all numbers are not visible at all times and you have to explore the map to find them, this adds an element of fog of war(M) to the game. These three mechanics combined results in memorizing(D). Since a player can run by a number that is not the one he is currently looking for, it is beneficial if the player remembers the place of that number for when it is time to collect it. If the player has a hard time memorizing(D) the numbers, that in combination with the time pressure might cause frustration(A)

Gratification (A)

If the player does a good job memorizing(D) the numbers it can result in the feeling of gratification(A) instead, as the player gets rewarded for memorizing(D). Completing the different level and sensing progression(D) can also be a contributing factor to gratification(A).

Relaxation (A)

Since the game is single player(M), it is non-competitive(D) in the sense that the player can not compare himself with other players. This might lead to a feeling of relaxation(A).

6.1.3 Connection between "Sifferjakten" and Mathrix

Since "Sifferjakten" is based on an existing piece at Mathrix, the inclusive mathematics is the same as the one at the exhibition. In this game, the user can practice number sequences which they can perform at the exhibition. However, since the game is not an exact copy of the exhibition piece but a preparatory element, this game has fewer numbers and does not contain the same amount of sequences.

6.2 In i labrynten

The second game, with the working name "Maze" is called "In i labrynten" and compared to "Sifferjakten" this game is more exploratory and allows the user to walk around and explore a way to finish the game.

6.2.1 Game play "In i labrynten"

The user controls a player, an avatar, with the arrow keys and walks around a maze that has the design of the Mathrix exhibit. When opening the game, the user is met with an introductory screen with a start button (see Figure 6.7). The user then navigates to a pop-up window where the task of the game is described (see Figure 6.8). When the game starts, the player begins with a player number which is visible above the avatar (see Figure 6.9). The game contains locked doors and the goal is to get through the doors and out of the maze. Every door has a number on it and in order to unlock the doors, the player number needs to be the same as the number on the door. Around the maze there are various mathematical operations,

and the player number changes depending on which mathematical operation the player enters (see Figure 6.10).

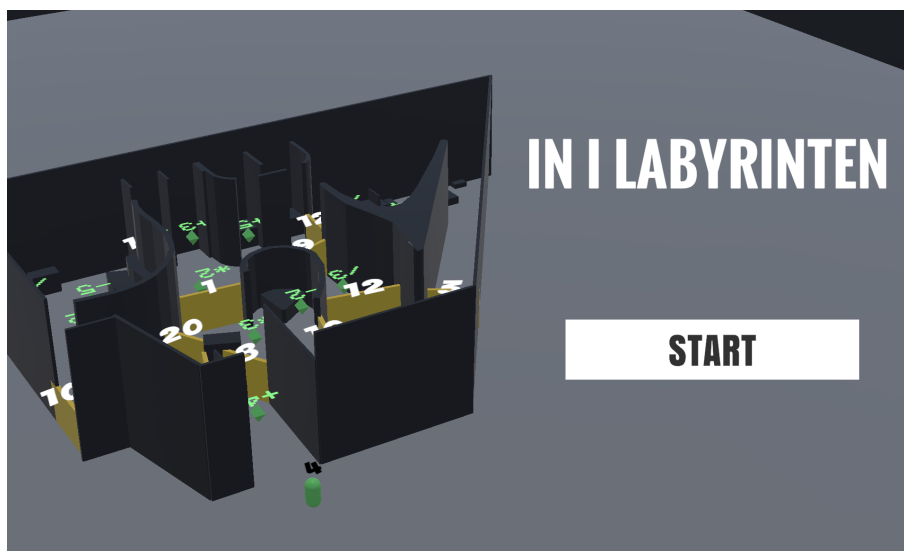


Figure 6.7: The menu view of "In i labyrinten"

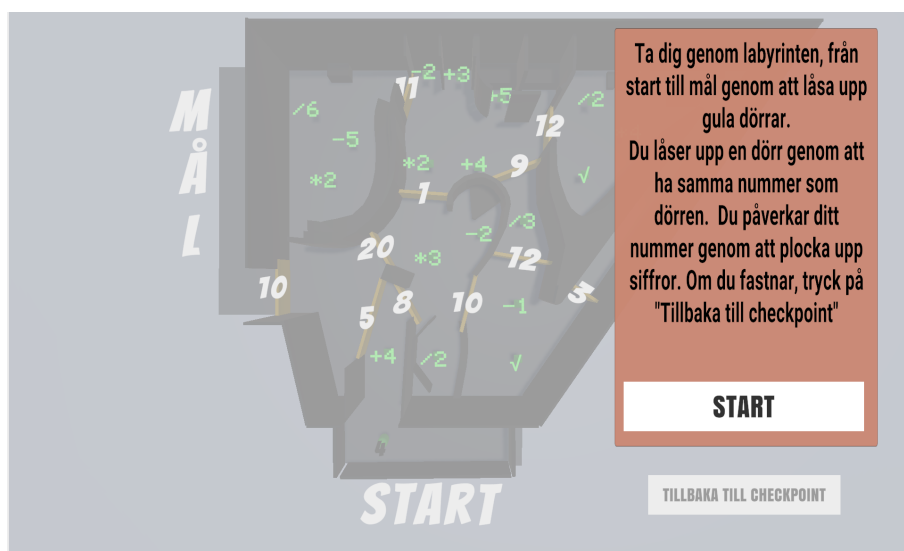


Figure 6.8: The menu view of "In i labyrinten"

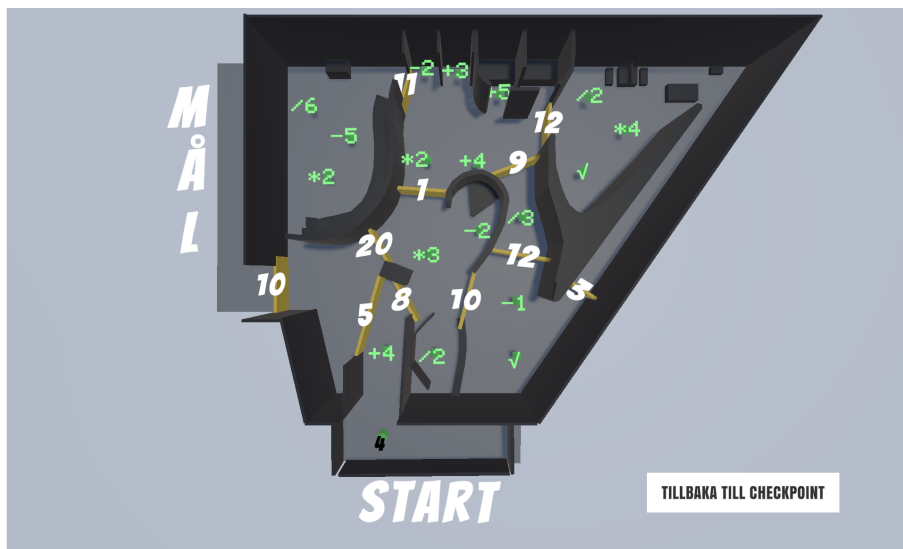


Figure 6.9: The view of the board in "In i labyrinten"

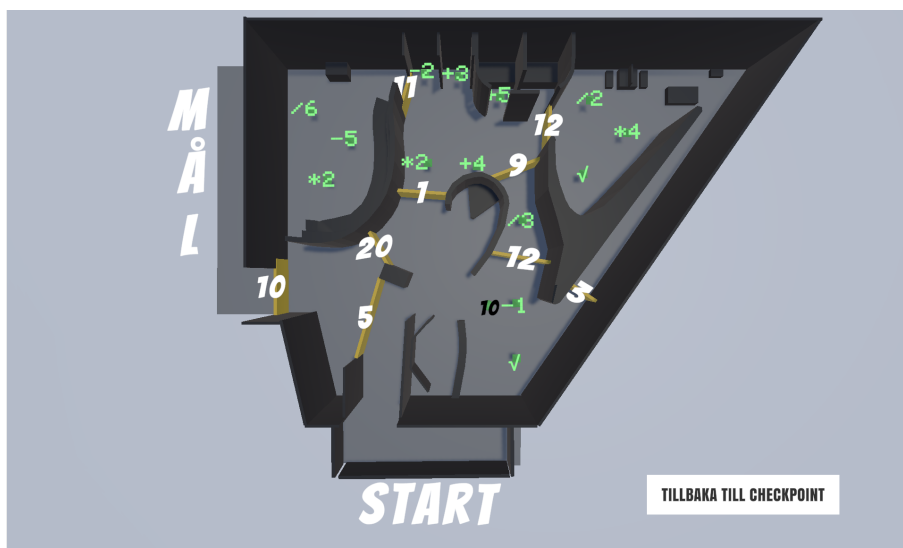


Figure 6.10: The view of how the player number changes when entering different mathematical operations

All doors contains a checkpoint and in the lower right corner, there is a reset button which gives the user the option to restart to the last checkpoint. When the user passes the game, the screen navigates back to the introductory view.

6.2.2 MDA-framework "In i labyrinten"

The final MDA-framework for "In i labyrinten" (See Appendix D) also went through a few changes from the initial state (See Appendix C). The MDA-framework will be explained by stating an aesthetic of the game and then describing what mechanics and dynamics that forms the aesthetic. In this chapter, all mechanics, dynamics and ascetics will be followed by its first letter of the word in parenthesis for the sake

of clarity.

Discovery (A)

The games core is walking(M) around, collecting(M) operations to change the player number to be able to unlock(M) doors. There are several ways to go which accounts for freedom of choice(D). There doors also work as checkpoints(M) and the player is able to rewind(M) to the last checkpoint(M). This accounts for trial and error solutions(D) which in combination with freedom of choice (D) leads to exploration(D) and furthermore discovery(A).

Fullfillment (A)

The collectibles with different operations can be defined as clues(M) which in combination with collecting(M) and unlocking(M) forms puzzle solving(D). The puzzle solving(D) and the trial and error solutions(D) can lead to fulfillment(A) when the player manages to move forward to a new part of the map.

Frustration (A)

Just as puzzle solving(D) and trial and error solutions(D) can lead to fulfillment(A) when the player advances through the map it can also lead to frustration(A) if the player feels stuck in the maze.

Relaxation (A)

Just as "Sifferjakten", "In i Labyrinten" is also single player(M), the player can not comperer himself with other players which makes the game non-competitive(D) and might result in relaxation(A).

6.2.3 Connection between "In i labyrinten" and Mathrix

The layout, rather than the inclusive mathematics, reveals the link between the exhibition and this game. The user walks around a maze that looks like Mathrix from above. In contrast to the previous game, the mathematics in this game complements the exhibition instead of teasing it.

6.3 Key considerations

This section presents key considerations, identified during the process, for developing an introductory interactive game intending to lower the visitors' entry barrier for a mathematics exhibition at a science center.

Connection between game and exhibition

In the workshop with the target group, they expressed a desire to be more prepared with certain mathematical concepts used in the exhibition. Both the controlled user tests and the final test with the target group also showed that "Sifferjakten", that introduced Fibonacci's number sequence, showed an improvement in understanding for that concept. The game was also related to an enjoyment of performing that piece at Mathrix. From the final user test, several participants mention that they found some pieces at Mathrix unclear and difficult to understand. They gave examples of specific pieces, but no one of the participants mention any confusion about the piece "Sifferjakten". A key consideration to take from this, is that if the game includes elements from the exhibit that tease a specific piece with specific mathematical concepts, it might reduce the confusion and frustration of pieces being difficult to understand. The connection between the exhibition and "In i labyrinten", was not as apparent. Users did not recognize that the game's layout was inspired by Mathrix's floor plan and no increased expected enjoyment for the exhibition were shown in the controlled user test among the participants playing that game.

However, it must be taken into account that a direct connection between the game and the exhibition can have negative consequences. Some users in the controlled user test did not pass "Sifferjakten" but found it too difficult. This caused them to have a conflicting feeling towards that piece. It is therefore worth considering the potential negative consequences a concrete connection might bring. If the game fails to introduce a mathematical concept in an understandable way, it might have a negative effect and give the visitor a higher entry barrier instead of a lower one.

To summarize, the most prominent consideration is *to consider in which way the game is connected to exhibition and if there are any distinct elements of recognition.*

Importance of MDA-framework

Our design challenge for the project were *What mechanics, dynamics and aesthetics are important to consider while designing an introductory interactive game for the Mathrix exhibition at Universeum?*. This helped us analyze our own games and keep track of how the changes made to them during the process affected the game play. It also was of great help when comparing "Sifferjakten" and "In i labyrinten" to each other and see what the biggest differences and similarities were.

However, we have discovered that a clear connection between the game and the exhibition is of utmost consideration for providing the possibility to facilitate the visit. Theoretically, a connection can be provided even if the game itself is not entertaining in any way and therefore an MDA-framework was not as central as we initially thought for the purpose of facilitating the visit.

During user tests, participants expressed that the games provided a fun way of learning math, in a similar way as the exhibition, and therefore formed a more vague connection between the two. To achieve this, the game has to be engaging on its own, and then an MDA-framework can help sort out what elements that should

be included. With all this in mind, we state that *it is worth considering the importance of the MDA-framework when developing the game.*

Incorporation of mathematics

Science centers provide informal learning and aims to present subjects in a way that differ from how it is presented in textbooks. From the expert review it was stated that a common mistake when developing games with incorporated math is that the math becomes an obstacle. The trend analysis showed that games that offered exploratory features often succeeded in presenting math as a tool instead of as an obstacle. We also discovered that many games presented math as an element separate from the actual game play where the game paused and the player had to answer a question to proceed playing. Our game "Bingo" got critiqued in the expert review for having too few game elements that hid the mathematical content and presenting the math as questions, making the game too similar to a textbook. From user tests, the participants expressed that our games "Sifferjakten" and "In i labyrinten" resented math in a non-conventional and fun way. With all this in mind *it is important to consider how the mathematical content is incorporated into the game.*

Degree of difficulty

Observations at Mathrix showed that when people passed a task, they often wanted to try a more difficult level. For example, at the piece "Sifferjakten" at Mathrix, people begun with an easier sequence, such as even number, and when they managed to pass it, they wanted to try a more difficult number sequence. This was also confirmed in both the controlled user test and the user test with the target group, where several participants mention a willingness to continue playing if there were more levels with varying degrees of difficulty. The takeaway from this, is that incorporation of levels with varying degrees of mathematical difficulty might engage users to continue playing and keep the game interesting for longer. It might also help the players ease into the more difficult mathematical concepts by first getting introduced to a simpler concept they are familiar with. To summarize, *it is worth considering in which way the game includes levels with varying degrees of difficulty.*

Explicit start and end of the game

Observations at Mathrix showed that users felt a sense of satisfaction upon completing a task. In some cases, visitors showed signs of confusion when they did not understand if they had completed a task at the installation. The controlled user test, participants expressed a feeling of uncertainty regarding the start of "Sifferjakten". When the user selected a level, the timer started at the same time as the task description appeared. This caused some frustration since the game's start was not entirely evident to the user. Similar opinions were expressed regarding the ending of "In i labyrinten". When the player reached the goal, no noticeable feedback was expressed, leaving the user wondering if they completed the game correctly. Additionally, litterateur describe "user experience" as how someone feel about using a

system which includes both a beginning and an end of their interaction (see 2.1.1). The goal is to affect the experience of the science centers' visitors. To summarize, *it is worth considering to provide a distinct communication to player when the game starts and end.*

Understandable without an explanatory text

From our observations and interviews, we identified that people in general do not have the patience to read the explanatory text which can be found next to all pieces in the exhibition. Most people started to interact with the pieces first and if it is perceived as interesting, they may read the text to learn more. Therefore we aimed to include as little explanatory text as possible in our prototypes to make the threshold for playing them as low as possible. This was then confirmed in the user test with the target group. There were several positive answers about the understanding of the games and a lot of the participants expressed that they liked that the games were easy to understand and easy to play. However, some participants in the controlled user test did not understand the mathematical concepts introduced and might have benefited from explanatory text. Therefore, *it is worth considering to what extent explanatory text is used in the game.*

Importance of involving the teacher

Since the interactive game is an introductory part of the exhibition, it is important that the students get to use what they learned in the games at the exhibition. When the students perform the self-guided tasks at Mathrix, it is the teacher who hands out the tasks and who is in charge of the session. It was noted during observations that one teacher asked the students about their task before handing them a new one, while another teacher handed out a new task without asking anything. It was also noted that when students did not get asked about their task, they did not try as hard to complete the next one. If the teacher also is involved in the preparation in the classroom and get a deeper understating into the students' preparations, he or she might be able to optimize the visit for the class. With that said, *it is worth considering the importance of involving the teacher in the introductory game.*

Visual appeal

It was found from the last user test with target group that aesthetic elements and visual appeals of the games are important aspects (see 5.4.3). In this project, most focus has been on game play and the mathematical content of the games, and therefore less time has been chosen to be spent on visual appeal. However, since several participants mention the aesthetics as feedback for improving the games, *it is worth considering the visual appeal of the game.*

Maximize functional prototypes

As an extension of the previous statement, it was observed from the final evaluation

with target group that some feedback from the students was about the functionality of the games. It was acknowledged from before that the steering in the final prototypes was a bit challenging, but a decision was made to prioritize other aspects than spending more time on development. Since there are some functional shortcomings, it is unsurprising that the students mainly find these areas as opportunities for improvement. It may be possible to receive more and valuable feedback regarding the experience and learning of the game, rather than the functionality, if the features in the prototypes are more functional. To summarize, *it is worth considering the functionality of the prototype while performing user tests.*

7

Discussion

In this chapter we are going to discuss some aspects of the project. The topics that are going to be discussed are the results (see Section 7.1), discussion about generalisability and validity (see Section 7.2), thoughts and reflections regarding the process and choice of methods (see Section 7.3), reflections on ethical issues (see Section 7.4) and future work (see Section 7.5).

7.1 Result discussion

This project resulted in several key considerations as an answer for the research question: *What are key considerations for developing an introductory interactive game intending to lower the visitors' entry barrier for a mathematics exhibition at a science center?* Since this project has been using a research through design approach, one part of the result has been two developed digital games which has been used to answer the research question.

Our design challenge was *What mechanics, dynamics and aesthetics are important to consider while designing an introductory interactive game for the Mathrix exhibition at Universeum?*. User testing showed that some participants found both the games and the exhibition to be "fun ways of learning math". To establish this connection, the game must be perceived as fun and engaging while teaching math. In this context it is interesting which mechanics, dynamics and aesthetics are important to consider. However, according to theory (See 2.4) there are many ways to design a game to be perceived as fun. Some dynamics included in our game, for example, puzzeling and trial and error solutions has been mentioned as positive aspects during user studies. This indicates that these elements contribute to enjoyment and could be considered important when designing an introductory game. However, there are many ways of making a game enjoyable and how the MDA-framework should look like depends on the nature of the game. Therefore we find it better to focus on establishing a distinct connection between game and exhibition and then tweaking the MDA-framework to make the game enjoyable from there.

It has been seen that recognizing and distinct connection between an introductory interactive game and the exhibition might have advantages for learning new concepts and enjoyment of the visit. It has also been seen from literature (see 2.3) that repetition is a crucial element for learning. However, even though recognizing elements from the game in the exhibition can contribute to an increased understanding for

new concepts, it is not completely certain that it lowers the thresholds for visiting a mathematical exhibition at a science center. It has been of great value for this project that we had the opportunity to conduct a user test with students from a secondary school. However, in order to gain deeper knowledge that, it is essential to perform more user tests with the target group.

From the final user test, we could identify that the participants had difficulties understanding some of the pieces at Mathrix, but not the one which has a connection to the introductory game. This could be related to their exposure to concepts that are later presented at the exhibition. In order to establish this, it is essential to test digital games that are correlated to other pieces at the exhibition.

The takeaways and insights from the user tests has been based on qualitative feedback. Different patterns in the experience of using the digital games as an introductory part has been identified, but it is important to take into account that this findings are based on qualitative data and has been interpreted.

7.2 Generalisability and validity

Early in this project, a decision was made to make the introductory interactive game digital and playable on a computer. This decision was made based on two aspects. Partly, due to limited space at Universeum and the entrance of Mathrix, there is no natural place where an interactive game can be placed. The game should not be a part of the exhibition as it may be difficult to distinguish it from the remaining pieces in the exhibition. Also, since we are focusing on anticipated user experience, and the aim of this project is to investigate what should be considered to affect the anticipation of an exhibition visit at a science center, the game should be played prior to the visit to influence visitors' expectations. To use the game as an introduction, users should play the game a few days before their visit, rather than at the science center. By making the game digital, visitors can access the game in the teacher's guide and then play the game in school. The arguments for making the game digital are specific for Mathrix and therefore it is difficult to derive general takeaways from this. We argue that the decision to make the game digital is not a key consideration but a design choice based on the context of the exhibition.

Further on, this project has mainly focused on the context of a school class visiting Mathrix with self-guided tasks. Therefore, it is difficult to know whether the answers and insights from the user tests also can be applied to other visits at Mathrix, or if they are too specific for school visits.

Also, both games are connected to Mathrix specifically. "Sifferjakten", by being another version of the installation with the same name and "In i labyrinten" by resembling the exhibitions floor plan. This can be seen as a disadvantage since the games does not work as a general preparatory activity for any math exhibition. However, the clear element of recognition was shown to be the primary cause for facilitating the visit and therefore a more general game might be a less effective for

lowering the entry barriers.

Finally, one interesting takeaway we saw from the controlled user test was that there were some differences in quantifiable outcomes between the two digital games. If the game includes exploratory features, it may be important to consider whether and how the results should be measured. However, this observation was not confirmed in the final user test and nothing showed that the participants were aware of a lack of clarity around measurability. It is difficult to know whether this is due to the structure of the test or not, and therefore this observation was decided to not be a consideration.

7.3 Methodology discussion

This project has used a research through design approach, where the design has been a part of the research. Important to consider when designing for a specific target group is to regularly involve the end users in the process. We argue that we have included the target group mainly in the evaluation. We have also received feedback from other interaction designer and people working at Universeum. Therefore, we will mainly discuss about the methods in which participants were involved, how those worked out and what could have been done differently. We will also discuss some additional crucial methods conducted in this project. Finally, some of the methods that not have been used and why will be discussed.

Research in the context analysis phase

The context analysis began with a qualitative interview with one of the developers of Mathrix. This interview gave us valuable insights about the goal of Mathrix and how they wanted it to be presented. We think that beginning the research at Mathrix with this interview was a wise decision as it provided a solid foundation for how we moved forward. The first interaction with the context and the users began with observations and short interviews during the sport holiday week. This was carried out during one week and the goal was to get an understanding of the context and to provide inspiration for the end product of the project. Unfortunately, very few people in the intended target group visited Mathrix that week, which may have had affected the final result. However, spending a week at Mathrix gave us the opportunity to observe what had previously been emerged during the interview.

Expert review

Halfway into the project, we held an expert review with Lena Pareto, professor in digitization, IT and learning. Initially, this session was not scheduled to take place, but it provided us with valuable insights from a professional standpoint. During this session we had a fairly unstructured approach, asking her to play the games and give us her spontaneous thoughts. Although we got relevant feedback on what could be improved, a more structured approach could have given us more valuable insights.

Workshop with target group

The self-guided tasks were tested for Mathrix, where we participated by observing the users and asking questions. This was a good opportunity to observe the target group in the context, and we got relevant insights from asking them about their experience and expectations. Ideally, we should have had some time with them before the visit and tested our games. This would have enabled us to gain insights earlier in the project regarding whether the games lowered their entry barrier.

Controlled user test

A controlled user test was carried out in the end of the second iteration. In this test, the participants was selected by convenience sampling. Due to this choice of sampling method, the participants might have felt pressure to give accommodating answers in the interviews. On top of that, we were sitting next to the participants during the test in order to perform thinking aloud, which also may have pressured them to answer in a particular way. Moreover, the participants were students from Chalmers, and were therefore not part of the target group. Math skills differ between people who are in the eighth grade compared to people who have attended a technical college, which might have affected the outcome of the project. Lastly, the test was held at Universeum, meaning the participants played the game and then went straight to the exhibition. This may also have affected the final result since the purpose is to play the game a few days before the visit.

Final evaluation test with end users

At the end of this project, a final evaluation of the game was conducted with students from a seventh-grade class in Gothenburg. The test was divided into two sessions and both sessions were valuable in gaining an understanding of how the end users experienced the games as a preparatory element for the exhibition. It is often challenging to know the accuracy of the participants' responses as we asked them to give responses on games that we made they might feel less comfortable giving negative feedback. Even though the survey was entirely anonymous, the respondents may still feel compelled to provide positive answer and leave out feedback on areas that could be improved. However, the test was conducted in the real context, i.e. their classroom, which allows the participants to feel comfortable and hence to give honest answers.

In this test, the participants played the game individually on their own computer. This was a choice from our side, since all participants then take an active role in playing the game. For the self-guided task at Universerum, they are divided into smaller groups of 3-4 people. In such a constellation, it is easier for some people in the group to be more passive and not contribute to the assignment. We wanted all participants to express their own thoughts about the games. However, some of the participants talked to and helped each other while playing the game in the classroom since they sat two by two at the tables.

One important aspect that we realized during this test was how the teacher chooses to check or "interrogate" that the students have done their self-guided tasks. In the workshop with the two eighth graders earlier in this project, the teacher asked the students when they had finished an assignment what they had done and if they could tell a little bit about what they learned. This can make students more eager to do the task properly and understand the meaning of the piece they just visited. In the final evaluation test, their teacher did not ask those questions but just handed the students a new self-guided task. We could also see from our observations that in most cases the students did not perform the task properly but explored more the functions that were at each piece. This might be due to the teacher's omission to check if the students had accomplished the task.

Furthermore, the structure of the test and the content of the questions differ somewhat from how it was in the controlled user test. This was partly due to the context and the time limit. Both in the classroom and at Universeum, we only had the class for a short time. Also, the participants for this test are younger, with less experience in participating in user tests, and therefore the questions were more adapted to their age and experience. This made us shorten everything and ask the questions in a very concise manner. It might have been desirable to ask more questions to get further insights.

Throwaway prototyping

The method throwaway prototyping (see 3.4.2.1) has been important throughout the project since it gave us the opportunity to learn and develop in Unity. All time spent in this program did not contribute to the final product, but it contributed to a deeper understanding of how the program works and the feasibility of the concepts.

MDA-Framework

In this process, an MDA-framework has been used for the two final prototypes. The frameworks were developed during the second iteration when we had two prototypes in place and have then been modified as the prototypes have changed. Since the frameworks were constructed based on the prototypes, we wrote down all mechanics in the game and then speculated around which eventual dynamics and aesthetics this could bring. During user testing, participants mentioned some dynamics and aesthetics from our MDA-framework. For example, puzzling, memorizing, trial and error solutions, stress, frustration and gratification has been identified to exist in the games. However, all the elements in our MDA-framework has not been confirmed by users to exist. There might also exist dynamics and aesthetics in our prototypes that we have not identified that could be revealed through more user testing.

Both frameworks went through minor modifications along the process. Both initial frameworks included autonomy as a dynamic. After discussion and consideration this dynamic were removed from both frameworks as we thought that it did not fit.

It was originally placed as a dynamic that led to relaxation but we figured that it was rather the fact that the game is single player and non-competitive that could potentially lead to relaxation. In "Sifferjakten" we included trial and error solutions and frustration in our MDA-framework since it was acknowledge in user tests. For "In i labyrinten"s framework, self-improvement was removed as an aesthetic. We initially thought trial and error solutions could lead to the feeling of self-improvement but after getting a better understanding of our prototype, we found that not to be the case.

UX curve

Initially, UX-curves was planned to be used in the pre-study to learn about the users experience and emotions during a visit at Mathrix. The idea was for the users to draw a curve over how their feelings changed during a visit. However, after further discussion, this idea was scrapped. The reasoning behind deciding not to use UX-curves consisted of a few arguments. First off, UX-curves are intended to be used for longer periods than the time span of a exhibition visit. We also realized that using UX-curves required a lot of engagement from the user and therefore brought a risk of getting few participants. Lastly, we came up with the idea of just letting visitors anonymously write down their expectations before the visit and what they enjoyed the most after the visit. We argued that this was a better way of understanding the visitors experiences and therefore the UX-curve would be redundant.

Co-creation workshop

A co-creation workshop was scheduled to be held in the beginning of the second iteration. The plan was to involve the target group in a brainstorming session to gather direct input about what they would like to do in an introductory game. However, due to difficulties in gathering participants, the co-creation workshop was not held. Instead, we got the opportunity to participate in a workshop held by Catharina Djurelind, where we observed the target group perform the self-guided tasks in Mathrix. This was the first time we saw how this session was done. We claim that this gave us valuable insights into how to adapt the game based on the session's setup. A co-creation workshop might have given us more in-depth insights about how the game could be designed.

Scenarios

The scenario method was decided to not be constructed, since we at that stage thought it would not do justice to the various ways the visitors can experience the exhibition. In retrospect, it was a wise decision not to implement that method in the first iteration, because at that point, we had not yet learned how the self-guided tasks sessions worked. However, it might have been beneficial to introduce the method in a later iteration, for example after the workshop with target group. This may have increased an understanding of potential future outcomes with the concepts.

A/B testing

The evaluation method A/B can measure which one of two versions presents the best results. A decision was made in the planning phase that the questions about the concepts and the experience of using them as introductory elements would benefit from having qualitative rather than quantitative answers. However, if an A/B test was conducted, it would be possible to compare the experience between people who have played the game before the visit with people who have not. While investigating this would have been interesting, it does not align well with our scope.

7.4 Ethical issues

Throughout the project, we have always strived to inform the participants about the nature of the study and we also made sure to keep the data gathering anonymous. When the participants have been under 18 years old, we have had to get consent not only from the participants but also from their teachers. In these cases, no names have been recorded or pictures with faces documented.

One ethical aspect that is worth to consider is the accessibility aspect. Throughout this project, we have not put as much focus on accessibility as desired. For example, more focus could have been put on changing the color of the interface in order to make it more viewable for people with color blindness. The interface could also be improved by including options for changing the font size.

7.5 Future work

The games developed in this thesis are both prototypes and there are various things to keep working on. We will present a few ideas of changes that would be interesting to implement and test.

Further developing the resemblance between "In i labyrinten"s map and the exhibition

It would be interesting to investigate if changes in "In i labyrinten" could result in the user feeling a stronger correlation between the game and the exhibition. A more detailed replication of Mathrix's appearance could be developed. As of current, the game and exhibition is somewhat similar but all exhibition pieces is represented by solid cubes and could be further improved and detailed to look exactly like the actual pieces.

The players view in the game could also be experimented with. It now shows the map from a birds perspective and could be changed to a third person or first person view to show the map from a perspective that is more similar to the one of an actual visit to Mathrix. This would however change the nature of the game as it would not let the player get an overview of the entire map. This could be solved by letting

the player switch between camera angles or provide a birds eye view as a smaller window in one of the corners of the screen.

Lastly, the map could be color coordinated to resemble the map that is given out to the school classes on their visit (see Appendix C). This could potentially lead to an increased understanding of the space and reduce confusion during the visit.

Combining the games

Another idea that we have discussed is combining the games, using the spatial resemblance from the maze, but changing the camera angle to a first or third person camera. The player could then walk around in a virtual version of Mathrix before the visit and interact with the installations. The installations would then consist of a mini game with a connection to the actual exhibition item. For example, "Sifferjakten" would be on the same place in the virtual space as it is in the real exhibition.

Test the games in different contexts

The game is digital so it could theoretically be used both as a preparing tool in the classroom before a school class visit, and as a teaser published on Universeums website for general visitors. However, in this thesis the focus has been on school visits and it would be interesting to test the games more in the context of general visitors and investigate if and how the games will be perceived differently in the different contexts.

Investigating the visual appearance of the games

The tests in this thesis has focused on game play and mathematical incorporation. Another interesting factor that could be investigated and further looked into is the visual appearance of the games. The game can be perceived in different ways depending on how it looks which can affect both the users experience of the game and the expectation on the exhibition.

The importance of including the target group

Additional aspects worth considering for future work is to perform user tests with more participants in the target group. One of the user test in this project was conducted with students from Chalmers, which provided us with inspiration and ideas for improving the concepts. However, since these participants are not part of the intended target group it is important to note that their responses are not entirely reliable. It is also of importance to continuously test the concepts with the target group to make sure the designer do not develop and design for themselves but for the end users.

8

Conclusion

This thesis has investigated what are key considerations for developing an introductory interactive game intending to lower the visitors' entry barrier for a mathematics exhibition at a science center. Throughout this project, a research through design approach has been used, where qualitative data has been collected and analyzed. The final design resulted in two digital games: "In i labyrinten" and "Sifferjakten". These digital prototypes has been used as a tool to identify the key considerations. The project resulted in nine key considerations as answer to the research question, these are listed below:

- Connection between game and exhibition
- Importance of MDA-framework
- Incorporation of mathematics
- Degree of difficulty
- Explicit start and end of the game
- Understandable without an explanatory text
- Importance of involving the teacher
- Visual appeal
- Maximize functional prototypes

The most essential key consideration that has been identified is to consider in which way the game is connected to the exhibition. This connection is most likely to become apparent if the games contains specific concepts from pieces at the exhibition. It was observed from user tests that games containing concepts from pieces at the exhibition contributed to an improvement in understanding for that concept as well as an enjoyment of performing that piece at the exhibition. Participants also expressed an enjoyment in playing the games, and they thought it was a fun way of learning math. In order for this to be achieved, the games also has to be engaging on its own. Using and processing of an MDA-framework can help sort out what elements that should be included to make the games engaging on its own.

An additional consideration that has been recognized is the incorporation of levels with varying degrees of mathematical difficulty. A number of participants from the conducted user tests indicate a willingness to continue playing if there were more levels in the games and the main feedback for improvement from the target group was to introduce more levels. Further on, it's important to consider to what extent explanatory text is used. From observations of how the user interact with pieces at Mathrix, it was identified that people in general do not want to read about a task,

but start interacting with the piece. We had this in mind while designing our games, where we tried to make them as intuitive as possible. This was then confirmed from the user tests that the digital games were easy to understand and it was actually one of the aspects they enjoyed most about the games.

Finally, since a science center is a place for informal learning that aims to present subjects in a way that differ from how it is presented in a textbook, it is beneficial if the introductory game use the same approach. The games should not be a test for the students, but a fun way of learning math. From the user test it was confirmed that several participants thought that the prototypes were an effective and enjoyable way for learning mathematics.

In conclusion, the project presents knowledge in form of key considerations regarding the design of an introductory game for a mathematics exhibition. The insights presented can have value both for theoretical and practical use. They can be used as foundation for further research within the subject of lowering thresholds for mathematics. However, they can also have value in a more practical sense for exhibition designers. Sub-parts of the findings might also be of value for educators and game designers.

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A

Context analysis

This Appendix contains data from the context analysis. It includes the questions from the interview with Håkan Sigurdsson, a picture of the station where visitors could describe their expectations of Mathrix and also an overview of the affinity diagram which was created out of the findings from the first observations and interviews.

- Berätta gärna, vad är tanken bakom Mathrix?
 - Vad är målet med Mathrix?
- Vilka "intressen"/aktiviteter är Mathrix baserat på?
- Vilka likheter finns det i utformningen av mathrix och de tidigare utställningarna?
-
- Hur ser tanken ut med vilken väg användarna ska ta?
 - Finns det en "rätt" väg att gå?
- Finns det en tanke bakom placeringen av de olika installationerna? isf, vilken?
 - Har ni några tankar om entrén och vad som ska vara första intrycket?
- Vad förväntar ni er att förskunskapen i matematik är hos en besökare?
 - Har ni haft något introducerande element? Någon förberedelse på plats eller som skickats ut i förväg.
- Har ni tidigare haft en installation som visat sig vara svårbegriplig och isf hur har ni åtgärdat det?
- Hur har era tankar gått kring fördelningen av objekt som kräver flera personer vs en person?
 - Ser ni att fler-personers-utställningar är mer populära eller vice versa?
- Workshop, hur funkar det? vem bestämmer om vi kan ta dit 12 personer? vilka skolor? finns det några som varit med innan?
- Finns det plats för bord som står innan utställningen? A3/A2 på väggen/bordet?
Finns det krav från er sida hur detta ska vara utformat?

Figure A.1: Questions from the interview with Håkan Sigurdsson

A. Context analysis

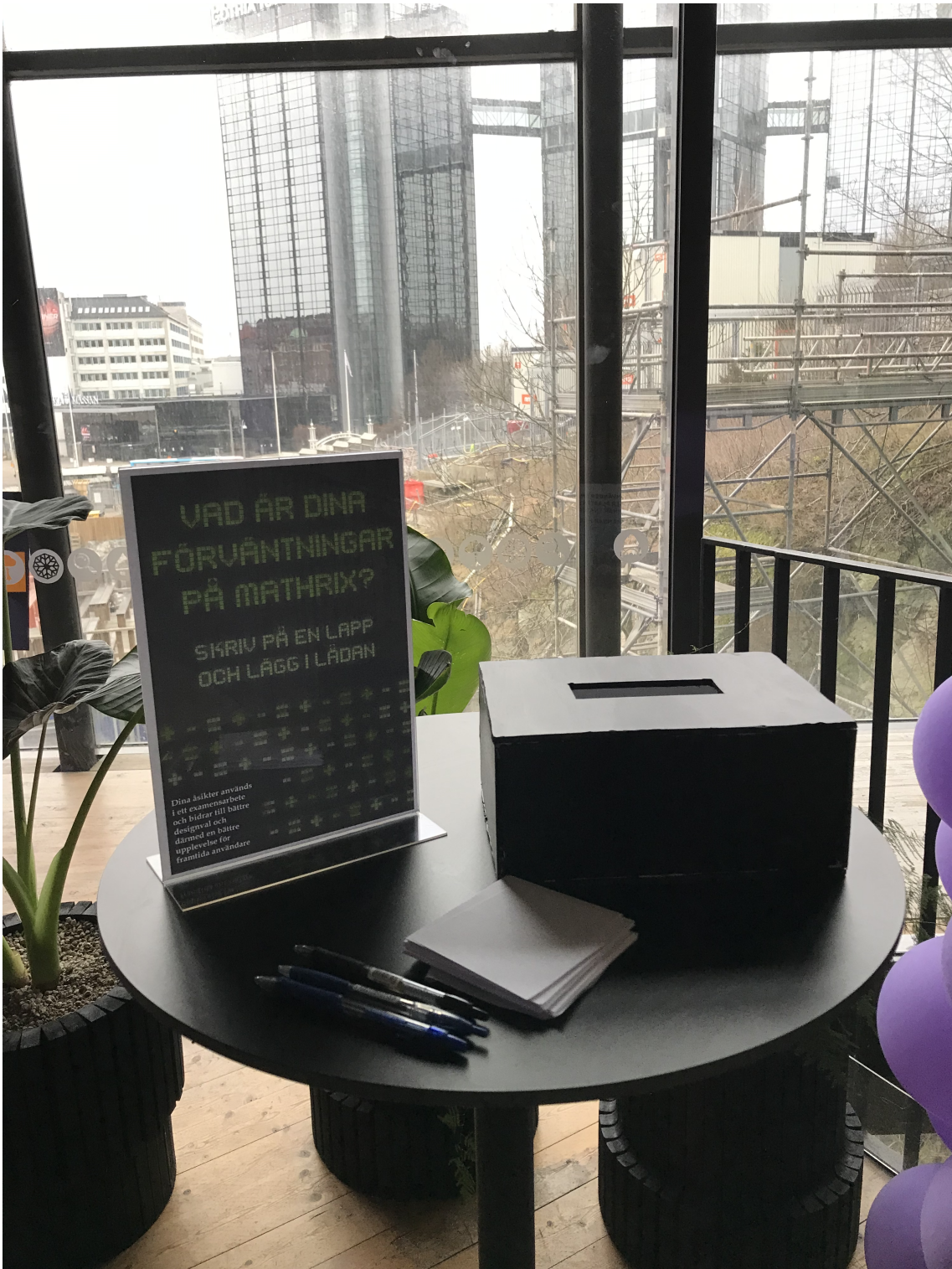


Figure A.2: The station outside of Mathrix

A. Context analysis

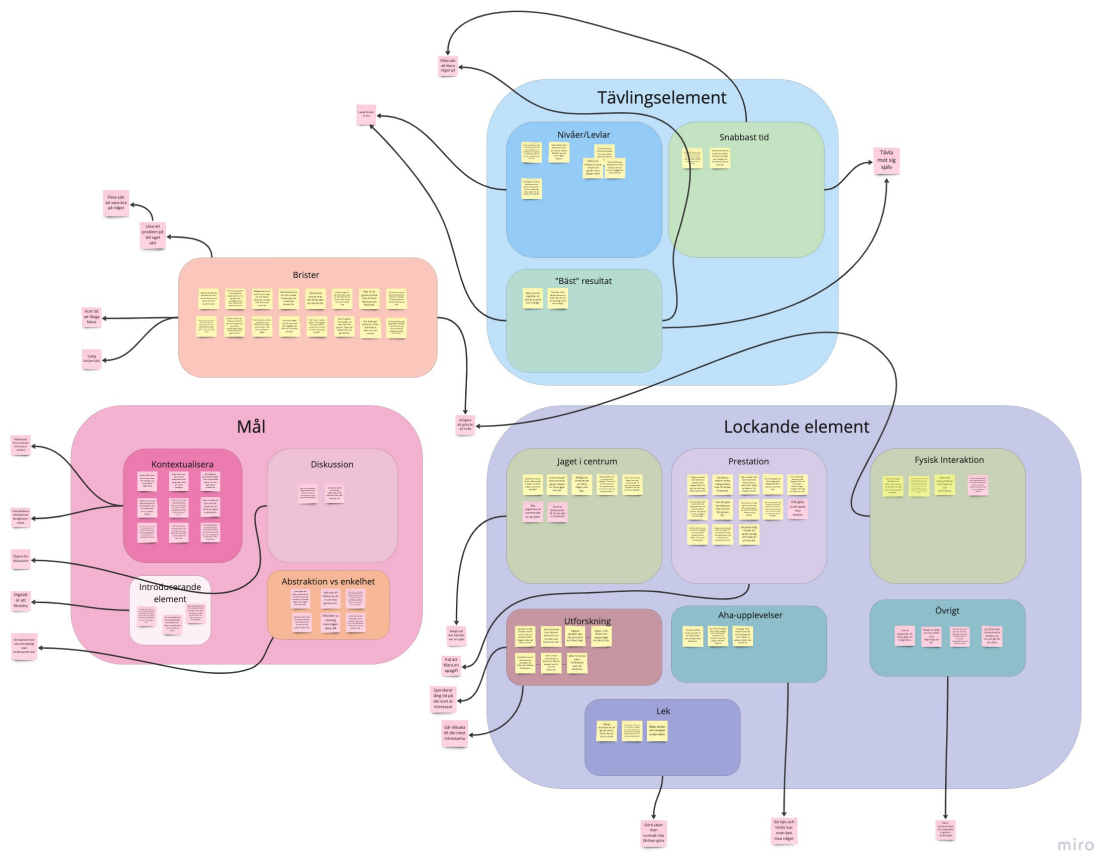


Figure A.3: A screenshot of the Affinity diagram that was made from the interview with Håkan Sigurdsson and the observations during the sport holiday week.

B

First iteration

This Appendix contains data from the first iteration. It partly includes a summary of the trend analysis, a screenshot of the low-fidelity prototypes which was a part of the brainstorming session and a picture of the modified version of a prioritization matrix the evaluate the feasibility of the concepts.

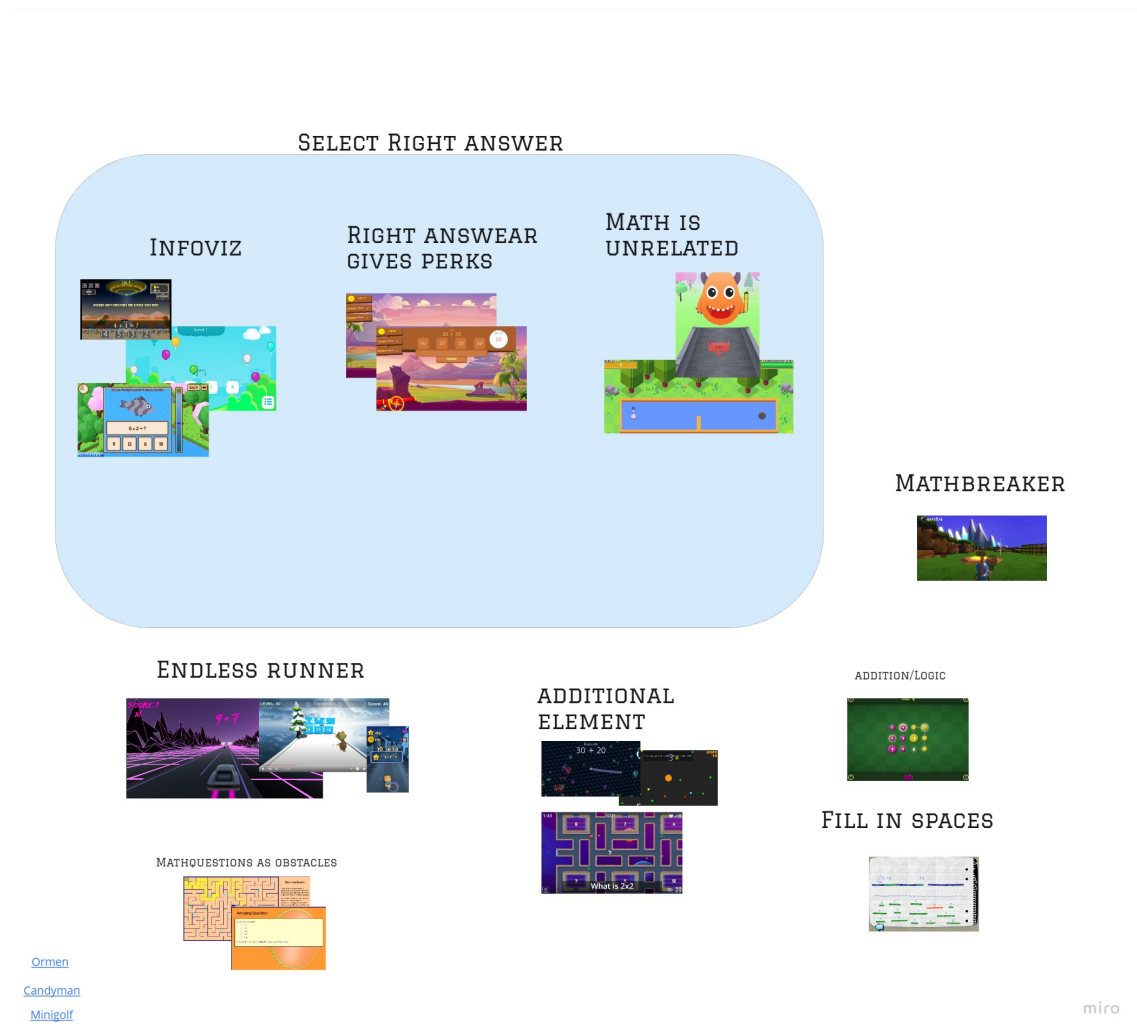


Figure B.1: A screenshot of the summarized Trend Analysis.

B. First iteration

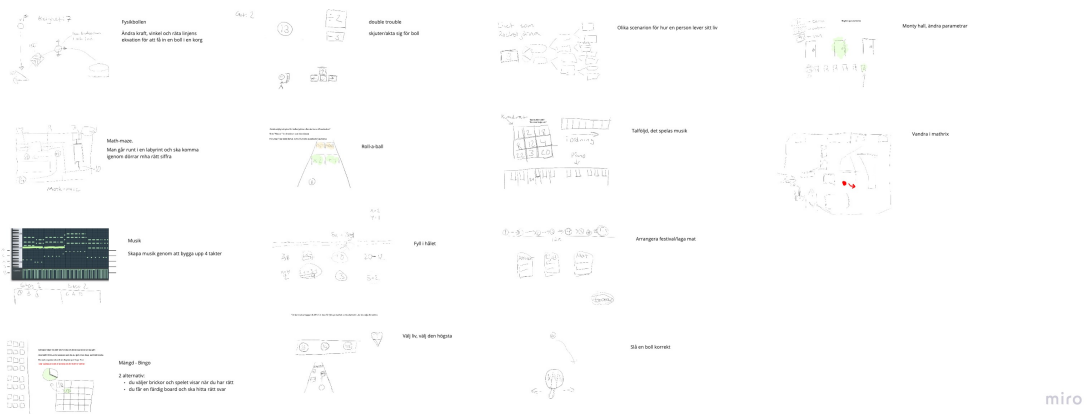


Figure B.2: Lo-fi prototypes from the first iteration

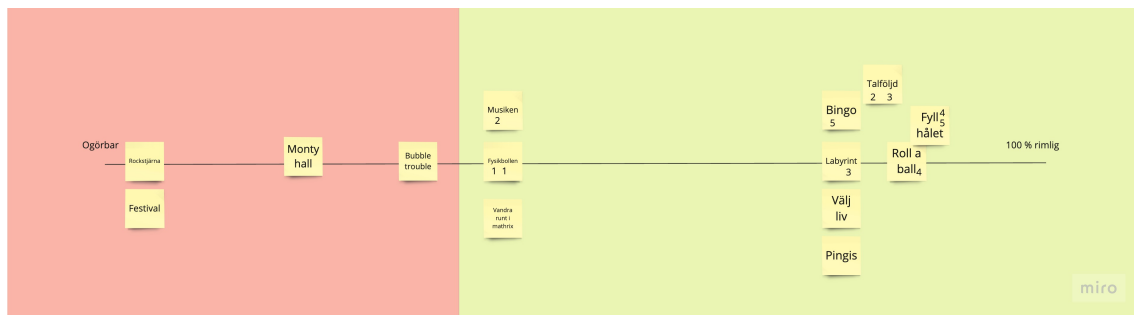


Figure B.3: The modified version of a prioritization matrix the evaluate the feasibility of the concepts

C

Second iteration

This Appendix contains data from the second iteration. This section includes a summary of the feedback from the expert review session, initial MDA-frameworks of the two concepts, example of a self-guided task, a map over Mathrix divided in different areas, questions from the controlled user test and the insights from the controlled user test structured in an affinity diagram.

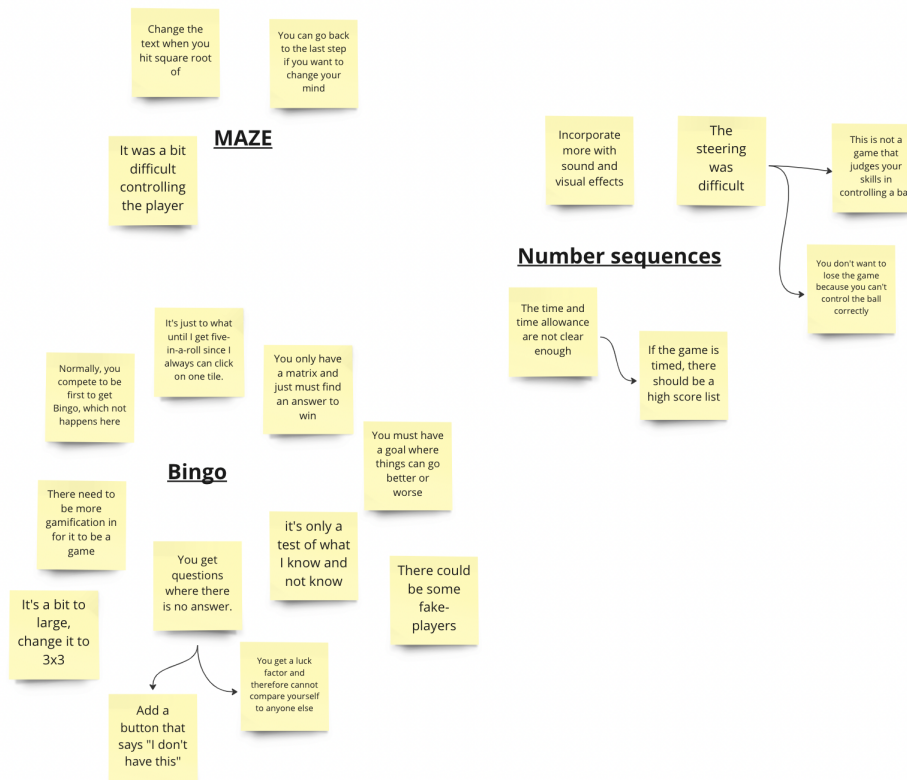


Figure C.1: Summary of the feedback from the expert review

C. Second iteration

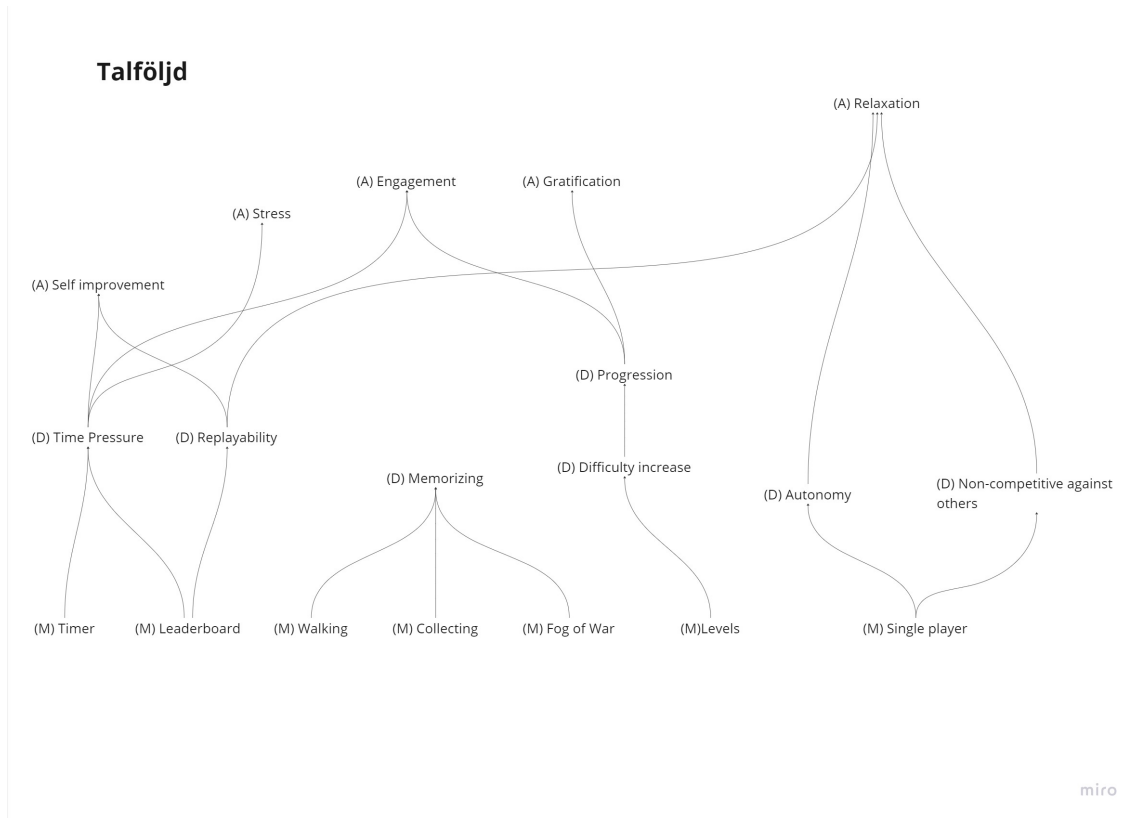


Figure C.2: Initial MDA-framework Number Sequence

C. Second iteration

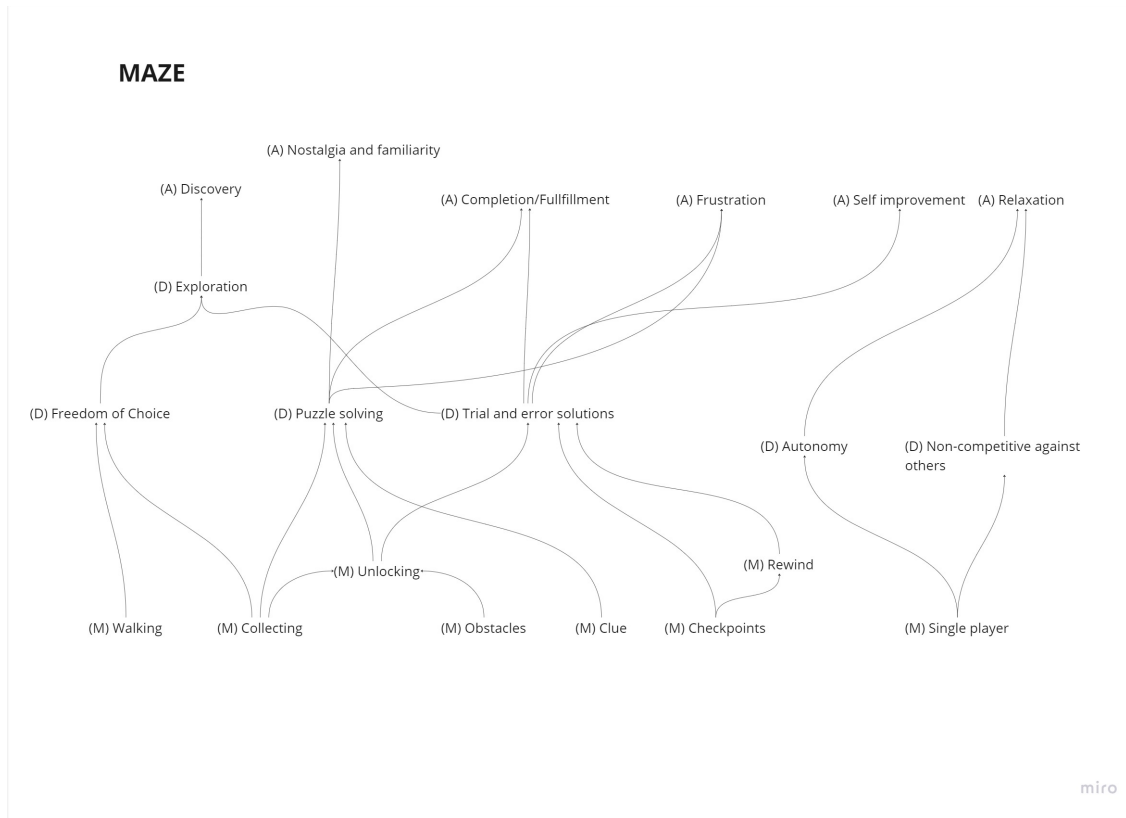
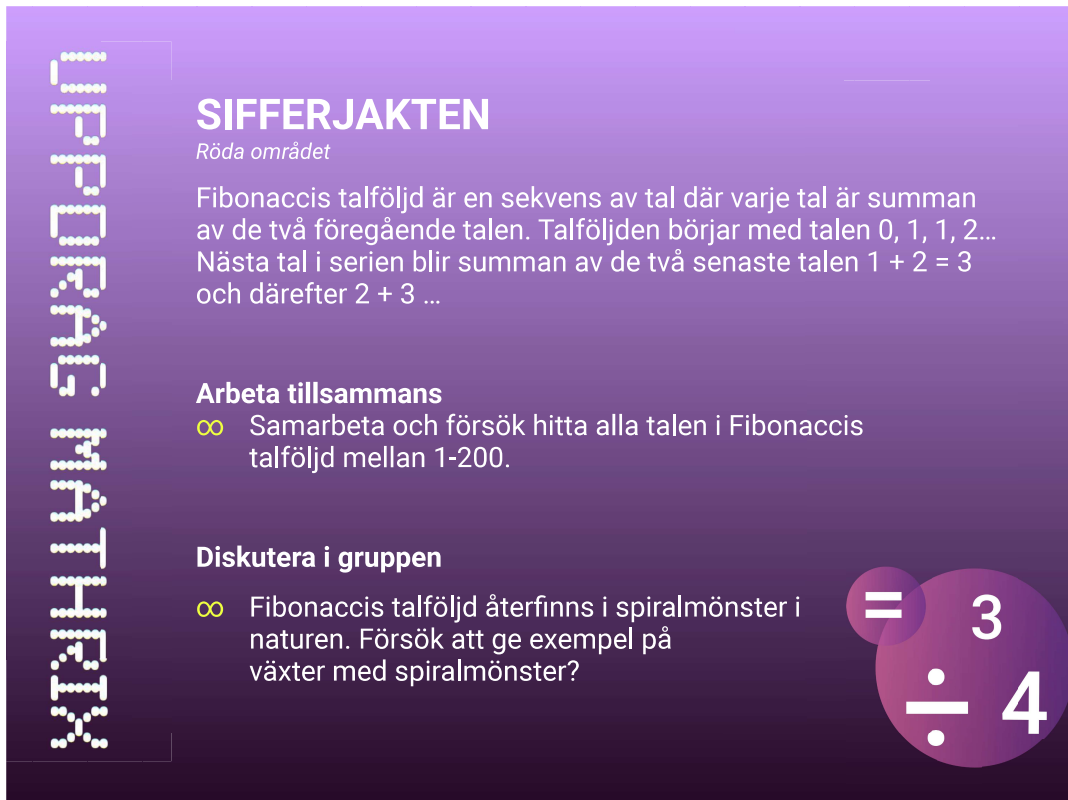


Figure C.3: Initial MDA-framework Maze



SIFFERJAKTEN

Röda området

Fibonaccis talföljd är en sekvens av tal där varje tal är summan av de två föregående talen. Talföljden börjar med talen 0, 1, 1, 2... Nästa tal i serien blir summan av de två senaste talen $1 + 2 = 3$ och därefter $2 + 3 = 5$...

Arbeta tillsammans

- ∞ Samarbeta och försök hitta alla talen i Fibonaccis talföljd mellan 1-200.

Diskutera i gruppen

- ∞ Fibonaccis talföljd återfinns i spiralmönster i naturen. Försök att ge exempel på växter med spiralmönster?

= 3
÷ 4

Figure C.4: Example of a self-guided task

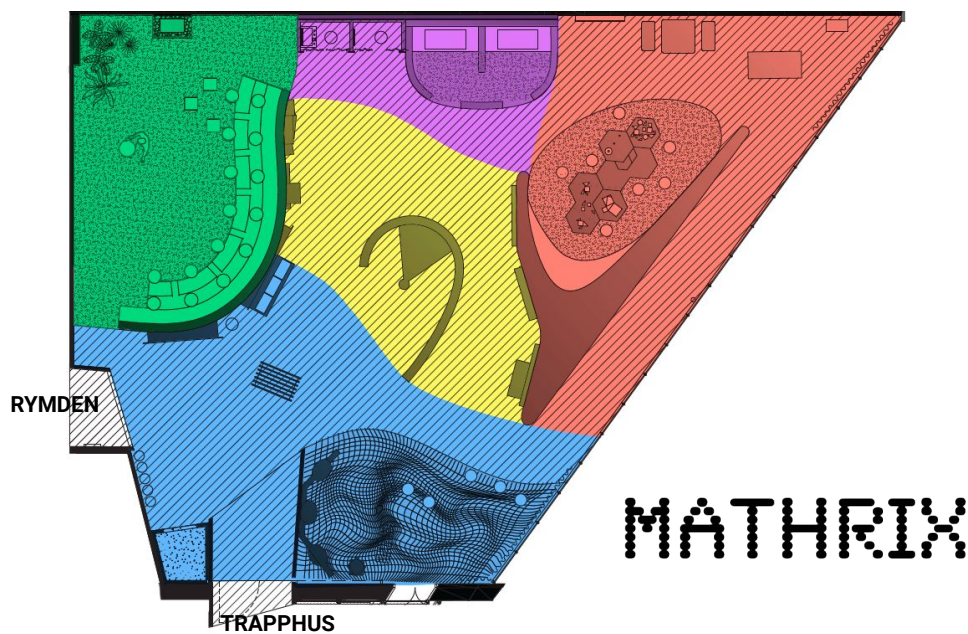


Figure C.5: Map over Mathrix

Enkät

Kön:

Ålder:

Frågor om spelet:

1. Jag upplevde spelet enkelt att förstå

1	2	3	4
---	---	---	---

Håller inte med

Håller med

2. Jag tyckte spelet var intressant att spela

1	2	3	4
---	---	---	---

Håller inte med

Håller med

3. Om fler nivåer funnits i spelet hade jag velat spela vidare

1	2	3	4
---	---	---	---

Håller inte med

Håller med

4. När jag spelade spelet kände jag mig:

Frustrerad ————— Belåten

5. När jag spelade spelet kände jag mig:

Stressad ————— Lugn

6. Hur skulle du beskriva det här spelet för någon som inte har spelat det.

7. Beskriv dina förväntningar på utställningen.

Figure C.6: Questions about the experience after playing the game

Frågor om utställningen:

8. Hur skulle du beskriva utställningen för någon som inte varit där tidigare?
9. Upplevde du att någon monter i Mathrix var mer intressant än någon annan?
10. Vilken monter i Mathrix stannade du längst vid?
11. Upplevde du att det fanns en koppling mellan spelet du spelade innan och själva utställningen? Om ja, på vilket sätt.
12. Hur skulle du beskriva syftet med spelet du spelade innan?
13. Övriga tankar eller funderingar?

Figure C.7: Questions about the experience after running the mathematical exhibition

C. Second iteration

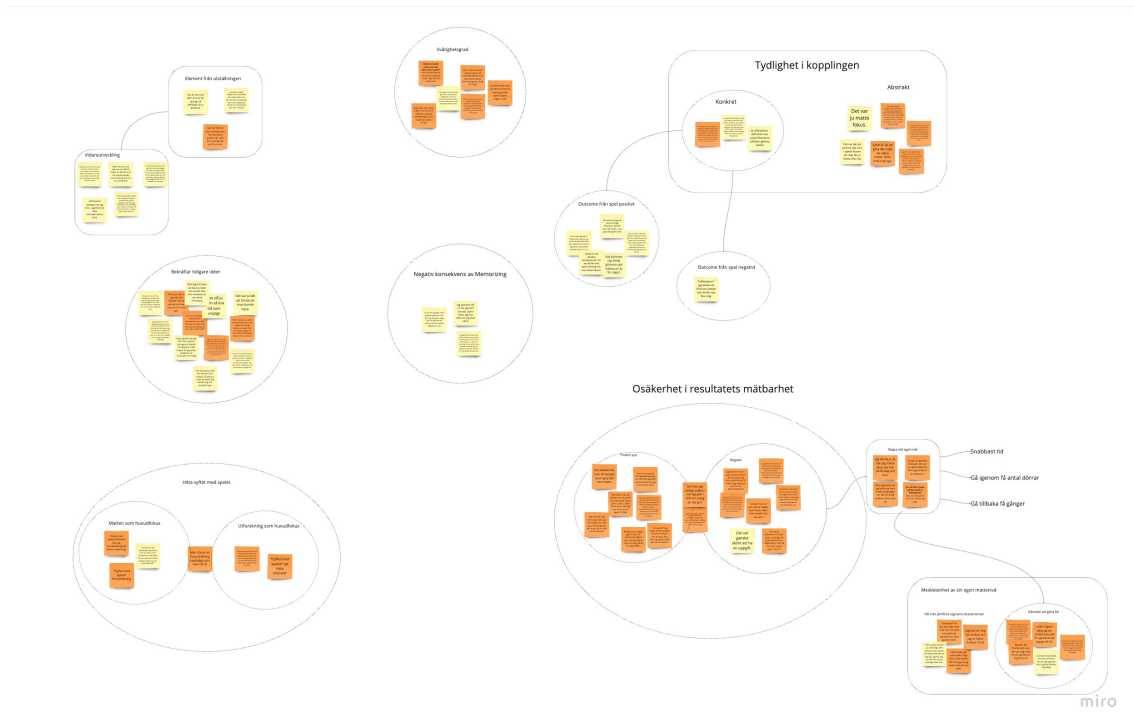


Figure C.8: A picture of the Affinity diagram from the controlled user test

D

Third iteration

This Appendix contains data from the third iteration. This includes the questions asked in the final user test about the prototypes, the analysed data from the final user test about the experience at Mathrix, the quantitative responses from the final user test about the prototypes and the final MDA-frameworks for both games.

D. Third iteration

2023-05-09 10:05

Enkätfrågor om spelen

Enkätfrågor om spelen

Du kommer nu få svara på några frågor om hur du upplevde spelen du precis spelade. Först kommer frågor om "Sifferjakten" och därefter kommer frågor om "In i labyrinten".

* Indicates required question

Frågor om "In i labyrinten"

Detta spel gick ut på att du skulle gå runt i en labyrint och låsa upp dörrar för att ta dig till mål.

1. Jag upplever spelet enkelt att förstå *

Mark only one oval.

Håller inte alls med

1

2

3

4

5

6

Håller med helt

https://docs.google.com/forms/d/1K3gkCIA47dkbs2pF0Fa_HdsTQiwNSXPkMXdok6Ur4/edit

1/7

Figure D.1: Questions about the prototypes from the final user test (1 out of 7)

D. Third iteration

2023-05-09 10:06

Enkätfrågor om spelen

2. Jag tyckte spelet var roligt att spela *

Mark only one oval.

Håller inte alls med

1

2

3

4

5

6

Håller med helt

https://docs.google.com/forms/d/1K3gkCIA47dkbs2pF0Fa_HdsTQawNSXPknMXdok6Ur4/edit

2/7

Figure D.2: Questions about the prototypes from the final user test (2 out of 7)

D. Third iteration

2023-05-09 10:06

Enkätfrågor om spelen

3. Jag tyckte spelet var lärorikt *

Mark only one oval.

Håller inte alls med

1

2

3

4

5

6

Håller med helt

4. Vad gillade du mest med spelet? *

5. Vad tycker du kan förbättras med spelet? *

https://docs.google.com/forms/d/1K3gkCIA47dkbs2pF0Fa_HdsTQiwNSXPknMXdok6Ur4/edit

3/7

Figure D.3: Questions about the prototypes from the final user test (3 out of 7)

D. Third iteration

2023-05-09 10:06

Enkätfrågor om spelen

Frågor om "Sifferjakten"

Detta spel gick ut på att du skulle samla siffror i en viss talföljd i rätt ordning, från lägst till högst.

6. Jag upplever spelet enkelt att förstå *

Mark only one oval.

Håller inte alls med

1

2

3

4

5

6

Håller med helt

https://docs.google.com/forms/d/1K3gkCIA47dkbs2pF0Fa_HdsTQawNSXPknMXdok6Ur4/edit

4/7

Figure D.4: Questions about the prototypes from the final user test (4 out of 7)

D. Third iteration

2023-05-09 10:07

Enkätfrågor om spelen

7. Jag tyckte spelet var roligt att spela *

Mark only one oval.

Håller inte alls med

1

2

3

4

5

6

Håller med helt

https://docs.google.com/forms/d/1K3gkCIA47dkbs2pF0Fa_HdsTQiwNSXPkMXdok6Ur4/edit

5/7

Figure D.5: Questions about the prototypes from the final user test (5 out of 7)

D. Third iteration

2023-05-09 10:07

Enkätfrågor om spelen

8. Jag tyckte spelet var lärorikt *

Mark only one oval.

Håller inte alls med

1

2

3

4

5

6

Håller helt med

9. Vad gillade du mest med spelet? *

10. Vad tycker du kan förbättras med spelet? *

https://docs.google.com/forms/d/1K3gkCIA47dkbs2pF0Fa_HdsTQiwNSXPknMXdok6Ur4/edit

6/8

Figure D.6: Questions about the prototypes from the final user test (6 out of 7)

D. Third iteration

2023-05-09 10:07

Enkätfrågor om spelen

11. Vad är dina förväntningar inför besöket på Universeums matematiska utställning Mathrix? *

12. Övriga kommentarer

This content is neither created nor endorsed by Google.

Google Forms

https://docs.google.com/forms/d/1K3gkCIA47dkbs2pF0Fa_HdsTQawNSXPknMXdok6Ur4/edit

7/7

Figure D.7: Questions about the prototypes from the final user test (7 out of 7)

Undersökning Mathrix

Detta är ett undersökande arbete om den nyöppnade utställningen Mathrix på Universeum. All feedback är av stort värde och vi är tacksamma för både positiva och negativa kommentarer om din upplevelse.

I fredags spelade du två digitala mattespel i klassrummet. Underlättade dessa spel på något sätt när du besökte och använde Mathrix-utställningen?

Om ja, på vilket sätt?

Detta kan till exempel vara om du kände igen något från spelen eller om du hade lärt dig något från spelen som du använde i utställningen?

Om nej, varför inte?

Detta kan vara om spelet fick dig att känna dig osäker på något eller om spelet fick dig att känna dig förvirrad över något.

Du kan fortsätta skriva på baksidan

Figure D.8: Questions about the exhibition visit from the final user test (1 out of 2)

D. Third iteration

Masterarbete inom interaktionsdesign
Chalmers Tekniska Högskola

Figure D.9: Questions about the exhibition visit from the final user test (2 out of 2)

D. Third iteration



Figure D.10: Analysis of the data gathered from the first session of the test with target group

D. Third iteration

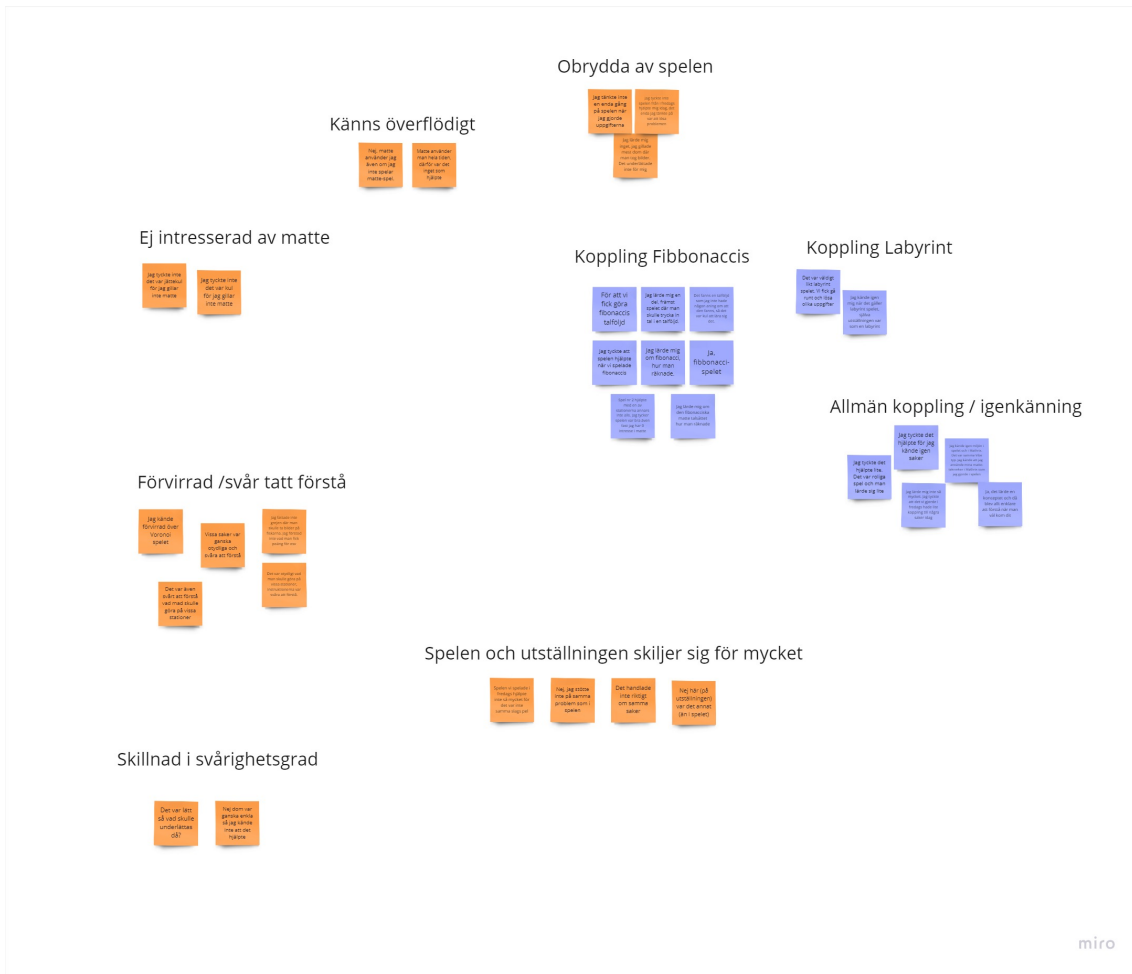


Figure D.11: Analysis of the data gathered from the second session of the test with target group

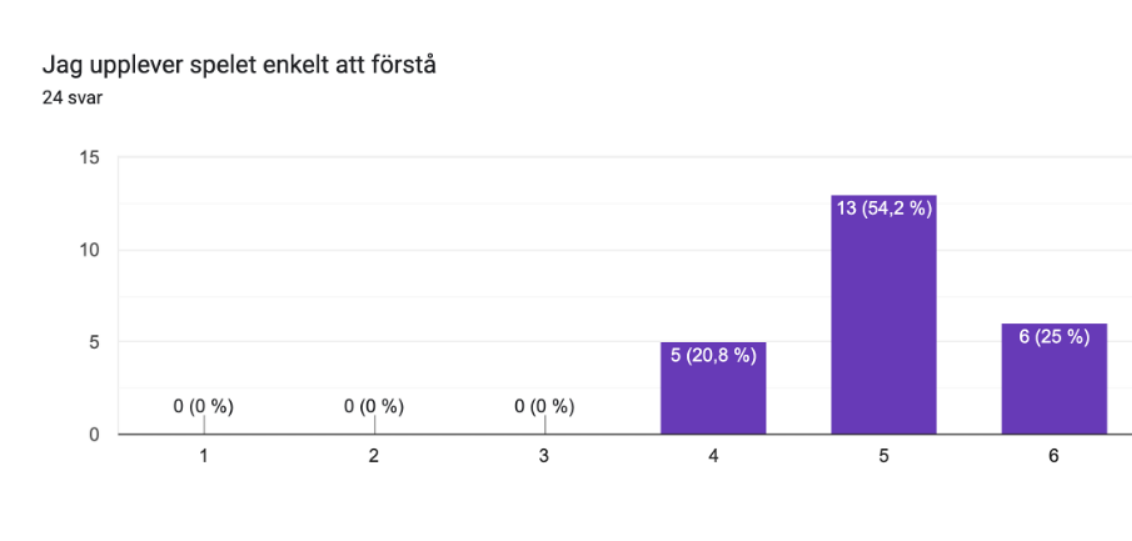


Figure D.12: Responses about how easy it was to understand "In i labyrinten"

D. Third iteration

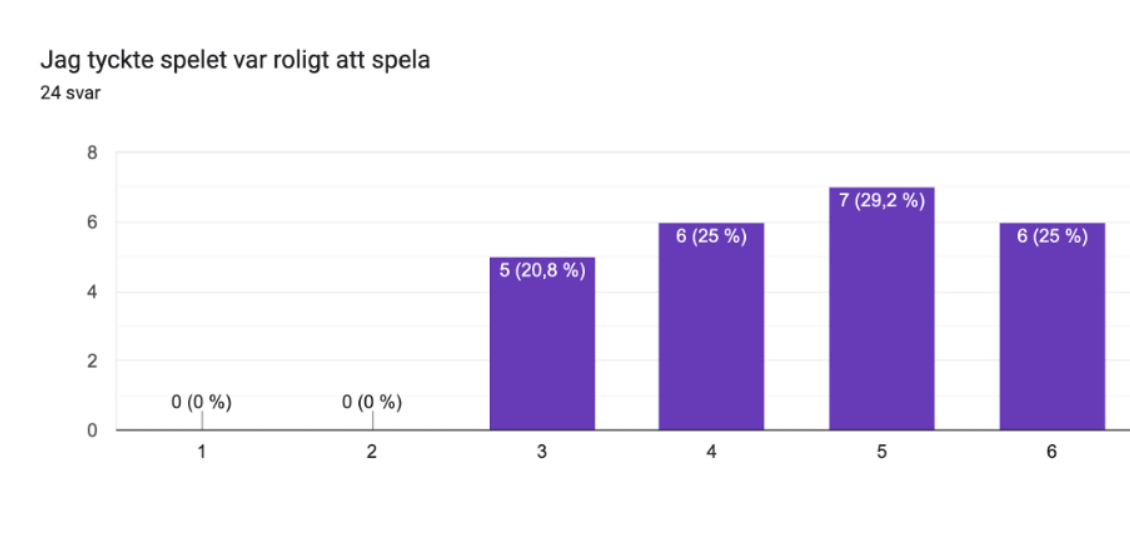


Figure D.13: Responses about how fun it was to play "In i labyrinten"

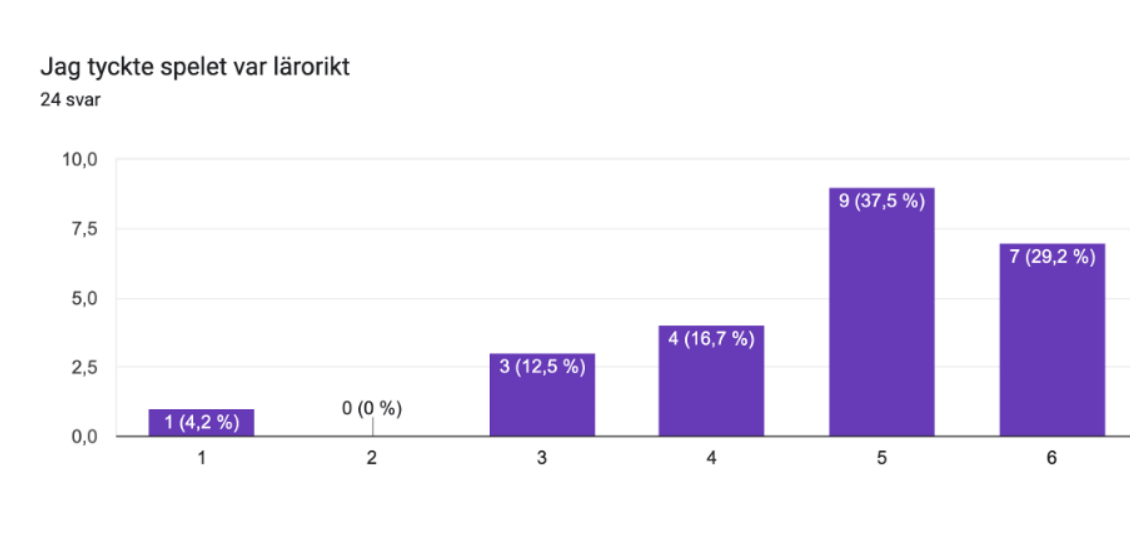


Figure D.14: Responses about how educational "In i labyrinten" was

D. Third iteration

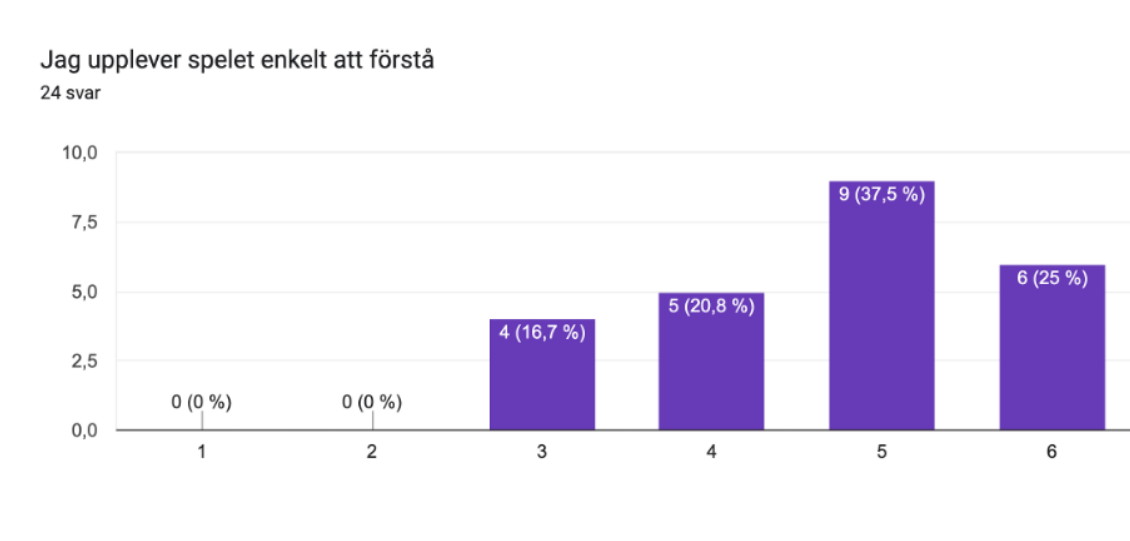


Figure D.15: Responses about how easy it was to understand "Sifferjakten"

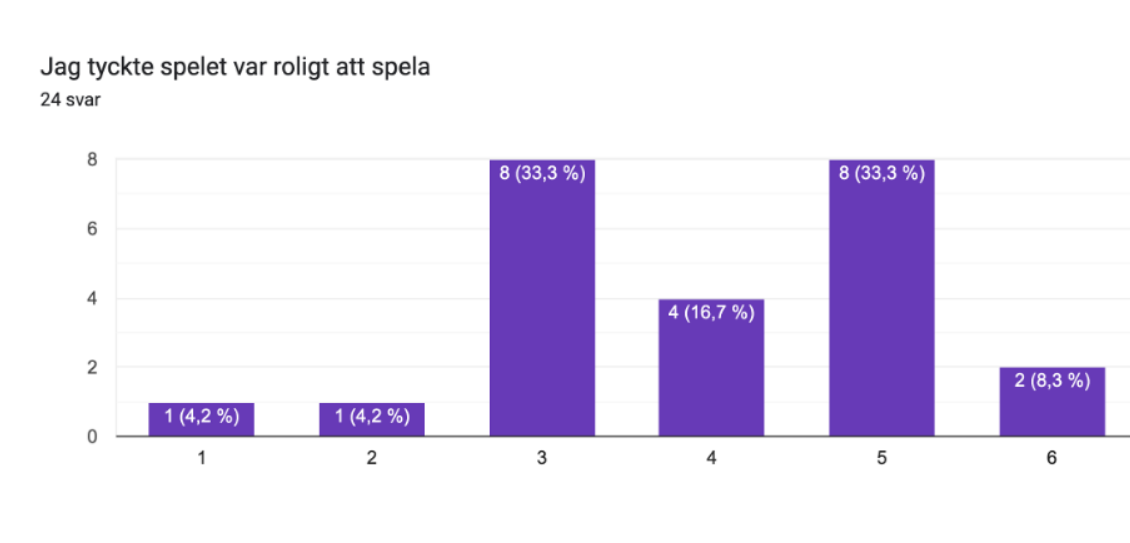


Figure D.16: Responses about how fun it was to play "Sifferjakten"

D. Third iteration

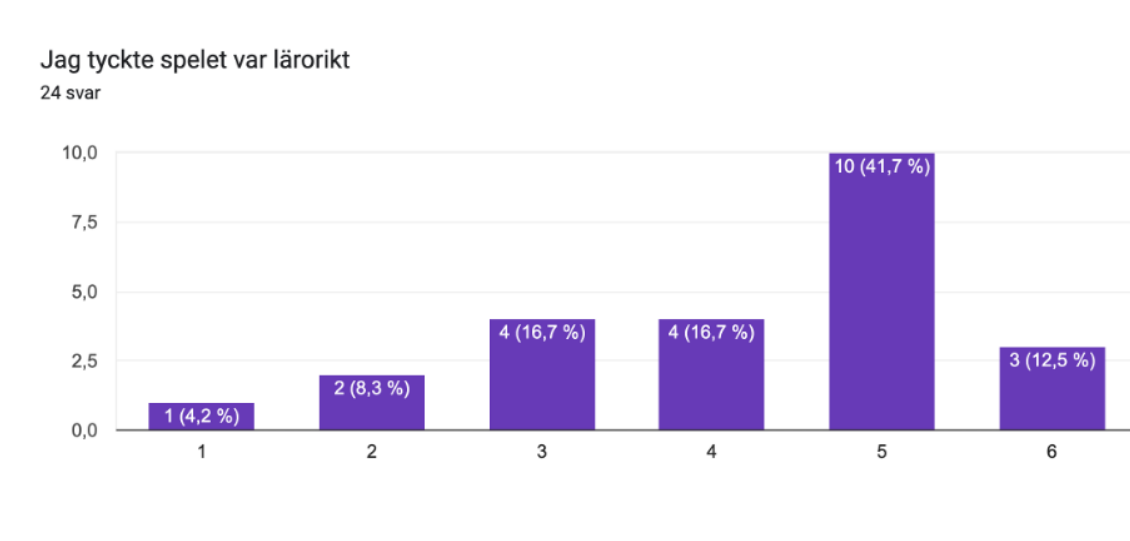


Figure D.17: Responses about how educational "Sifferjakten" was

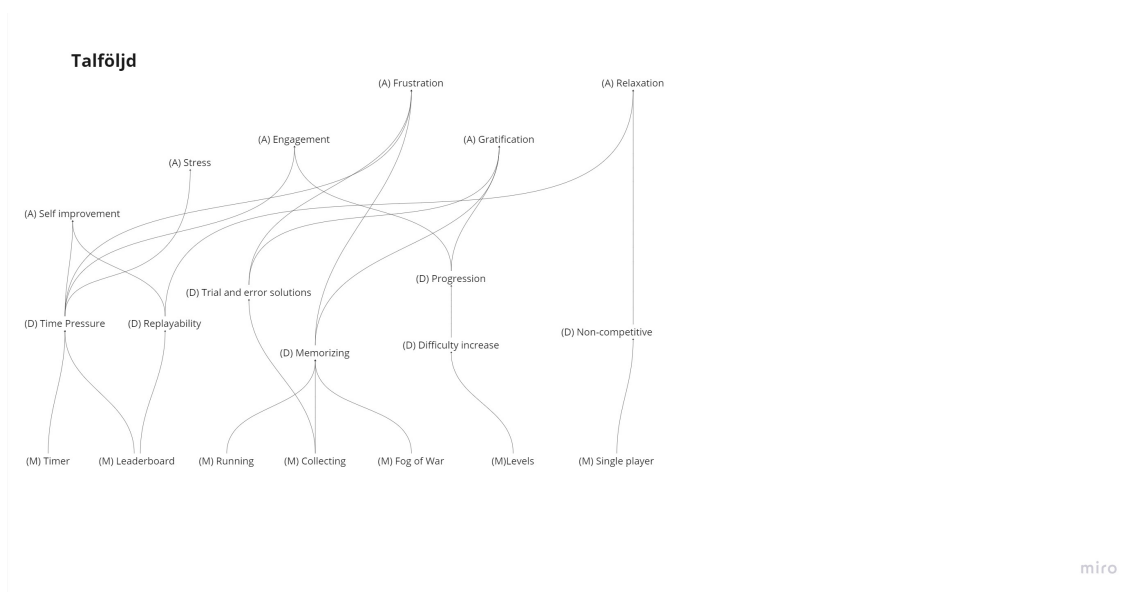


Figure D.18: Final MDA-framework for "Sifferjakten"

D. Third iteration

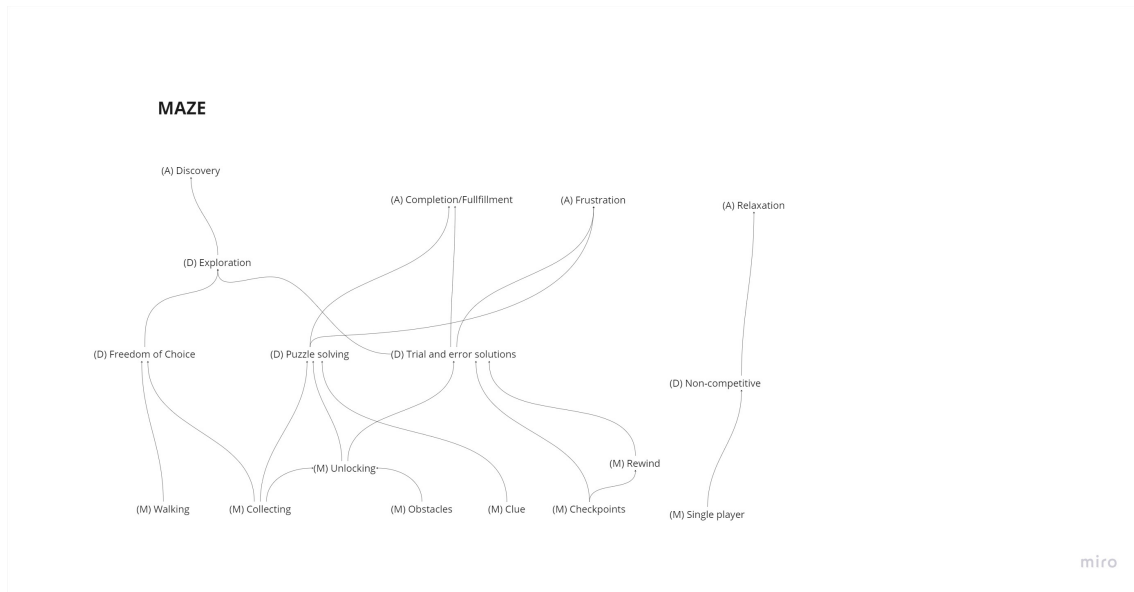


Figure D.19: Final MDA-framework for "In i labyrinten"