LOWERING ENTRY BARRIERS FOR INFORMAL LEARNING IN MATHEMATICS THROUGH INTERACTIVE GAME DESIGN

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J. Wideström[1], E. Axell[1], A. Hansson[1], C. Djurelind[2], C. Sandberg[2]

[1]Chalmers University of Technology (SWEDEN)
[2]Universeum Science Centre (SWEDEN)

Abstract

Our research project contributes to the field by examining learning experiences in mathematics exhibitions through interactive game design. Emphasizing informal learning principles, we aim to lower entry barriers, foster positive attitudes toward mathematics, and promote deeper engagement with mathematical concepts. The study introduces three types of factors for the development of introductory interactive games aimed at bridging the gap between the classroom and the exhibitions at science centres. These factors encompass establishing seamless connections between games and exhibitions, strategically integrating mathematical concepts, and involving educators in the process. These insights are instrumental in creating educational tools that facilitate engaging mathematics learning experiences within science centre environments. This study is distinctive in its approach as it explores games not as primary tools for direct learning but as preparatory elements to reduce entry barriers to mathematics exhibitions. Unlike traditional game-based learning, where games are central to teaching, our study highlights the use of games to ease visitors into the exhibition and bridge the gap between formal classroom learning and informal science centre experiences. This perspective opens up perspectives for enhancing the visitor experience and fostering positive attitudes towards mathematics in an authentic and accessible manner.

Keywords: Mathematics, exhibitions, science centers, informal learning, interactive game design, game-based learning.

1 INTRODUCTION

Interactive exhibits provide opportunities for visitors to engage in active exploration, experimentation, and problem-solving, leading to a deeper understanding of scientific concepts [1]. Mathematics exhibitions in science centres provide a unique opportunity to engage visitors in hands-on experiences related to mathematical concepts. However, the complicated relationship that students often have with mathematics can create a threshold that inhibits their engagement with these exhibitions [10]. To address this challenge, our project adopts a design-driven approach with a focus on creating an introductory digital game aimed at lowering the visitors' entry barrier and promoting informal learning within the mathematics exhibition.

Informal learning, characterized by self-directed and interest-based exploration, is a key component of the visitor experience in science centres [2]. Visitors have the freedom to engage with exhibits and educational resources in a way that suits their interests and learning preferences. By designing interactive games, we aim to enhance informal learning experiences, encouraging visitors to actively explore mathematical concepts and fostering a positive attitude towards the subject. Our project is grounded in the theory of informal learning, as proposed by Falk and Dierking [2] [3], which emphasizes the importance of self-directed and interest-based exploration in science center settings. We draw on this theory to inform the design of our digital game, aiming to create an environment that aligns with the principles of informal learning. By providing opportunities for visitors to explore mathematical concepts at their own pace and according to their interests, we seek to enhance their engagement and foster positive attitudes towards mathematics.

Using games as a tool for mathematical learning is a proven concept with mixed results [4] [5]. In this study, games are not explored as a learning element but as a preparatory element used to lower the entry barrier for informal learning at a mathematics exhibition, and also bridging the gap between the classroom and the exhibition. Utilizing games in this context is not as widely researched as using games for direct learning.

Ethical considerations are central to our project. We are committed to obtaining informed consent from visitors who engage with the digital game and ensuring their data privacy. All data collection will adhere to strict ethical guidelines to protect visitor anonymity and confidentiality. On a societal level, our project addresses the broader issue of math education and its accessibility. By developing a game that lowers entry barriers, we aim to contribute to more inclusive math education, potentially reducing the math achievement gap and fostering a greater appreciation for the subject among diverse learner populations.

Moreover, our project encourages the integration of innovative technology into informal education, raising questions about the role of digital tools in enhancing the visitor experience at science centres. This aligns with broader discussions about the evolving landscape of education and technology's impact on learning outcomes.

2 METHODOLOGY

This study uses a research-through-design approach where the design is a part of the research [6]. We have used the Design thinking framework and followed an iterative process: empathizing and understanding the pedagogical context, defining requirements, ideating, prototyping, and testing [7] [8]. For this study, we have done 20 observations on how visitors interact with installations in the exhibition and their experiences from it. We have collected qualitative and quantitative data from one interview with a developer of the exhibition and 5 interviews with visitor surveys. Moreover, we have conducted one workshop and one user test together with the target group of children in lower secondary school.

The process is divided into two phases, where the first phase was conducted at Mathrix, an interactive mathematics exhibition at Universeum Science Center. The focus in this phase is to understand the context and the users' experiences. We held an interview with one of the developers of Mathrix 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. Observations were also conducted, where we were focusing on how visitors at Mathrix interacted with the installations and how they went through the exhibition.

Figure 1. Exhibits at Mathrix, Universeum.

The second phase of this study was divided into three iterations all containing ideation, prototyping, and testing. Based on the findings from the context analysis, we created concepts for digital games with the goal of lowering the entry barriers for visitors. Throughout the three iterations, these concepts were developed and tested. At the end of the second iteration, two of the concepts were tested by six participants in a controlled user test. In the third and final iteration, the same two concepts were further developed and then tested with a class in a lower secondary school with 24 participants. The class tested the two digital games individually, and then answered questions about their experiences. A few days later, the same class visited the exhibition at Universeum Science Center for one hour, where

they were handed exercises to perform in the exhibition. Afterwards, the participants were handed a questionnaire with qualitative questions.

3 RESULTS

Using a research-through-design approach [9], part of the result has been two developed digital games. Through the design and development process, key considerations have been examined, providing a set of guidelines for developing an introductory interactive game intending to lower the visitors' entry barrier for a mathematics exhibition at a science centre. The two games explore different elements of recognition between the game and exhibition.

3.1 Game 1: Sifferjakten

The first game is called *Sifferjakten* (The Number Hunt) and it has the same name and mathematical concept as an installation at Mathrix with the same name (Fig. 2). The player should collect numbers in different number sequences in the right order.

Figure 2. The Sifferjakten game (left) and Sifferjakten exhibit at Mathrix (right)

When the player clicks the start button, a timer starts and the user can walk around as an avatar using the arrow keys. 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. If the user collect a correct number, it turns green and a sound effect is played indicating that you have selected correctly. If an incorrect number is selected, it turns red for a few seconds, another sound effect is played and the user gets 3 seconds added to their time. 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.

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.

3.2 Game 2: In i Labyrinten

The second game is called *In i labyrinten* (Into the Labyrinth). The players are supposed to navigate through a maze and solve equations on the way. The maze mimics the layout plan of Mathrix, providing a connection between the two (Fig. 3).

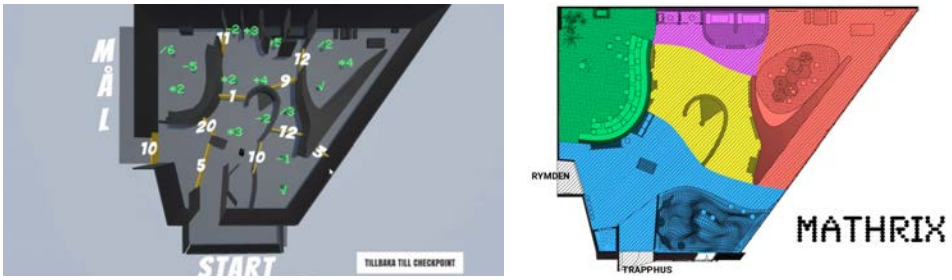

Figure 3. The In i Labyrinten game (left) and the layout of exhibits at Mathrix (right)

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. The user then navigates to a pop-up window were the task of the game is described. When the game starts, the player begins with a player number which is visible above the avatar. 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

3.3 Evaluation and Considerations

To evaluate if and how the games affected the exhibition visit, tests were made in the context of the exhibition. A class of 7th graders played the games, completed a questionnaire, visited the exhibition, and subsequently filled in another questionnaire. The answers from the questionnaires led to insights regarding the games and their ability to facilitate the visit.

Participants acknowledging a recognition between the game and the exhibition was typically stated as a positive thing. However, the task-based connection between *Sifferjakten* game and *Sifferjakten* exhibit at Mathrix was recognized by participants to a larger extent than the spatial connection between *In i labyrinten* game and the Mathrix exhibition. When asked whether or not the games facilitated the exhibition visit in any way, the answers were mixed. 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 *Sifferjakten* game.

Typical answers regarding the connection between the games and the exhibition were:

- *"It was very similar to the labyrinth game. We had to walk around and solve different tasks."*
- *"I felt that the games were helpful when we played Fibonacci."*
- *"I recognized the environment in the game and in Mathrix. It had a similar vibe. I felt like I was using my math techniques in Mathrix as I did in the games."*
- *"I thought it helped because I recognized things."*
- *"I learned quite a bit, especially the game where you had to input numbers in a sequence."*

These responses indicate that the users had help from playing the games prior to their visit to Mathrix. We found that connections were made regarding physical similarities between the digital game and the physical exhibition, similarities in how the games were played, and also regarding using the same mathematical concepts. A typical response was that these connections helped the users when interacting in the exhibition.

The project resulted in considerations for designing and developing an introductory interactive game intending to lower the visitors' entry barrier for a mathematics exhibition at a science centre. The considerations are divided into three categories A, B, C:

A) Lowering entry barriers

• Provide a distinct connection between game and exhibition
• Consider in which way mathematics is Incorporated in the game.
• Consider the importance of involving the teacher

Three important considerations regarding lowering the entry barriers for the exhibition were discovered. For example, it is worth considering providing a distinct connection between the game and the exhibition. The three main connections explored in this study was physical resemblance, similar mathematical content and similar gameplay.

B) General game design

• Consider the importance of a design framework
• Consider the game's degree of difficulty

• Provide an explicit start and end of the game
• Make the game understandable without an explanatory text

In summary, this evaluation highlights considerations regarding general game design. The study showed that the general game design affects the games' ability to lower entry barriers. For example, the degree of difficulty, regarding both gameplay mechanics and mathematical content, is worth considering. 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.

C) User testing

• Consider the game's visual appeal
• Consider maximizing functional prototypes during the development

Two considerations regarding user testing and prototype fidelity were discovered. In this study, the visual appeal and some functionalities in the games were of low priority. However, during user testing, these flaws were often mentioned as potential areas for improvement. This suggests that feedback regarding previously unknown flaws might not have been received, as these already acknowledged issues took precedence.

4 DISCUSSION

The key takeaways and insights from the user tests are based on qualitative feedback. We have identified different usage patterns and experiences with digital games as an introductory component. However, it is important to note that these findings rely on qualitative data and have been subject to interpretation. Quantitative data collection primarily occurred during the final user test. Nonetheless, due to the relatively small sample size of only 24 participants, the quantitative data does not yield statistically significant insights.

In addressing ethical concerns, our research project is committed to both respecting the well-being of our science centre visitors and maintaining the educational integrity of their experience. We have strived for transparency and consent, ensuring visitors fully comprehend the game's purpose and data collection process while respecting their privacy. Data privacy measures have been implemented to protect personal information. We have also been aware of bias and exclusivity, actively designing the game to avoid maintaining stereotypes or discrimination. In terms of transparency, we have striven to openly communicate our intentions and avoid manipulative tactics. Furthermore, accessibility is crucial, with the games aimed to accommodate individuals with disabilities even though sight impairment is a hinder for using the games. This ethical framework promotes inclusivity, even as we acknowledge room for continuous improvement in future work.

When it comes to designing games for science centres, we must consider how our project can impact education and society at large. First and foremost, there's the issue of educational fairness. Our game could reshape how people learn math, potentially either bridging or widening gaps in math learning opportunities. Moreover, it is important to acknowledge that not everyone has equal access to technology. The use of digital games could increase disparities between socio-economic groups. Additionally, we should question whether gamifying education is a sustainable approach in the long run. Does it genuinely enhance motivation and learning strategies? Our project might also intersect with broader educational policies, influencing how math is taught in science centres and schools. Furthermore, we should recognize that public perceptions of the role of science centres in education and the integration of digital tools can be influenced by our initiative. Encouraging the use of digital games also raises concerns about excessive reliance on technology for learning. Finally, our project could stimulate discussions about innovative methods of teaching math. While these points underscore our commitment to our project's objectives, they also underscore the need for ongoing assessment and adaptability to ensure a positive societal impact.

Future work includes exploring our approach of using introductory games for lowering entry barriers also for other topics than mathematics and for other contexts.

5 CONCLUSIONS

In conclusion, our project seeks to enhance the visitor experience in mathematics exhibitions through the design of interactive games. By fostering informal learning principles, we aim to lower the entry threshold for visitors, promote positive attitudes towards mathematics, and encourage deeper engagement with mathematical concepts in an authentic and meaningful manner. Through our research, we hope to inspire further exploration and utilization of game-based approaches to enhance pedagogical experiences within science centres and mathematics education.

The project has produced three categories of considerations for the design and development of interactive games intended to enhance visitors' engagement with mathematics exhibitions in science centres. These considerations encompass a) lowering entry barriers, b) general game design, and c) user testing. Our findings offer valuable insights into the development of effective educational tools, enhancing the overall experience of mathematics learning within the context of science centres.

In conclusion, this study has focused on utilizing digital games not as primary learning tools but as preparatory elements to facilitate informal learning at mathematics exhibitions, thereby bridging the classroom-exhibition gap. Ethical and societal considerations are at the core of our project. On a societal level, our work addresses issues of math education accessibility, aiming to reduce the achievement gap and promote math appreciation among diverse learners. Furthermore, by incorporating innovative technology into informal education, our project sparks discussions about the evolving role of digital tools in enhancing the visitor experience at science centres, contributing to broader conversations about technology's impact on learning outcomes.

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