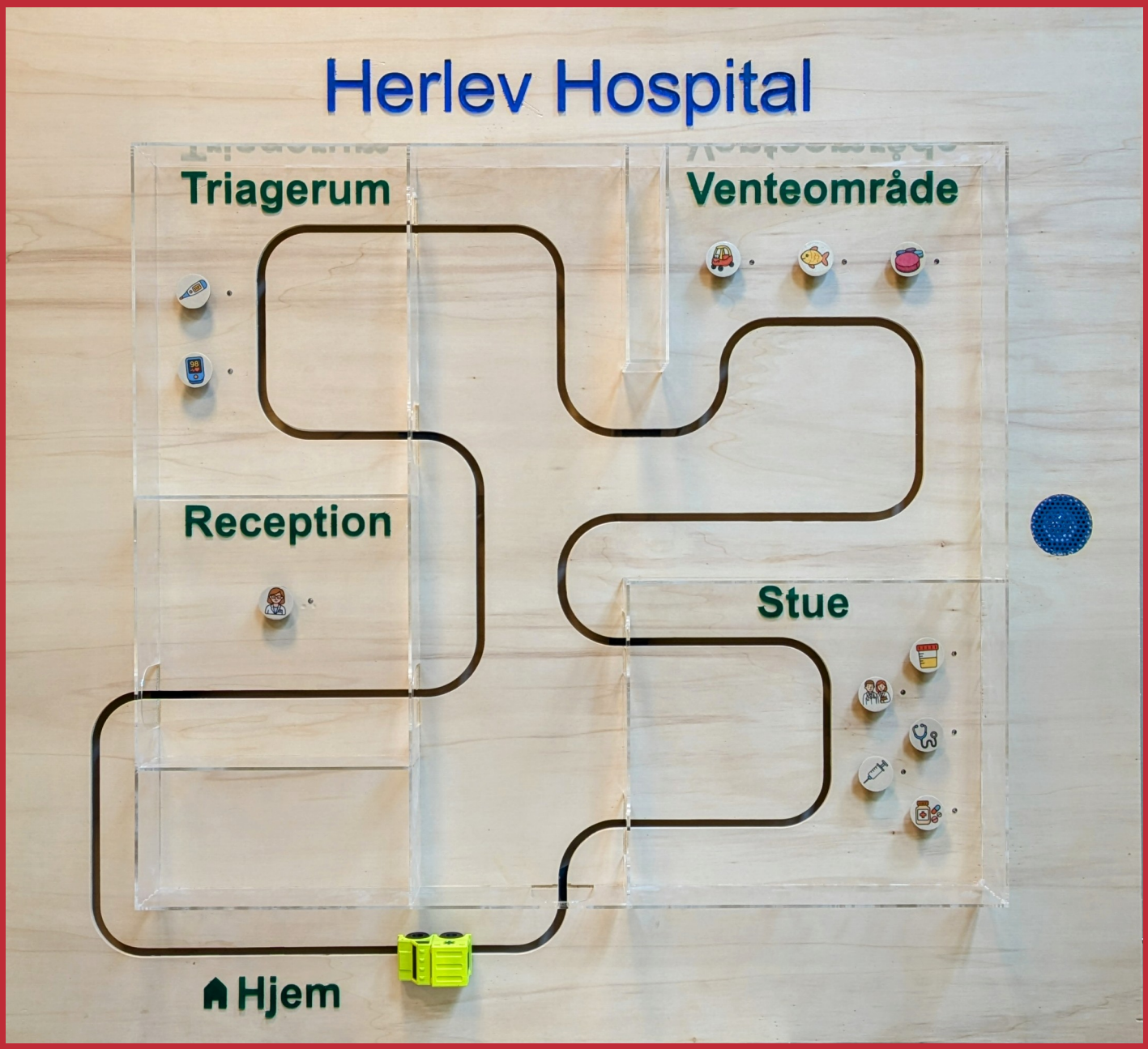
DTU Compute
Department of Applied Mathematics and Computer Science

Developing Interactive Solutions to Reduce Children's Anxiety in the Pediatric Emergency Department

Master Thesis



Developing Interactive Solutions to Reduce Children's Anxiety in the Pediatric Emergency Department

Master Thesis
July, 2025

By
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and
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Approval

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The research also involved collaboration with Herlev Hospital (Borgmester Ib Juuls Vej 1, 2730 Herlev).

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Abstract

Hospital visits can be a distressing experience for young children, particularly in emergency settings where anxiety is often exacerbated by unfamiliar environments, medical procedures, and lack of understanding. This thesis explores how interactive, play-based systems can be designed to reduce anxiety in children aged 4-7 visiting the Pediatric Emergency Department (PED) at Herlev Hospital. Three low-fidelity concepts were tested with children in clinical settings, and ”Ambulance Adventure,” an interactive, wall-mounted board game, was selected for high-fidelity development. The final prototype used RFID-triggered interactions and audio-based explanations to guide children through a simplified hospital journey. A mixed-methods evaluation with 13 participants indicated a statistically significant reduction in self-reported anxiety, as measured by the Wong-Baker FACES scale (mean score decreased from 2.46 to 1.54, $p = 0.027$). Observational assessments using the modified Yale Preoperative Anxiety Scale (m-YPAS) showed a smaller, non-significant reduction (mean score decreased from 28.39 to 26.60, $p = 0.152$). Even so, the prototype was positively received by both children and caregivers, indicating strong potential and warranting further exploration and refinement.

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Georgia Tsoukala and Konstantina Freri,
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1 Introduction

1.1 Context and Motivation

In the domain of pediatric healthcare, visiting an emergency department can be a distressing and anxiety-inducing experience for children and their families. This anxiety not only affects children's cooperation during treatment but may also impact their long-term emotional well-being.

Recognizing the importance of supporting children beyond clinical procedures, this Master's Thesis investigates the design, development and evaluation of interactive, play-based solutions aimed at reducing pediatric anxiety during emergency visits. By targeting the waiting period in the PED, a time often overlooked, the project focuses on developing a physical intervention that is intuitive, developmentally appropriate and engaging for children aged 4 to 7.

Various strategies to alleviate pediatric anxiety are implemented by different hospitals, such as employing medical clowns or specially trained nurses. This project, conducted in close collaboration with Herlev Hospital, explores the specific approaches implemented there. This partnership provides a unique opportunity to combine real-world observations and clinical insights from healthcare professionals with human-centered research and technology development methods.

A key area of interest lies in examining different types of interventions and their potential to mitigate anxiety. Ultimately, the motivation behind this thesis is to contribute to the development of a more child-centered emergency care environment, one where anxiety is recognized and addressed as a central aspect of the patient experience.

In order to design effective interventions, it is first necessary to develop a comprehensive understanding of pediatric anxiety, its causes, impact, and how it can be reliably measured.

1.2 Understanding Pediatric Anxiety in Emergency Settings

1.2.1 Definition and Types of Anxiety

Anxiety is a fundamental brain response to perceived danger, manifesting as an emotion that organisms actively attempt to avoid. This response, present from infancy, exists on a continuum from mild to severe and is not inherently pathological, as it serves an adaptive function by promoting avoidance of potential threats [1]. Physiologically, anxiety is characterized by increased tension, worried thoughts, and bodily responses such as elevated blood pressure [2].

Anxiety can be categorized into state anxiety and trait anxiety, each representing distinct aspects of the anxiety spectrum. State anxiety refers to a temporary emotional response triggered by adverse events or specific stressors. It is characterized by heightened sympathetic nervous system activity, leading to physiological responses such as increased heart rate and alertness. However, state anxiety is transient and does not necessarily indicate any underlying pathological condition [3].

In contrast, trait anxiety is a stable personality trait that predisposes individuals to respond with persistent concerns, troubles, and worries across various situations. Unlike state anxiety, trait anxiety is considered an enduring characteristic of an individual's personality

and is often linked to psychopathological conditions and chronic high physiological arousal [3]. High trait-anxious individuals tend to experience heightened state anxiety in stressful situations, indicating a strong interaction between these two forms of anxiety [4].

Anxiety is distinct from fear, though the terms are often used interchangeably. Anxiety is a future-oriented, long-lasting state broadly focused on diffuse threats, whereas fear is a present-oriented, short-lived response to a specific, identifiable danger [2]. While significant research has been conducted on pediatric pain and its management [5, 6, 7], fewer studies focus explicitly on anxiety assessment methods and the differentiation between pain and anxiety. The lack of clear differentiation has led to challenges in effectively addressing anxiety in pediatric emergency care [8].

1.2.2 Causes and Triggers of Pediatric Anxiety in Emergency Departments (EDs)

Preventive clinic visits, acute care, medical procedures, and hospitalization can be emotionally threatening and psychologically traumatizing for pediatric patients, as they often experience heightened anxiety in emergency medical settings due to a combination of environmental, psychological, and physiological factors, Figure 1.1.

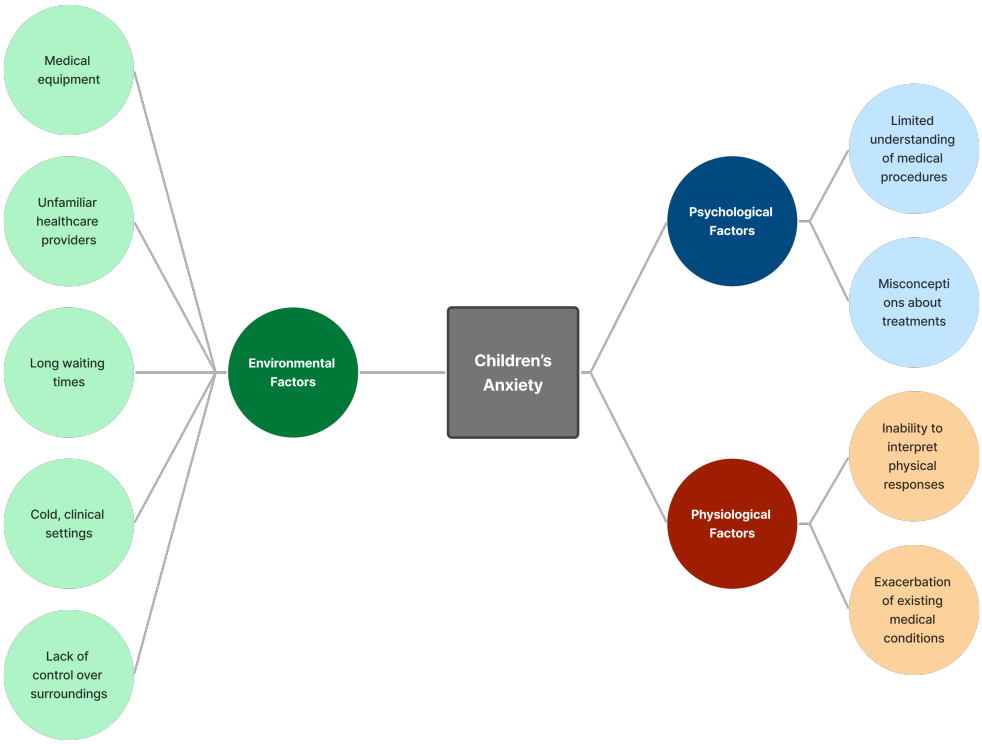


Figure 1.1: Anxiety factors in PEDs, based on findings synthesized from the literature

The environmental factors of emergency medical settings contribute significantly to heightened anxiety in pediatric patients. The unfamiliar and chaotic atmosphere, filled with medical equipment, unfamiliar healthcare providers, and a fast-paced nature of care, can induce fear and uncertainty. Additionally, prolonged waiting times increase distress in children [9]. Going to the hospital can intensify anxiety, as children must leave their home

and caregivers, disrupting their routines. Hospital wards are often perceived as “cold and medical” environments associated with pain, particularly for elementary school-aged children undergoing critical developmental adjustments [10]. Moreover, due to their lack of control children may develop a sense of helplessness, which coupled with fear and pain can cause them to feel powerless in healthcare settings. All these can delay treatment and increase procedure times [11].

The psychological factors contributing to pediatric anxiety in emergency medical settings stem largely from children’s cognitive development and limited understanding of medical procedures. Misconceptions about treatments and interventions can amplify fear, particularly when explanations about their necessity and process are unclear. Without adequate information, children may experience heightened distress, as uncertainty can make medical experiences more intimidating [12].

The physiological factors of anxiety can significantly contribute to distress in pediatric patients. Physical symptoms such as increased heart rate and hyperventilation can be particularly alarming for children who may not understand these bodily responses. For those with pre-existing medical conditions, such as asthma or gastrointestinal illnesses, anxiety can be further heightened by fears about their health and potential medical emergencies. This creates a cyclical effect, where anxiety intensifies physical symptoms, which in turn exacerbates emotional distress [13].

Understanding, identifying, and addressing these factors are essential for improving pediatric patient care in emergency medical settings by effectively mitigating anxiety in young patients.

1.2.3 Methods for Measuring Anxiety in Children

The measurement of anxiety in children can be broadly categorized into self-report methods, observational methods, and physiological assessments, Figure 1.2. Each of these approaches has its strengths and limitations, and their applicability depends on the child’s age, verbal ability, and the clinical setting.

1.2.3.1 Self-Report Methods

Self-reported anxiety assessments rely on children’s ability to understand and express their emotional state.

- **State-Trait Anxiety Inventory for Children (STAI-C)**: Developed by Spielberger et al. (1973) [14], the STAI-C is widely regarded as the gold standard for measuring childhood anxiety. It consists of 40 items, scored on a 3-point rating scale, with higher scores indicating greater anxiety [15, 16]. The STAI-C is divided into two subscales: state anxiety (20 items), which assesses temporary symptoms, and trait anxiety (20 items), which measures chronic or generalized anxiety. It is designed for children 9 to 12 years but can also be used in children as young as 5 years old. It takes approximately 15-20 minutes to complete. Despite its validity, the STAI-C is lengthy and not suitable for younger children or fast-paced environments like the ED [15].
- **Revised Children’s Manifest Anxiety Scale (RCMAS)**: Originally derived from the Children’s Manifest Anxiety Scale (CMAS), the RCMAS developed by Reynolds and Richmond (1978) [17], comprises 37 dichotomous (Yes/No) items assessing generalized anxiety in children. A total anxiety score is computed based on 28 anxiety items (divided into 3 subscales: physiological anxiety, worry/oversensitivity, social concerns/concentration). The remaining 9 items on the RCMAS constitute the Lie subscale. It takes approximately 10-15 minutes to complete. It has been widely

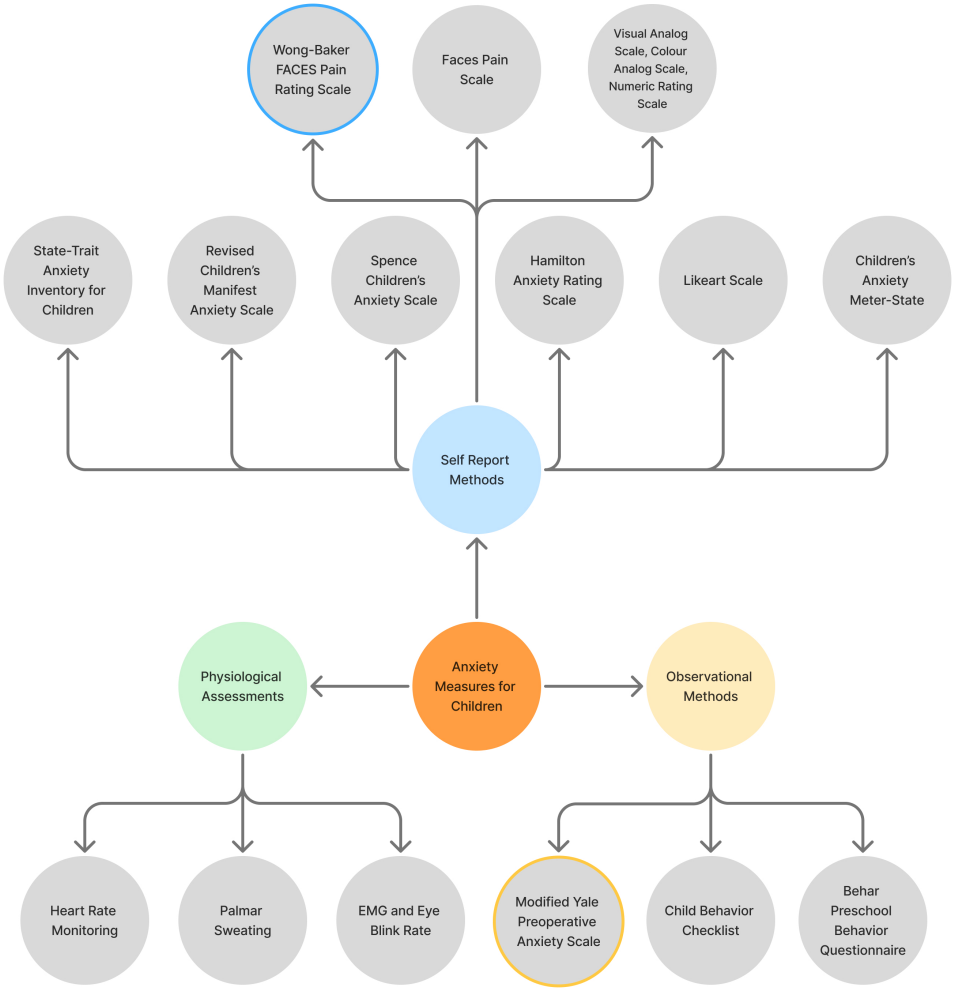


Figure 1.2: Overview of methods for measuring anxiety in children, highlighting the ones later used in this report

used in pediatric research but, like the STAI-C, its length and complexity limit its clinical utility in emergency settings [8, 18].

- **Spence Children's Anxiety Scale (SCAS)**: Developed by Spence (1998) [19], the SCAS is a 44-item self-report questionnaire assessing six domains of anxiety: separation anxiety, social phobia, obsessive-compulsive disorder, panic/agoraphobia, physical injury fears, and generalized anxiety. It is suitable for children aged 8 to 12 years and has demonstrated strong psychometric properties and it takes approximately 10 minutes to complete.
- **Hamilton Anxiety Rating Scale (HAM-A)**: Originally developed for adults by Hamilton (1959) [20], the HAM-A consists of 14 clinician-rated items assessing both psychological and somatic symptoms of anxiety and can be completed in 10-20 minutes. Modified versions have been adapted for use with children, although its applicability in pediatric settings requires further validation. [21]
- **Likert Scale Assessments**: The Likert scale is a simpler alternative used to gauge anxiety levels quickly. This one-item scale asks children to rate their anxiety on a scale from 1 (not anxious) to 4 (very anxious). Research has shown that the Likert scale can serve as an effective substitute for the STAI-C in clinical settings where time constraints are a concern [15].
- **Children's Anxiety Meter-State (CAM-S)**: Recognizing the need for brief and efficient tools in fast-paced clinical environments, the CAM-S by Kleiber et al. (2002) was developed as a concise measure of state anxiety. The CAM, Figure 1.3, is a visual tool resembling a vertical mercury thermometer, in which children are asked to show how much worry or anxious feelings they have by showing how far up the thermometer their feelings are.Its brevity and simplicity make it particularly useful in settings like PEDs. [18]

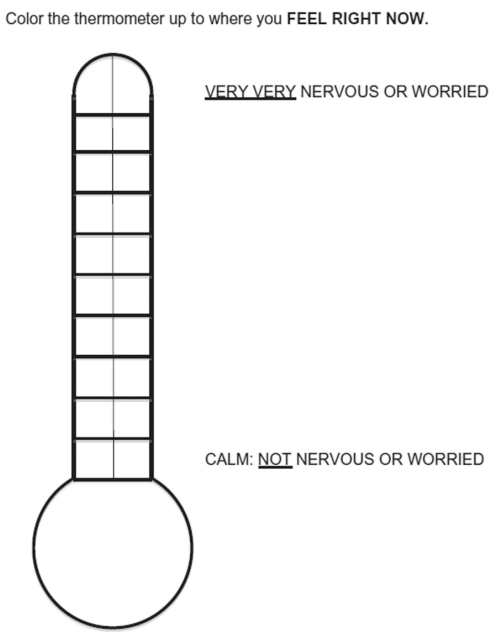


Figure 1.3: Children's Anxiety Meter-State (CAM-S) [18]

In younger children, pain and anxiety are often expressed interchangeably. Therefore, certain pain scales can serve as proxies for assessing anxiety:

- **Wong-Baker Faces Pain Rating Scale (WBFPRS)**: The Wong-Baker FACES, Figure 1.4, developed by Wong and Baker (1983) [22] is a horizontal scale of 6 hand-drawn faces, scored from 0 to 10, that range from a smiling "no hurt" face on the left to a crying "hurts worst" face on the right. Although this scale is widely preferred by children of all ages and nurses, it may conflate emotional distress (smiles, tears) with pain intensity. [23]

Figure 1.4: Wong Baker Faces Pain Rating Scale [24]

- **Faces Pain Scale (FPS)**: The FPS, Figure 1.5, developed by Bieri et al. (1990) [25] consists of a series of horizontal gender-neutral faces that depict a neutral facial expression of "no pain" at the left to "most pain possible" expression at the right. The FPS has 7 faces (scored 0 - 6). The Faces Pain Scale Revised (FPS-R) that includes 6 faces (scored 0 - 5), was adapted from the Faces Pain Scale to make it possible to score the sensation of pain on the widely accepted 0-to-10 metric. [23] This scale is particularly recommended for use with very young children and avoids the emotional cues present in the WBFPRS. [26]

Figure 1.5: Faces Pain Scale, scored 0-6 [23]

- **Visual Analog Scale (VAS)**, **Colour Analog Scale (CAS)**, **Numeric Rating Scale (NRS)**: These scales require children to rate their pain intensity on visual or numerical scales and have been used to infer anxiety levels when children cannot distinguish between emotional and physical distress. [27]

1.2.3.2 Observational Methods

Since young children may struggle to articulate their anxiety levels, observational methods provide an alternative means of assessment. These methods evaluate visible behaviors and signs of distress, such as facial expressions, body movements, and vocalizations.

- **Modified Yale Preoperative Anxiety Scale (m-YPAS)**: Originally designed for children aged 2-6 years undergoing surgery, the m-YPAS [28] has since been adapted for older children and ED use. It assesses anxiety based on five behavioral categories: activity, vocalization, emotional expressivity, state of arousal, and use of parents. Each item rating is 1 to 4 or 1 to 6, according to the category. The total m-YPAS score ranges from 23.33 to 100, with higher values indicating greater anxiety. The m-YPAS is advantageous in emergency settings due to the fact that it can be completed in approximately 5 minutes [15, 29].

- **Child Behavior Checklist (CBCL)**: The CBCL is a parent-report questionnaire consisting of 113 items that assesses a broad range of emotional and behavioral problems in children. There are separate versions for preschool (ages 1.5-5) and school-age (ages 6-18) children. The checklists consist of statements about the child (such as "argues a lot"). Responses are coded as 0 (not true), 1 (somewhat or sometimes true), or 2 (very true or often true). Completion time is approximately 15-20 minutes. [21]

- **Behar Preschool Behavior Questionnaire and Behavior Rating Scale for Blood Sampling**: These tools involve adult observers rating children's behaviors to assess anxiety levels, especially in specific medical contexts like blood sampling. Teachers, parents, or clinicians rate children's behaviors to determine anxiety levels. [8]

While observational methods are useful, the lack of self-reporting is a limitation as anxiety is an inherently subjective experience and these methods may not always reflect that experience. [29]

1.2.3.3 Physiological Assessments

Anxiety also manifests through physiological responses, making biometric measures a useful complementary tool in anxiety assessment. Common physiological indicators include [8]:

- **Heart Rate Monitoring**: Increased heart rate is a well-documented physiological response to anxiety. Studies have used heart rate variability as a reliable marker of anxiety states in children.

- **Palmar Sweating (Electrodermal Activity)**: Increased sweating is a reliable indicator of sympathetic nervous system arousal in response to anxiety, though it is less commonly used in pediatric settings.

- **Electromyography (EMG) and Eye Blink Rate**: These measures have been employed in laboratory settings to assess anxiety but are rarely practical for clinical use due to the complexity of administration.

While physiological measures provide objective data, they assess only one component of anxiety and often require specialized equipment, making them less feasible in fast-paced ED environments.

1.2.4 Impact of Anxiety on Medical Procedures and Long-Term Effects

Anxiety in pediatric medical settings can have profound short- and long-term consequences. In the ED, heightened anxiety can lead to increased distress, lack of cooperation with medical personnel, and greater difficulty in performing necessary procedures, such as venipunctures or sedation [16, 5]. Children experiencing severe anxiety may also require higher levels of sedation, leading to increased medical risk and extended procedure times [16].

Beyond the immediate setting, repeated exposure to distressing medical experiences can contribute to long-term psychological consequences, including the development of phobias related to medical staff or hospitals, avoidance of medical care, and emotional distress that persists into adulthood [15, 5, 11]. Pediatric patients with anxiety are also at higher risk of noncompliance with medical recommendations, potentially affecting their long-term health outcomes [15].

1.3 Thesis Overview

This thesis followed the IMRaD structure (Introduction, Methods, Results, and Discussion) which has become the standard for research reports due to its consistency, and adaptability. It serves primarily as a framework and it is not rigid but flexible and adaptable. Modern research papers often include additional chapters beyond the core IMRaD structure to improve clarity, organization, and completeness [30]. In this project, two such chapters were added, one describing the current state of pediatric emergency care at Herlev Hospital, and one reviewing related work. These additions help contextualize the study and connect it to existing literature.

The structure of the thesis is as follows:

- **Chapter 1 - Introduction:** Presents the background and context of pediatric anxiety, explores causes and assessment methods, and explains the motivation behind this project.
- **Chapter 2 - Current State of Pediatric Emergency Care at Herlev Hospital:** Provides an overview of the Pediatric Emergency Department, its layout, the patient journey, and current practices for identifying and managing anxiety.
- **Chapter 3 - Related Work:** Reviews existing non-pharmaceutical interventions aimed at reducing children's anxiety in healthcare settings and categorizes them.
- **Chapter 4 - Methods:** Explains the overall design approach and methodology used to research, design, develop and test the interventions.
- **Chapter 5 - Results:** Presents the outcomes of the design process and user testings.
- **Chapter 6 - Discussion:** Interprets the results, reflects on the study's limitations, and outlines opportunities for future work.
- **Chapter 7 - Conclusion:** Summarizes the contributions of the thesis and the potential impact of the developed intervention on pediatric emergency care.

2 Current State of Pediatric Emergency Care at Herlev Hospital

This chapter provides an in-depth look at the Pediatric Emergency Department (PED) at Herlev Hospital, which offers specialized treatment for children and adolescents. The content is informed by research from the hospital's official website, on-site observations, and interviews with medical personnel.

2.1 Overview of Herlev Hospital's PED

Herlev Hospital [31] has been a key institution in Denmark's healthcare system since its establishment in 1976. The Department for Children and Adolescents (Afdeling for Børn og Unge) operates as a "hospital within a hospital," with its own reception area dedicated to the examination, treatment, and care of young patients.

The department handles both acute and chronic conditions in children from premature birth to 17 years old and manages approximately 12,000 inpatient sessions and 26,600 outpatient consultations annually, with 80% of cases being acute and 20% chronic conditions. The medical team includes doctors, nurses, psychologists, social workers, and other specialists. Additional staff such as dietitians, physiotherapists, occupational therapists, and hospital clowns contribute to creating a supportive environment for young patients.

For emergency cases, children aged 0-12 years are referred to the Pediatric Emergency Room (Børnelægevagten) by general practitioners or via the emergency hotline (1813), while those over 12 years old are directed to the main Emergency Department. Certain cases, such as injuries to the arms and legs or lacerations requiring stitches in children over two years old, are treated in the general emergency department rather than the pediatric unit.

2.2 General Layout of the Department

The Pediatric Emergency Department (PED) consists of several areas, Figure 2.1, designed to support the care and comfort of young patients and their families.

The triage room, Figure 2.2, is where nurses first meet their patients, typically within 10 minutes of the child's arrival at the hospital. In this room, children undergo pre-examinations such as the Pediatric Early Warning Score (PEWS), which includes measurements of heart rate, respiratory rate, blood pressure, and temperature. Additionally, self-reporting scales are used to quantify the child's pain level.

The single-patient rooms, Figure 2.3, are used to monitor urgent pediatric patients while they wait for treatment or lab results. In these rooms, children are weighed and their height is measured as part of the initial assessment. Depending on their condition, they may also be asked to provide blood or urine samples. These rooms are also where children receive medication or any other necessary medical treatment. Each room contains a hospital bed equipped with a tablet, essential medical equipment, and a couple of chairs to accommodate the parents.

The common waiting area, Figure 2.4, is shared between the ER and the Outpatient Clinic and is used by patients and their families while waiting to be called for triage or examination. This space is accessible to all children and their caregivers, and it is equipped with

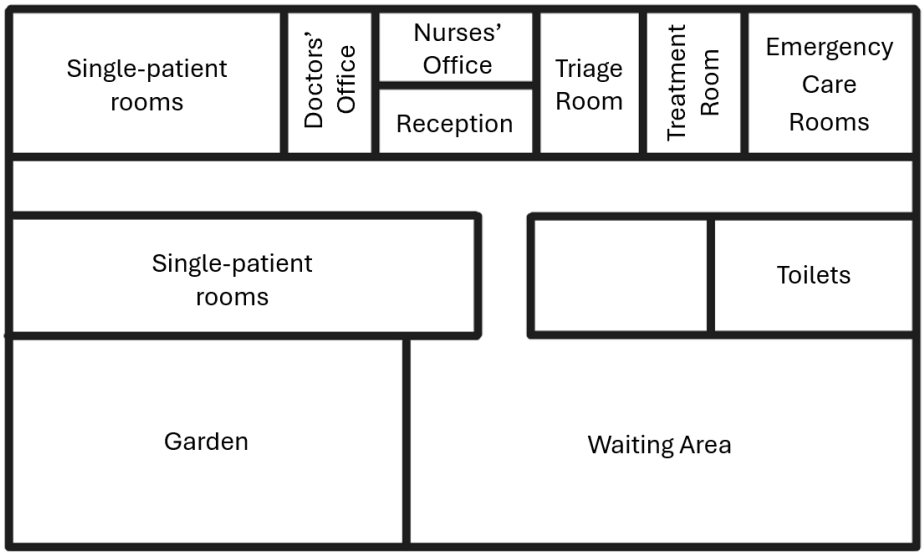


Figure 2.1: Layout of the PED

Figure 2.2: Triage room

Figure 2.3: Single-patient room

books, toy cars and bikes, a foosball table, coloring supplies, and an aquarium, creating a welcoming and child-friendly atmosphere. The walls are decorated with stickers and posters, and the seating includes a variety of chairs, tables, and sofas, including some colorful round ones.

Figure 2.4: Waiting area

Accessible through the waiting area, “Den Røde Have”, Figure 2.5, is a garden space designed to offer children and their parents the option to play outside the hospital setting. This outdoor area features a hilly red rubber surface, balance beams, stepping stones, and benches.

Additional facilities include a treatment room (Skadestue) for children under the age of 2, where injuries like broken bones, cuts that need stitches, or sprains can be treated, as well as two emergency care rooms (Akutstuer) for patients brought in by ambulance who need immediate attention. The area also includes nurses’ and doctors’ offices, toilets and a reception desk that handles patient coordination.

Figure 2.5: Garden

2.3 Patient Journey

The patient journey at Herlev Hospital's Pediatric Emergency Department (PED), Figure 2.6, follows a structured process. From arrival to discharge or hospitalization, children and their families follow a predetermined path through check-in, triage, waiting and consultation.

Upon arrival at the hospital, children with their families follow a white line on the floor leading to the PED reception area. At the Children and Youth Reception (Børne- og Ungemodtagelsen), families check in with a reception secretary, where the child's name, age, symptoms and referral details are validated.

After check-in, families wait in the common waiting area until a nurse is available to take them for an initial triage assessment. Triage typically occurs within 10 minutes of arrival, where nurses assess the child's temperature, breathing and pain levels using standardized pain scales. If a child has a fever for example, they may be given paracetamol to reduce discomfort while waiting (Appendix A.1).

Following triage, patients are either sent to a single-patient room if space is available or return to the waiting area if their condition is stable but no rooms are available. The waiting time varies by triage category:

- **Green:** Up to 2 hours wait
- **Yellow:** Seen within 1 hour
- **Orange:** Requires a doctor within 15 minutes
- **Red:** Immediate care needed

However, due to high patient volume, children may sometimes wait 4-5 hours before seeing a doctor. In such cases, families are allowed to leave the waiting area, and nurses communicate with parents when it is time for their child's consultation (Appendix A.1).

Once called in for a medical consultation, the child is either moved from the waiting area to an examination room or seen in their single-patient room if already placed there after triage. The doctor meets with the family only once or twice during their visit and, in some cases, may not see the child until after diagnostic tests like blood samples are completed.

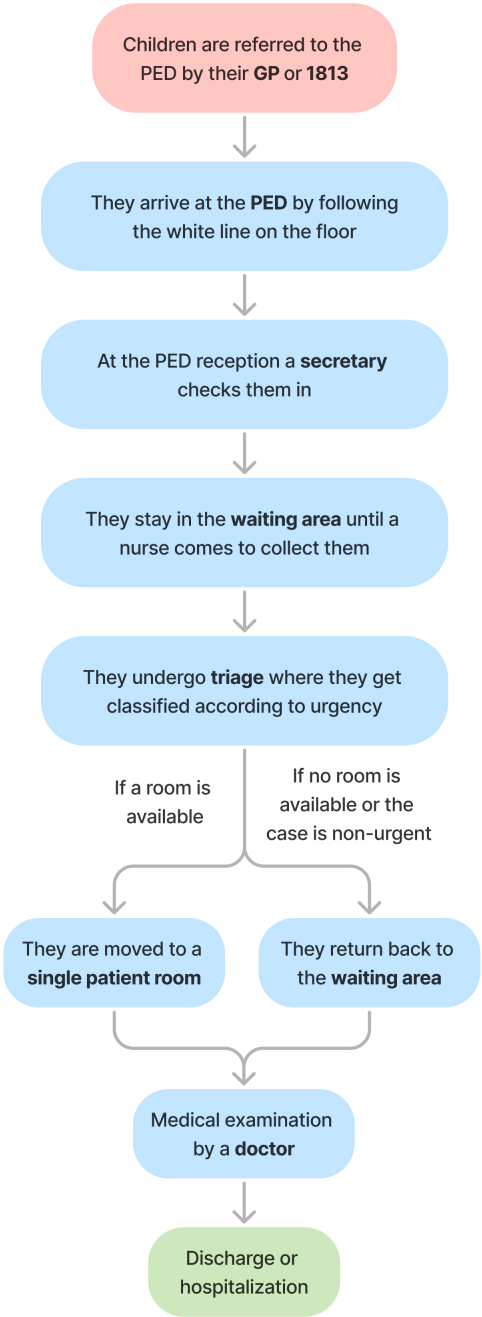


Figure 2.6: Patient journey at Herlev Hospital's PED

Nurses often communicate patient conditions to the doctor, who may decide on further diagnostic tests or treatment plans without direct consultation. When a doctor does see the child, the consultation lasts approximately 10-15 minutes, during which they conduct a physical examination, discuss symptoms, and determine the necessary treatment steps.

If required, additional tests or specialist consultations are arranged before a final decision is made. After evaluation, the child may be discharged with treatment instructions, sent for further observation, or admitted to the pediatric ward for extended care. Throughout the stay, medical staff continuously monitor the child's condition and adjust treatment as needed.

2.4 Recognizing and Managing Anxiety

To gain a deeper understanding of how anxiety manifests in children, as well as the strategies used to assess and manage it at Herlev Hospital's Pediatric Emergency Department (PED), interviews were conducted with healthcare professionals, including experienced nurses. This section presents the key findings from these interviews, while the full interview transcripts can be found in Appendix A.1.

2.4.1 Identifying Signs of Anxiety

Recognizing anxiety in children at the Pediatric Emergency Department (PED) requires experience and observational skills. Nurses rely on both verbal and non-verbal cues to assess a child's emotional state. Common signs include:

- **Verbal expressions:** Some children explicitly state their anxiety by saying, "I am nervous" or "I do not want to do this."
- **Body language and facial expressions:** Children may avoid eye contact, look down, withdraw into themselves, or physically move closer to their parents.
- **Physical behaviors:** Signs such as crying, repeatedly saying "No", or resisting medical procedures can indicate distress.
- **Learned professional intuition:** Experienced nurses develop the ability to distinguish between fear and other emotions based on subtle cues, such as changes in tone of voice or behavior patterns.

2.4.2 Measuring Anxiety Levels

Healthcare providers at Herlev Hospital use self-assessment tools to gauge anxiety levels:

1. **Wong-Baker FACES Pain Rating Scale**: A widely used tool (see *Section 1.2.3.1*) that asks children to point to a face that best represents their pain, Figure 2.7. Nurses must interpret whether high pain scores may actually reflect fear.
2. **Scary Scale by Stephanie Thurillet** [32]: A scale, Figure 2.8, that allows children to self-report their fear levels, helping healthcare providers distinguish between pain and anxiety. While it is not yet a globally standardized tool, it is currently being piloted at the hospital to explore its clinical usefulness. This scale rates fear with a score ranging from 0 to 10 (rated two by two, gradually) so that is consistent with pain rating scales.

Although biometric tools such as smartwatches could potentially be used to track physiological indicators of anxiety, such as elevated heart rate, nurses at the hospital note a key limitation. In clinical practice, an increased heart rate is typically interpreted as a sign of a medical issue rather than as a symptom of anxiety, making it less reliable as a standalone measure of emotional distress.

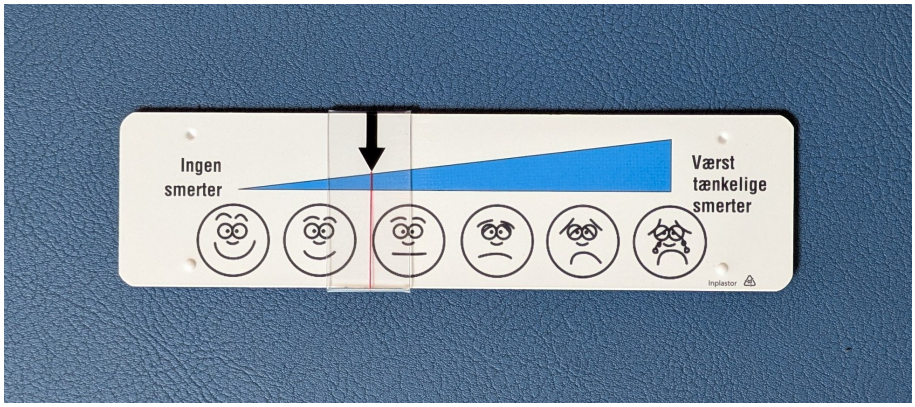


Figure 2.7: Wong-Baker FACES Scale used at Herlev Hospital

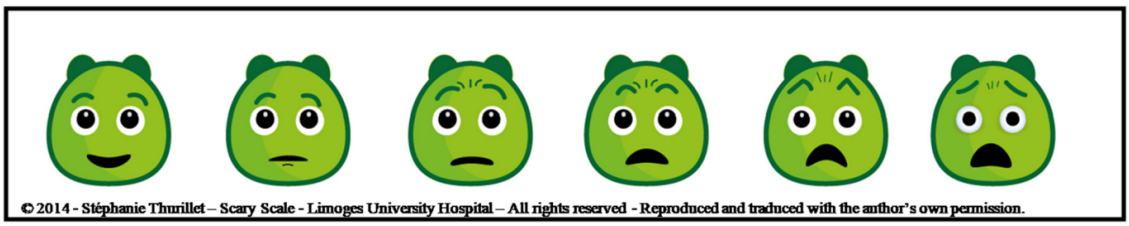


Figure 2.8: Scary Scale by Stephanie Thurillet [32]

2.4.3 Triggers of Anxiety in Children

Several environmental and procedural factors contribute to children's distress at the hospital according to nurses:

- **Medical procedures:** Blood samples, injections, and stitches are among the most feared experiences.
- **Fear of the unknown:** Not knowing what will happen next increases fear levels.
- **White coat syndrome:** Many children develop anxiety in response to hospital uniforms and the sterile white environment.
- **Visual environment:** The predominantly white hospital setting can feel cold and intimidating.
- **Parental anxiety:** Children often mirror their parents' emotional states; if a parent is visibly distressed, the child is likely to feel more anxious.

2.4.4 Strategies for Managing and Reducing Anxiety

Healthcare professionals at Herlev Hospital employ a variety of techniques, Figure 2.9, to alleviate children's anxiety:

- **Distraction techniques:**
  - Watching TV or listening to music
  - Engaging in conversations about everyday topics or subjects of interest to the child
  - Playing with bubbles or toys
  - Utilizing Virtual Reality (VR) headsets, Figure 2.9a

(a) VR headsets

(b) Wall stickers

(c) Laughing gas

(d) Hospital clowns

Figure 2.9: Managing and reducing anxiety techniques at Herlev Hospital

- **Environmental modifications:**
  - Incorporating posters, sticker decorations, Figure 2.9b, and colorful visuals to soften the sterile appearance of the hospital
  - Painting walls in child-friendly designs (although currently permitted in only one room)
- **Medical interventions:**
  - The use of sedatives when necessary, particularly for highly anxious children undergoing procedures
  - Laughing gas (nitrous oxide), Figure 2.9c, may be used to reduce anxiety and pain, especially for blood draws and minor procedures
- **Psychological and interactive engagement:**
  - Singing or using humor to comfort children
  - Encouraging play as a means of reducing stress
  - Incorporating professional hospital clowns [33], Figure 2.9d, to entertain and relax children
- **Parental involvement:** Encouraging parents to participate in distraction techniques and comfort their child during procedures.

However, while Herlev Hospital employs a variety of techniques to reduce anxiety, these strategies are often used with limitations. For example, not all children are willing or able to use VR headsets, and in practice, these are often underutilized because nurses must facilitate their use and may be too busy or forget to offer them during peak times.

Despite all these efforts, hospital staff have expressed an ongoing interest in improving the care experience for children, often asking, “Can we do this better?” This highlights a need for continued exploration of alternative anxiety-reducing interventions.

3 Related Work

A literature review was conducted to identify non-pharmaceutical interventions aimed at reducing children's anxiety in healthcare settings. More details about this process can be found in the Methods chapter (see *Section 4.1.1*). Various interventions were identified and categorized to enhance understanding. The most relevant ones were examined in greater depth to gain a clearer picture of existing approaches targeting children in the specified age group within emergency settings.

3.1 Categories of Interventions

Anxiety in children receiving medical care can lead to distress, reduced cooperation, and physiological responses that may complicate treatment. It is commonly addressed through a range of structured interventions.

Based on a synthesis of findings from the literature, the interventions identified were organized into types according to their primary mechanisms for anxiety reduction. This categorization includes three main types: Educational Interventions, Relaxation-Based Interventions, and Distraction-Based Interventions. In practice, these are often combined to enhance effectiveness, giving rise to what could be considered a fourth, integrative category.

- **Educational Interventions:** These provide children with age-appropriate information about medical procedures to reduce fear and uncertainty. By offering clear explanations and familiarization techniques, such as instructional videos/games, comic information leaflets, and role-playing at the Teddy Bear Hospital (TBH), children gain a sense of control and emotional preparedness.
- **Relaxation-Based Interventions:** These aim to activate the parasympathetic nervous system to counteract anxiety symptoms like increased heart rate and muscle tension. Techniques include breathing exercises, guided imagery, mindfulness activities, aromatherapy, hypnotherapy, and calming sounds such as nature noises or a recorded mother's voice.
- **Distraction-Based Interventions:** These redirect attention away from medical procedures through engaging and expressive activities. Examples include digital distractions (e.g., virtual reality, games), play-based methods (e.g., therapeutic play, balloon inflating, toy-making), and expressive tools like storytelling, music, or art.
- **Combined Approach:** Many effective pediatric interventions integrate educational, relaxation, and distraction techniques to address different facets of anxiety simultaneously, enhancing both emotional and physiological coping.

This initial categorization can provide a clearer understanding of available interventions, aiding clinicians, caregivers, and designers in selecting or developing suitable approaches for anxiety reduction in children undergoing medical care. The diagram in Figure 3.1 visually presents this classification, including examples of specific interventions within each category that were identified through the literature review process.

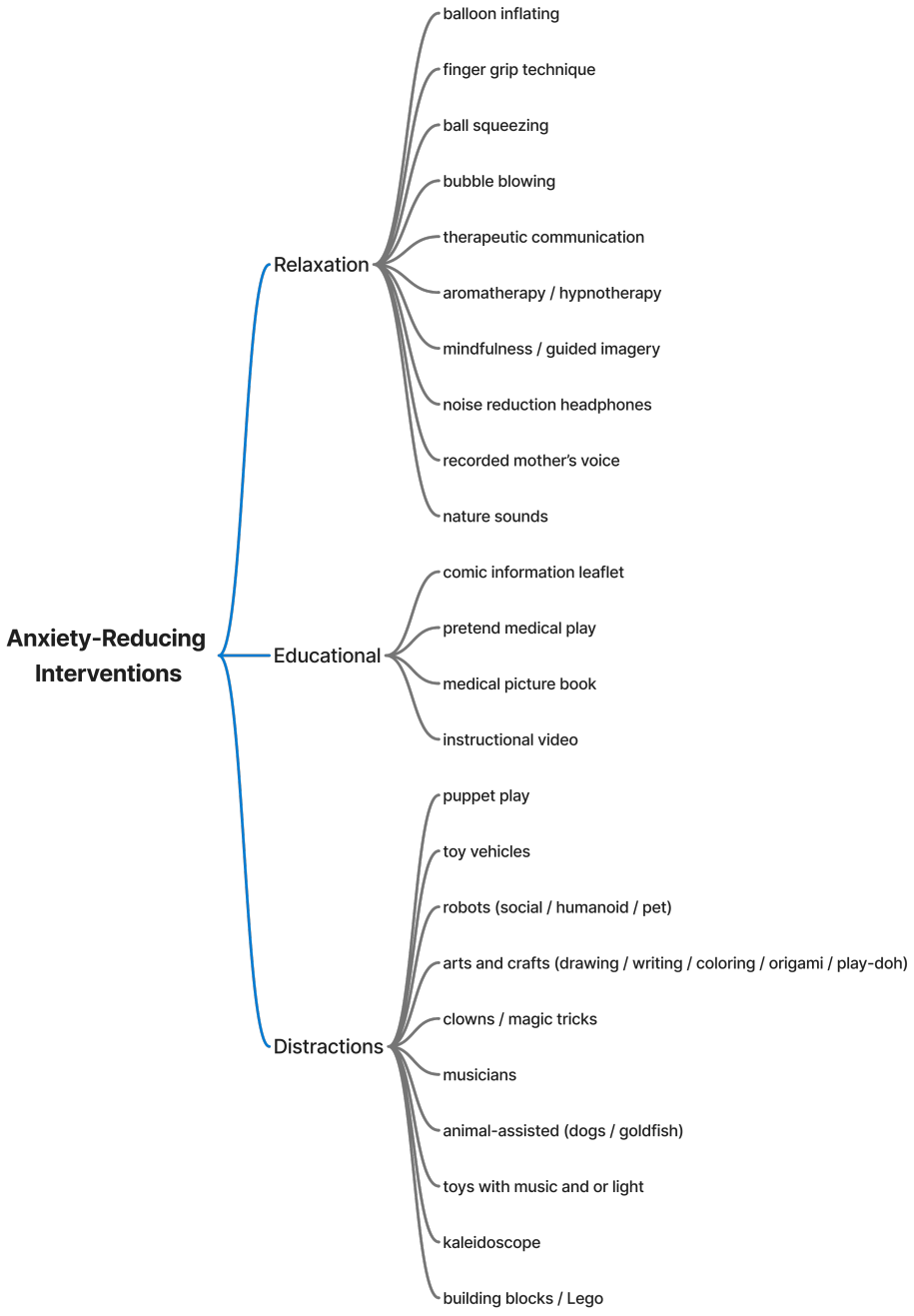


Figure 3.1: Types of interventions based on the underlying anxiety reduction mechanism

Based on insights that emerged from a workshop session, it was recognized that interventions can also be defined by the medium through which they are delivered and the level of child engagement they require. Further information about the workshop can be found in Appendix A.2.

The media-based classification offers an additional perspective for analyzing and designing pediatric anxiety-reducing interventions by focusing on how the intervention is delivered and experienced by the child. Understanding the medium provides valuable insights into the form of interaction and the type of engagement each intervention promotes. Specifically, interventions can be categorized into three main types: Digital-Based Media, Physical-Based Media, and Human / Animal. The types, their descriptions, and some examples are presented in Table 3.1.

Type	Description	Examples
Digital	Interventions delivered through screens or digital devices	Instructional videos, VR, Robots
Physical	Interventions involving tangible, manipulable objects or physical materials	Building blocks, Board games, Art supplies
Human and Animal	Interventions carried through interaction with living beings (humans or animals)	Storytelling by parents, Therapy dogs, Clowns

Table 3.1: Types of interventions based on the medium of delivery

Furthermore, interventions can also be classified as either active or passive, depending on the level of child engagement they involve, as shown in Table 3.2

Type	Description	Examples
Active	Require the child's participation, interaction, or physical engagement	Playing a game, Building with blocks, Practicing breathing exercises
Passive	Allow the child to remain relatively inactive while the intervention is delivered	Watching a video, Listening to music, Being comforted by a therapy animal

Table 3.2: Types of interventions based on child engagement

This distinction provides another important dimension for analyzing interventions, particularly when considering factors such as the child's age, medical condition, or energy levels.

Overall, a single intervention can be characterized across all three dimensions: the underlying mechanism for anxiety reduction, the medium through which it is delivered, and the level of child engagement it requires. For example, an intervention may be educational, delivered through a digital medium, and require active participation from the child. This multidimensional perspective highlights the diversity and flexibility of pediatric anxiety-reducing interventions, allowing for numerous combinations that can be tailored to different clinical contexts, age groups, and individual needs.

Additionally, a single intervention may address multiple anxiety-related factors or triggers simultaneously or it may target a specific one more directly. This flexibility underscores the potential of well-designed interventions to offer both broad and focused support.

3.2 Implemented Interventions

A comprehensive literature review was conducted to identify and compile previously implemented and tested interventions aimed at reducing anxiety in children within healthcare settings. This process resulted in a selection of 22 relevant studies, as shown in Table 3.3, that included children aged 4-7 and examined the effectiveness of specific interventions on anxiety reduction. While the majority of these studies were conducted in general hospitalization contexts, very few were situated in pediatric emergency departments. However, hospitalization was considered a sufficiently comparable context, as children in both settings often experience similar conditions of uncertainty, unfamiliarity, and prolonged waiting times. To maintain contextual consistency, studies focusing on pre- and post-surgical procedures, chronic illness treatments such as cancer care, or highly specific medical procedures like venipuncture were excluded from the review.

Author	Intervention Type	Anxiety Measurement Method	Results
Abdi et al. (2025) [34]	Storytelling vs. Play Therapy	Spence Children's Anxiety Scale (SCAS), Visual Facial Anxiety Scale (VFAS)	Storytelling significant (p=0.03), play therapy not significant
Andi et al. (2023) [35]	Puzzle Play Therapy	Hamilton Rating Scale for Anxiety (HARS)	Significant reduction (p=0.000)
Arbianingsih et al. (2021) [36]	Brain Gym	Modified Hamilton Anxiety Rating Scale / Zung Self-Rating Anxiety Scale	Significant reduction (p=0.006 preschool, p=0.016 school-age)
Bernaerts et al. (2022) [37]	VR Relaxation App	Visual Analog Scale and Revised Faces Pain Scale (FPS-R)	Significant reduction (p<0.001)
Castiglioni et al. (2022) [38]	Robot Play Therapy	Likert Scale, Visual Analog Scale	Improved mood and well-being (p<0.05)
Dian & Mariyani (2023) [39]	Coloring Play Therapy	Questionnaire refering to the HRS-A component	Significant reduction (p=0.000)
Hikmah Nanda et al. (2023) [40]	Animal Recognition Game	Not mentioned	Significant reduction (p=0.003)
Jeong (2017) [Thesis] [41]	Social Robot (Huggable) vs Plush Toy vs Virtual Avatar	Facial Affective Scale, PANAS, STAIC, EDA sensor, video analysis	Robot group showed longest engagement, most positive affect, and highest emotional and social interaction.
Kulal & Ray (2020) [42]	Art Therapy	Five Facial Anxiety Scale	Significant reduction (p<0.001)
Lawrence & Lazer (2024) [43]	Bibliotherapy	Modified Spence Children Anxiety Scale	Significant reduction (p=0.001)

Li et al. (2016) [44]	Hospital Play Program	Visual Analogue Scale (VAS)(3-7), Chinese version of the State Anxiety Scale for Children (CSAS-C)(8-12)	Significant reduction ($p<0.001$)
Mahimai Jacquline Josephine et al. (2022) [45]	Origami Play Therapy	Stress assessment scale and Anxiety assessment checklist (unspecified)	Significant reduction ($p<0.001$ stress, $p=0.002$ anxiety)
Naning Puji et al. (2019) [46]	Playdough Therapy	Modified Yale Preoperative Anxiety Scale (m-YPAS)	Significant reduction ($p=0.000$)
Nisa et al. (2023) [47]	Building Block Play	Taylor's Manifest Anxiety Scale (T-MAS)	Significant reduction ($p=0.000$)
Novita Dewi Kok et al. (2024) [48]	Coloring Play Therapy	Faces Anxiety Scale (FAS)	Significant reduction ($p=0.008$)
Padila et al. (2022) [49]	Educational Snake	Ladder Game Hamilton Anxiety Rating Scale (HARS)	Significant reduction ($p=0.000$)
Pita et al. (2023) [50]	Storytelling Video Play	Spence Children's Anxiety Scale (SCAS)	Reduction observed, one mild, one reduced but moderate
Siti Fadhila Sepfiani (2023) [51]	Puzzle Play Therapy	Preschool Anxiety Scale (PAS)	Anxiety reduced from moderate to mild
Stein Duker et al. (2020) [52]	Audiobook Distraction	Children's Fear Scale (CFS), modified State-Trait Anxiety Inventory for Children (m-STAIC)	Small but significant reduction
Van der Heijden et al. (2019) [53]	Music Distraction vs Cartoon Watching	Alder Hey Triage Pain Score, Faces Pain Scale-Revised (FPS-R), Observational Scale of Behavioral Distress-revised (OSBD-r)	Music reduced pain ($p=0.003$), cartoon not effective
Yildirim et al. (2025) [54]	Medical Material Toys	Children's State Anxiety scale (CSA)	Significant reduction ($p\leq0.000$)
Yilmaz & Demir (2024) [55]	Animal-Assisted Therapy (Goldfish)	Children's Fear Scale (CFS)	Significant fear reduction ($p=0.001$)

Table 3.3: Overview of implemented interventions and their results on anxiety reduction in children

The above 22 studies illustrate a wide range of non-pharmaceutical interventions for reducing anxiety in young children in healthcare environments. The full table of the studies can be found in Appendix A.3.

Play-based interventions, such as puzzle solving, playdough manipulation, building blocks, and storytelling, were the most common, emphasizing the critical role of engagement and distraction through play. For example, Yildirim et al. [54] found that toys made from medical materials significantly reduced anxiety in hospitalized children aged 4-6, with a notable reduction in Children's State Anxiety (CSA) scores after the intervention. Another example, signifying that storytelling is particularly impactful is from Abdi et al. [34] that conducted a randomized controlled trial comparing storytelling, play therapy, and a control group, and found that storytelling had the greatest effect in reducing anxiety, especially in children aged 3-8.

Digital solutions, including virtual reality and robot interactions, represent a growing trend in technology-assisted anxiety management. For example, research by Bernaerts et al. [37] supports the use of immersive technologies (VR) in pediatric care settings concluding that it can reduce anxiety, pain and tension (stress), and increase happiness in a hospital setting.

The studies varied widely in sample size, from single case studies to larger randomized controlled trials. For example, the study by Siti Fadhila Sepfiani [51] included only one child, while Li et al. (2016) involved over 300. While many interventions reported positive outcomes, those with smaller sample sizes may offer less generalizable evidence compared to the larger-scale trials.

It is also important to note that each study was conducted within a single hospital setting in a single country. However, some intervention types do appear repeatedly across different regions. For example, both Andi et al. [35] and Siti Fadhila Sepfiani [51], conducted studies related to puzzle play therapy in different islands of Indonesia. This limited cultural and institutional diversity means that findings may not generalize universally across healthcare systems, especially when considering variations in clinical workflows, parental roles or how healthcare professionals interact with child patients.

An important observation across the reviewed studies is the diversity in anxiety measurement tools. Most studies employed standardized scales such as the Spence Children's Anxiety Scale (SCAS), Visual Analog Scale (VAS), Hamilton Anxiety Rating Scale (HARS), and the Modified Yale Preoperative Anxiety Scale (m-YPAS), and some studies did not specify their instruments at all. This variation complicates direct comparison across interventions.

A key gap identified in the literature is the limited number of studies conducted specifically in emergency department settings. From the aforementioned studies that were included in the final synthesis after full-text screening, only three of them are conducted in emergency settings, including Stein Duker et al [52], Van der Heijden et al. [53] and Yilmaz & Demir [55]. Although the findings were positive, the limited number of PED-specific studies suggests that this area is still underexplored. This trend was already apparent during the initial screening of titles and abstracts for the broader pool of 180 studies, where very few were situated in emergency contexts. The unique nature of the PED, marked by acute medical needs may partly explain why research in this setting remains limited. Nonetheless, given that emergency visits often involve more uncertainty, less preparation time and a lack of continuity in caregiver support, it is crucial to develop and evaluate interventions that are tailored to the unique emergency context.

It was also noted that most existing interventions rely on passive or semi-passive forms of engagement (e.g., listening to music or audiobooks, watching videos, coloring). Few of them utilized elements of physical interaction or embodied engagement. Exceptions include the hands-on creation of toys from medical materials [54], patient-doctor roleplay using toy medical kits [44] or creating structures using blocks and plasticine [47]. These examples highlight the potential of active, hands-on interaction to enhance emotional processing and cooperation during hospitalization.

4 Methods

This thesis adopted a human-centered design approach structured around the Double Diamond framework [56], Figure 4.1, which supports iterative problem-solving through four distinct phases. The Double Diamond design process comprises two diamonds. Diamond One focuses on Discovering and Defining the problem, often referred to as the "Problem Space." Diamond Two involves Developing and Delivering the solution, often referred to as the "Solution Space."

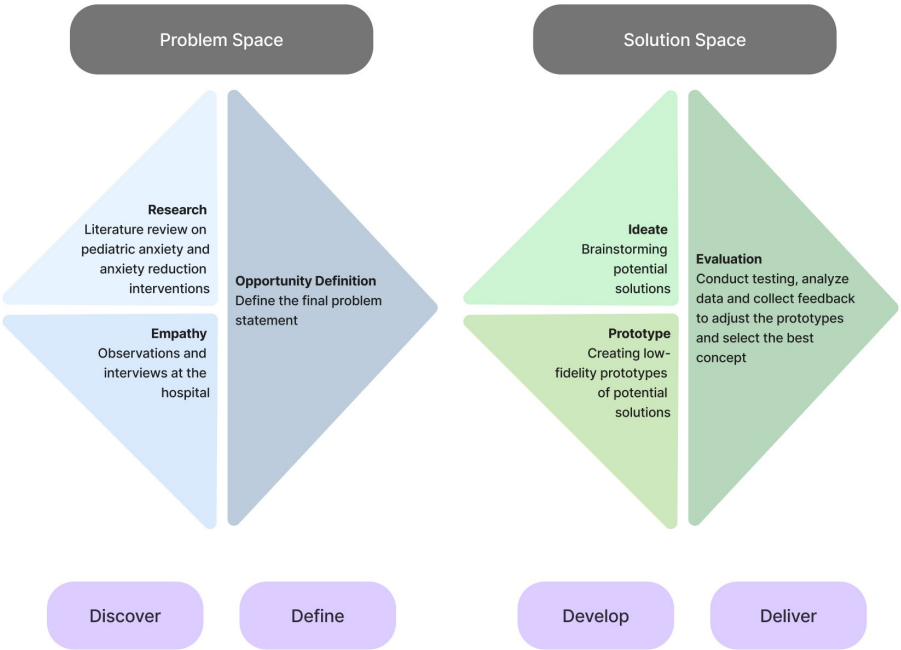


Figure 4.1: The Double Diamond design process as followed in this project

Discover: This phase involved extensive research, including literature review and field studies, interviews and observations conducted at Herlev Hospital. The goal was to gather as much relevant information as possible to understand the problem space.

Define: This phase synthesized the insights gathered into a clear and actionable problem statement that provided a focused direction for developing solutions aimed at reducing pediatric anxiety.

Develop: This phase involved ideating and exploring multiple potential solutions through brainstorming, sketching and low-fidelity prototyping. Minimum viable products (MVPs) were used to visualize and test ideas, allowing for the exploration of various solutions and approaches.

Deliver: This phase focused on finalizing and implementing the most promising intervention and evaluating its effectiveness in reducing anxiety. The most promising prototype was refined and developed into a final solution. This involved testing, validation and iteration to ensure the final outcome is both engaging and effectively addresses the initial problem.

4.1 Problem Discovery

4.1.1 Literature Review Methodology

A literature review aims to provide an overview/synthesis of existing research. The literature review for this thesis was conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [57, 58] and aimed to address the research question: *What non-pharmaceutical interventions have been implemented to reduce children's anxiety in healthcare settings?*

The review focuses on studies published in English from 2015 until the beginning of this project in February 2025. Literature was sourced from PubMed and DTU FindIt, using a carefully designed search string to ensure a comprehensive exploration of relevant studies. The PRISMA flow diagram, screening criteria and other details of this process are available in Appendix A.4.

To manage the review process efficiently, Silvi [59] was used as a screening and data extraction tool for Systematic Literature Review. Initially, 1,964 references were imported into Silvi for screening. The process involved multiple stages, starting with the removal of 503 duplicate references. Next, the titles and abstracts of the remaining 1,461 studies were screened, leading to the exclusion of 1,281 papers that did not align with the research focus (Irrelevant). From these studies, a categorization of the different interventions used to reduce anxiety in children in medical settings was made (see *Section 3.1*).

The third step involved re-screening the titles and abstracts of the 180 remaining papers to further refine the selection. Here, studies were excluded based on various criteria, such as focusing on a different age group or addressing pre- or post-surgery anxiety. This process helped narrow the results to better align with the scope of our thesis, ultimately resulting in 63 relevant papers.

A fourth step involved a full-text eligibility assessment. The remaining 63 studies, which appeared relevant based on their titles and abstracts, were thoroughly reviewed to determine their suitability for inclusion. Eligible studies focused on evaluating, measuring the effectiveness and testing an intervention in mitigating anxiety in children within the target age group, specifically in emergency departments or among hospitalized children. In the end, 22 studies met the defined eligibility criteria and were included in the literature review, providing valuable insights into reducing anxiety in pediatric care settings for children aged 4-7.

4.1.2 Interviews and Observations

This study employed a combination of semi-structured interviews and informal observations to gather insights into pediatric anxiety within the emergency department at Herlev Hospital. Two one-on-one interviews were conducted with nurses working in the Pediatric Emergency Department, using a semi-structured format that included prepared questions while also allowing space for open-ended discussion and follow-up. These can be found in Appendix A.1. In addition, observations were carried out in the waiting area by informally inspecting the physical environment and noting the behavior of children and their caregivers. These observations focused on how families interacted, how children responded to the setting, and the availability of distractions or comforting elements in the space.

4.2 Idea Generation, Concept Evaluation and Selection

4.2.1 Brainstorming

Brainstorming is a foundational method in creative problem solving and design thinking, particularly during early concept development. After the literature review, the design di-

rection was oriented towards developing physical interactive solutions for reducing pediatric anxiety in emergency settings. To support this focus, a structured brainstorming session was conducted. Although brainstorming is often characterized by its open-ended and informal nature, evidence suggests that sessions guided by clear structure and predefined categories tend to yield more focused results [60]. In this case, four key design dimensions were used to guide ideation:

- **Interactions / Mechanisms:** Define the physical actions through which a child engages with a toy, such as pressing, squeezing, blowing, or turning. These actions are central to toy-based design, shaping how children explore, manipulate, and derive meaning from the experience.
- **Sensors:** Enable the toy to respond to user input. A wide range of sensors (such as motion detectors, pressure sensors, RFID readers, and heart-rate monitors) can support personalized and adaptable interaction patterns.
- **Type of Toy/Game:** Refers to the overall form or typology of the intervention, such as plush toys, board games, interactive books, or digital hybrids. The physical form influences both the possibilities for interaction and the toy's emotional appeal.
- **Feedback / Stimuli:** Captures the sensory outputs the toy provides, including sound, vibration, light, or movement. Feedback mechanisms help close the interaction loop, enhance understanding, and sustain engagement by signaling responsiveness.

These dimensions were chosen because they reflect fundamental building blocks of interactive toy design. Each category offers a high degree of variability and supports systematic combination of elements.

The rapid ideation technique, in which participants independently write down their thoughts before sharing them, was chosen to efficiently produce a large volume of concepts for each dimension within a short timeframe. This method supports divergent thinking and can foster more creative outcomes by reducing performance anxiety and promoting cognitive independence.

The brainstorming session contributed to the early-stage exploration of possible design directions and laid the foundation for selecting and refining concepts for prototyping. The outcomes of the session were organized into a morphological matrix, which enables structured recombination of ideas and serves as a tool for the concept generation phase.

4.2.2 Concept Generation

The morphological matrix developed from the brainstorming session was constructed using four design dimensions (Interactions/Mechanisms, Sensors, Type of Toy/Game, and Feedback/Stimuli) identified as key components in toy-based interactive systems.

Rather than attempting to generate all possible permutations across these categories, which would have resulted in an unmanageably large number of combinations, a semi-random recombination strategy was employed. Exploring the full factorial set of combinations would not only have been infeasible but also likely to result in overly simplistic concept pairings without sufficient functional integration [61].

To balance creative exploration with feasibility, a small number of combinations were created by selecting a few elements from each dimension. Some combinations included more than one feature from a single dimension, which helped introduce greater functional richness. This process resembles the approach of grouping highly coupled functions and

exploring their combinations through focused ideation rather than systematic enumeration [61].

This process led to the creation of six distinct design concepts, each integrating features from all four design dimensions. These concepts varied in form, interaction style, technological complexity, and feedback modalities, resulting in a diverse but manageable set of early intervention ideas. At this stage, concepts were described at a functional level rather than in engineering detail, which is typical in morphological analysis where the focus is on exploration rather than immediate feasibility [61].

The six concepts developed during this stage were carried forward into the evaluation and selection phase (see *Section 4.2.3*).

4.2.3 Concept Evaluation and Selection

Following the generation of six distinct concepts through structured brainstorming and morphological recombination, a selection process was required to determine which ideas would proceed to prototyping. To support this decision, a Weighted Decision Matrix was constructed to evaluate and rank each concept based on a set of criteria. This method provides a systematic framework for multi-criteria decision-making (MCDM), enabling comparisons across diverse attributes by assigning numerical weights to reflect the relative importance of each criterion [62].

The evaluation criteria were selected to balance user-centered design priorities with practical implementation constraints and reflect core considerations relevant to the context and goals of the project. To indicate the relative importance of each criterion in the overall assessment, normalized weights were assigned, as shown in Table 4.1. Notably, safety was not included in the matrix as a scored criterion, as all concepts were required to meet basic safety standards from the outset.

Criterion	Description	Weight
Developmental Fit	Cognitive, emotional, and physical suitability	0.20
Engagement	Ability to sustain attention and allow the child to play with curiosity and control	0.25
Hospital Compatibility	Suitability for hospital use: portable, cleanable, durable, low noise, fast to set-up	0.20
Technical Feasibility	Realism of implementation using available technology and design complexity	0.10
Prototyping Feasibility	Ease and speed of prototyping within the thesis timeframe and available materials	0.25

Table 4.1: Evaluation criteria

Each concept was scored on a scale from 1 (low) to 5 (high) for each criterion. To calculate the final score, each criterion score was multiplied by its corresponding weight, and the resulting values were summed to produce an aggregate performance score.

The matrix made it possible to compare the overall potential of the concepts in a balanced and transparent way. Based on the final scores, the three highest-ranking concepts were selected for further development and prototyping in the next phase of the design process.

4.3 Prototyping

The prototypes were informed by early design research, including a literature review on pediatric anxiety, informal field observations at Herlev Hospital and research on age-appropriate toys.

Age-appropriate toys are the ones that comply with the cognitive and physical abilities of the kids. According to Jean Piaget [63], children aged 4 to 7 are in the preoperational stage of development. At this age, they are able to use symbols (such as words, drawings, or objects) to represent other things, which allows them to engage in imaginative play and role-playing. They begin to understand basic cause-and-effect relationships and can follow simple rules and sequences. Physically, they have developed better motor coordination and are able to perform actions like grasping, squeezing, stacking, and manipulating small objects. They are also capable of basic problem-solving and enjoy activities that involve constructing, sorting, and exploring. Based on these cognitive and physical abilities, the prototypes were designed to be age-appropriate.

4.3.1 Low-Fidelity Prototypes

To explore the potential of interactive, play-based systems for reducing anxiety in children in the Pediatric Emergency Department, three low-fidelity prototypes were developed. The concept of each prototype was chosen through the process described in *Section 4.2.3*. Each prototype was intentionally low-fidelity to allow for rapid iteration and user testing with minimal resources so that a final idea can be chosen to be further developed.

In order to set the stage for each prototype, a template for Lo-Fi Prototype Plan was developed including the following sections:

- Title
- Concept summary
- Purpose
- Interaction overview (input, feedback and used materials)
- Storyboard (the steps/actions of child needed to complete the game)
- Potential Testing Questions
- Notes for final prototype (any ideas that could be added in the final prototype)

The completed plan can be found in Appendix A.5.

This allowed for each of the concepts to be adequately defined for development. Emphasis was placed on interaction flow and playfulness rather than functional technology at this stage. Each experience was designed to simulate the intended feedback through Wizard of Oz facilitation.

4.3.2 High-Fidelity Prototype

Following the evaluation of the low-fidelity prototypes, Ambulance Adventure was selected for further development into a high-fidelity prototype. To prepare for this, key design considerations were identified, ensuring that the interaction remained intuitive, developmentally appropriate, and engaging. This phase involved a thorough planning process focusing on usability, physical accessibility, and alignment with interaction design principles to support independent play.

4.3.2.1 Design

The high-fidelity prototype was developed with reference to Don Norman's Design Principles [64], ensuring usability, intuitiveness, and emotional appropriateness for young children in high-stress environments like the PED. These are the following:

- Visibility: Refers to how easily users can see and understand available actions. Important elements should be noticeable and self-explanatory.
- Feedback: Provides users with immediate and clear responses to their actions so they know what effect they've had on the system.
- Constraints: These are design elements that restrict possible actions, helping to prevent errors and guide the user toward desired behavior.
- Mapping: Refers to the relationship between controls and their effects. Good mapping ensures that users can intuitively understand what actions do based on spatial or symbolic cues.
- Consistency: Ensures that similar actions yield similar results across different contexts. This reduces the learning curve and promotes intuitive use.
- Affordance: Refers to the qualities of an object that suggest how it should be used. Good affordance makes it obvious what users can do with an object.

These principles are especially relevant when designing for young children, who rely on direct, concrete cues to understand and engage with unfamiliar environments

4.3.2.2 Planning

Similarly to the Low-Fidelity Prototype planning, some important elements of the concept were outlined so that it can be defined in detail before fabrication.

- **Title**
  Ambulance Adventure
- **Goal**
  The main goal is to reduce anxiety in children aged 4-7 visiting the Pediatric Emergency Department (PED) by familiarizing them with the hospital environment through playful, interactive engagement. The toy aims to inform children in a non-threatening and developmentally appropriate manner about the hospital journey, including the purpose of different rooms, commonly used medical tools and procedures, and the roles of various healthcare professionals they may encounter.
- **Concept and Storyboard**
  Ambulance Adventure is a wall-mounted interactive board game designed for children in the PED waiting area. It features a toy ambulance that follows a route through a simplified top-down floor plan of the hospital.

  The toy car starts from "Home", and the child can move it manually along the route at their own pace. When the ambulance enters a room, the buttons in that room are activated, this is indicated by lights turning on next to each button. In each hospital room, the child can press the buttons, featuring large icons, that trigger audio messages explaining what the depicted item does (e.g. "The thermometer shows if your body is warm or cold"). After visiting all the rooms, the ambulance returns to "Home". The child can repeat the journey or interact with the rooms in any order.

- **Size and Placement**
  Since the game is wall-mounted, it is important that all required movements can be performed by the child within arm's reach. To determine the appropriate size and placement of the board, it was important to consider the average height [65] and arm length [66] of children aged 4-7 years. The numbers that have been used for the calculations refer to the 4 year old measurements to make sure that all of them can reach the board.

  Board Dimensions: The height of the map layout should correspond to the child's reachable area without requiring them to bend down or jump. This means it should be accessible when the child is standing, with their arm either hanging down or reaching upward.
  Board Height = 2 × 32 cm (total arm length) = 64 cm, which is rounded up to 70cm.

  Placement: The uppermost part of the ambulance route should be placed at a height that equals the average child height plus their forearm length. This ensures that children can reach the top section of the route comfortably.
  Maximum height = 103 cm (child height) + 15 cm (forearm length) = 118 cm, which is rounded up to 120cm.

  Accordingly, the lowest part of the route would be positioned approximately 50 cm from the floor, ensuring that the full route stays within the child's reachable range.

Unlike the low-fidelity version, which relied on Wizard of Oz techniques for simulating feedback, this version was designed to be fully functional and capable of supporting uninterrupted, independent interaction without the need for facilitator intervention, enabling a realistic experience that closely mimics the final intended product.

4.4 User Testing and Evaluation

To evaluate the proposed interventions, two testing phases were planned: an initial low-fidelity prototype testing phase to compare and assess early concepts, and a later testing of the selected final prototype to determine its effectiveness in reducing anxiety.

4.4.1 Selected Anxiety Assessment Methods

To evaluate the proposed interventions, a combination of self-report and observational tools was used in order to capture both the child's subjective experience and observable indicators of anxiety based on parents. This allowed for cross-validation of the measured anxiety response.

Two self-report measures were employed: the Wong-Baker FACES Pain Rating Scale (WBFPRS), which is traditionally used to assess pain but previous studies have demonstrated its effectiveness in capturing emotional distress, and the Scary Scale (Stephanie Thurillet), a visual analog scale representing fear levels, which is already in clinical use at the pediatric emergency department of Herlev Hospital (see *Section 2.4.2*). These scales were chosen for their visual simplicity and suitability for children aged 4-7.

For the final testing phase, the Modified Yale Preoperative Anxiety Scale (m-YPAS) was added to complement the self-reported tools (see *Section 1.2.3.2*). This validated observational measure is widely cited in the literature for assessing situational anxiety in young children. It offers a structured behavioral assessment that captures anxiety manifestations beyond what children may be able to express verbally.

The use of the m-YPAS was limited to the final prototype testing, where reducing anxiety is the primary focus. Earlier stages involve testing multiple low-fidelity interventions, so

shorter self-report tools are prioritized to reduce time burden and allow for testing with a larger number of participants without involving parents in lengthy assessments.

4.4.2 Low-Fidelity Prototypes

This initial testing phase was conducted using low-fidelity prototypes, primarily to assess usability and engagement. The emotional impact of the prototypes was also evaluated to gain a preliminary understanding of how children perceive pain and fear, and whether they can quantify their emotions using scales. Data collection combined behavioral observations with self-reported anxiety measures, following a qualitative approach appropriate for early-stage development and the young age of the participants. The goal was to compare the three design concepts and identify the most promising intervention for further development.

4.4.2.1 Type of Testing

The user testing conducted in this phase followed a Wizard of Oz methodology. Wizard of Oz testing is an established approach in Human-Computer Interaction (HCI) research in which a human operator simulates the behavior of a system that has not yet been fully implemented [67]. This technique allows for early exploration of interaction patterns, user expectations, and emotional responses without requiring a fully functional system. This was especially useful in the present case since the prototypes were low-fidelity and did not have full technical functionality.

During testing sessions, in response to user actions, visual changes and interactive feedback were manually simulated, for instance, by triggering a visual change or mimicking an interactive feedback mechanism. This allowed children to experience a version of the interaction flow as it was envisioned in the final system design, while allowing us to collect authentic user reactions and engagement patterns. The Wizard of Oz method was particularly appropriate given the nature of the interventions, where the illusion of responsiveness could be effectively created through real-time facilitation.

4.4.2.2 Participants

The participants were children aged between 4 and 7 years, each accompanied by at least one parent or caregiver. Recruitment was conducted informally within the Pediatric Emergency Department (PED) of Herlev Hospital, primarily in the waiting area or single patient rooms. Due to the low number of children visiting the PED during the testing period, it was decided to also include children from the outpatient clinic, located across the hall from the PED. This decision was supported by the rationale that, although these children visited the hospital by appointment and were likely less stressed or not in acute pain compared to those in the emergency department, they were still situated in a hospital environment and required to wait for treatment in the same waiting area. A total of six children participated in the testing of each of the three prototype interventions.

All participants were recruited on a voluntary basis. Prior to the testing session, parents were informed about the study and were asked if they wanted to participate. After the session, the parents were given a digital consent form which they accessed by scanning a QR code. This form included a short demographic questionnaire, to collect information on the child's age, gender, previous ED visits and previous hospitalizations. The form can be found in Appendix A.6. Participation was anonymous, and no identifiable personal data were collected (video/audio).

4.4.2.3 Procedure

At the start of each session, a brief introduction of the facilitators was given, followed by an explanation of the study's purpose and an invitation for children and their caregivers to participate. Then, the goal of the game was explained to the child in simple, age-

appropriate language. If the child appeared interested and willing to play, the session proceeded.

Parents were encouraged to remain present during the session and were permitted to support their child in any way necessary, for example, by helping to explain the game's objective, clarifying rules, or offering guidance during moments of confusion. This was particularly important since in most cases direct communication with the child was limited due to language barriers.

Before beginning the game, the child was asked to self-report their current emotional state using the two age-appropriate visual anxiety scales that are used by the hospital (see *Section 2.4.2*). The child then interacted with one of the prototype interventions while observations were recorded using an observation sheet, which can be found in Appendix A.7, noting factors such as engagement level, emotional expression, verbal reactions, confusion or support needs, and the duration of interaction. After the play session, the same scales were used to capture any change in reported anxiety. The session concluded with a short informal conversation to gather verbal feedback on the experience. Sessions lasted approximately 3-10 minutes depending on the child's engagement and the intervention.

4.4.3 High-Fidelity Prototype

The second and final testing phase focused on evaluating the high-fidelity prototype. This phase followed a mixed-method testing approach, emphasizing in the emotional and educational outcomes. Compared to the initial testing session, more structured data were gathered through the combination of quantitative and qualitative methods. The goal was to assess the prototype's effectiveness in reducing children's anxiety and enhancing their understanding of the hospital environment. Also, the testing focused on exploring the prototype's engagement, intuitiveness and ease of use.

4.4.3.1 Type of Testing

A mixed-methods strategy was adopted, incorporating both subjective self-report instruments and objective observational tools. For the quantitative part, two main instruments were employed. First, the modified Yale Preoperative Anxiety Scale (m-YPAS) was used to observe and score the child's anxiety level before and after the session. This validated tool provided a structured way to assess behavioral indicators of anxiety. Second, the Wong-Baker FACES Pain Rating Scale was used to capture the child's self-reported emotional state directly before and after the intervention.

To support structured data collection during the session, a custom observation form was developed and used. This form consisted of several sections, as described below, that capture important metrics for the child-toy interaction.

Engagement: This section included quantitative and qualitative measures such as total time spent with the toy, number of buttons pressed, number of audios listened to, whether the full ambulance route was completed, and the number of parent-child interactions. These indicators were selected in line with the User-Engagement Framework by O'Brien and Toms [68], which highlights total time, interaction count, and task completion as direct markers of engagement in child-computer interaction. These markers are independent of the modality and can also be applied whenever a child engages with any goal-directed activity. The inclusion of parent-child interaction follows Rogoff's guided-participation theory [69], which emphasizes the role of shared attention in sustaining engagement and supporting learning.

Intuitiveness: It was noted whether the child independently understood the mechanics of the game or required verbal explanation or support from the caregiver. Recording these

is based on Norman's concept of perceived affordances [70] and the ISO on Ergonomics of human-system interaction, that define intuitive interaction as the ability to grasp how to act without explicit instruction. This section was used to verify that the child can play independently.

Ease of Use: Observations focused on whether the child could reach all areas of the board without the need to tip-toe and whether moving the ambulance across the game path appeared easy and smooth. Since the prototype is body-centered, these metrics were informed by Embodied Interaction theory [71], which argues that physical reach and smooth manipulation really matter in this context.

Learning: This section was dedicated to noting the answers of the child to a set of three multiple-choice questions that were presented to them after the play session. These questions were designed to evaluate whether the child had gained any knowledge about the hospital emergency environment as a result of the interaction. The questions, which can also be found in Appendix A.8.2, were the following:

1. Which room has an aquarium you can look at while you wait? (Triagerum/Stue/Venteområde)

2. How many different rooms can you visit in the hospital with the ambulance? (3/4/5)

3. Which of these do they put in your finger to see how fast your heart beats? (oximeter/thermometer/syringe)

As post-activity quizzes are a standard way to check knowledge acquisition after an intervention, this section introduced a more objective evaluation of learning outcomes following the interaction.

After the child stopped playing, they were asked whether they would like to play again. If the child had already completed more than one route, the question included a clarification, asking whether they would like to play again later or another time they would be at the hospital. This simple yes/no item served as an indicator of continuation desire or replay motivation, a recognized proxy for sustained engagement in children's play experiences based on Read at al. [72] and the Self-Determination Theory's [73] definition of voluntary re-engagement .

For the qualitative aspect, short informal interviews were conducted with the parents or caregivers at the end of each session. Two questions were posed to gather their impressions of the intervention (a scaled question) and to capture any relevant reflections (an open ended question) on their child's emotional or behavioral responses. The questions were:

1. From 1 to 10, how likely would you be to recommend this toy to other parents whose children are visiting the hospital?

2. Do you have any other comments that you think might be important to us?

The first question is adapted from the Net Promoter Score (NPS) framework [74], a widely used metric in service and product evaluation that measures user loyalty and satisfaction through a single-item rating. In this context the question served as a proxy to assess the perceived value and relevance of the toy as experienced by the parent.

The responses provided complementary insights, helped contextualize the quantitative data and offered direction for potential improvements to the prototype.

Lastly, the form included a section for free-text comments, in order to record unexpected or noteworthy behaviors, emotional expressions, or environmental factors that arose during the session.

All of the testing materials, including the observation form, quiz items, and the m-YPAS form, can be found in Appendix A.8.

4.4.3.2 Participants

The participants were children aged 4 to 7 years old, each accompanied by at least one parent or caregiver. Recruitment and testing were conducted in the waiting area of the PED of Herlev Hospital. Unlike the previous phase, this round of testing included only children from the Emergency Room, with no participants recruited from the Outpatient Clinic. Initial observation using the m-YPAS was carried out before any interaction or consent process, allowing the child's pre-intervention anxiety level to be assessed naturally within the waiting area.

Participation was voluntary and anonymous. Parents received a digital consent form via QR code and were asked to complete a short demographic questionnaire covering the child's age, gender, hospitalization history, and prior visits to the emergency department. To be eligible for participation, the child was required to understand and speak Danish, as all audio elements of the prototype were in Danish and no English version was available. No audio or video recordings were made during this phase.

4.4.3.3 Procedure

In order to check for eligible participants, the hospital's internal screen system was used, Figure 4.2, located in the nurses' office behind the reception desk. These screens display information about children currently in the waiting area as well as those on their way to the PED. This allowed the facilitators to identify children within the target age range (4-7 years) in advance and prepare accordingly.

Figure 4.2: Screens with an overview of the patients in the nurses' office

Each session followed a structured protocol. First, the facilitators observed the child unobtrusively in the waiting room and completed the m-YPAS to capture a baseline measure of anxiety. To increase objectivity and reliability, the m-YPAS was independently filled out by two facilitators and their scores were combined. The parent was then approached and provided with information about the study. If they verbally agreed to participate, the child was invited to take part in the session.

At the start session, the child was asked to point to the face that best matched how they felt, using the Wong-Baker FACES scale. Then, the child engaged freely with the final prototype toy. Throughout the session, the parent was free to interact with the child and the toy as in a real life scenario. At the same time, the researcher documented the child's behavior, noting elements such as interest, engagement, intuitiveness and ease of use. Interactions between the child and parent were also recorded when relevant.

After the play session, the child was presented with the short quiz of three multiple-choice questions. These aimed to capture whether the toy had successfully communicated aspects of the emergency department's structure or procedures. Then, the FACES scale was used again to check if the self-assessment score changed post-intervention. Finally, the facilitators re-administered the m-YPAS through observational scoring once the child had settled again.

Parents were asked to scan a QR code to complete the digital consent and demographic form. The form can be found in Appendix A.6. At the end of the session, they were asked the 2 follow-up questions (as mentioned earlier) about their perceptions of the experience.

Each session, including the questions at the end, lasted between 4 and 12 minutes, depending on the child's level of engagement.

5 Results

This chapter goes through the same topics as the Methods chapter, but focusing on the results of the process followed each time.

5.1 Problem Discovery

5.1.1 Literature Review

The literature review conducted with the help of Silvi AI resulted in 22 studies that provide valuable insights into reducing anxiety in pediatric care settings for children aged 4-7.

The literature showed that play-based interventions are the most commonly used and consistently effective in reducing anxiety in young children. However, very few studies have been conducted in emergency settings, and most interventions do not rely on active, hands-on participation by the child.

An overview of these studies, along with detailed commentary, is provided in *Section 3.2*.

5.1.2 Interviews and Observations

Along with the Literature Review, two interviews with nurses were also conducted. Most of the interviews focused on the current state of recognising and managing anxiety at Herlev Hospital (see *Section 2.4*). Four significant points extracted from the interviews are the following:

Several systemic and environmental factors contribute to heightened anxiety among children in the Pediatric Emergency Department (PED). One recurring theme is the strong influence of prior hospital experiences. According to Gitte, a researcher and Clinical Nursing Specialist at the hospital, children who have previously visited often exhibit elevated anxiety levels during subsequent visits. In addition, the emotional state of parents plays a significant role in shaping the child's response to medical environments. She noted that children often mirror their parents' emotions. For example, when mothers cry or fathers appear visibly upset, the child's anxiety tends to increase.

Another challenge concerns the limitations of existing anxiety assessment tools. While the Wong-Baker FACES Pain Rating Scale and the Scary Scale are used for subjective self-reporting, concerns were expressed about their validity, particularly among younger children who may not yet have the cognitive maturity to accurately articulate or quantify their emotions. Moreover, although biometric measurements such as heart rate are sometimes captured using smartwatches, it was reported that elevated physiological responses are often interpreted as medical symptoms rather than indicators of anxiety.

An additional complexity lies in the time constraints inherent to emergency departments. While nurses recognize the value of allowing children time to adjust and feel secure, the demands of room turnover and limited staff availability often limit their ability to provide extended emotional support. As a result,interventions intended to reduce anxiety are often applied reactively, once a child is visibly distressed, rather than proactively. This reactive approach may lead to increased use of sedation or procedural restraint, especially when children are too anxious to cooperate with necessary procedures.

Finally, examples from other hospitals, such as programs where kindergartens are invited to tour the facility and familiarize children with the hospital environment and medical

equipment, were mentioned by Gitte as promising, yet currently unavailable, strategies for proactive anxiety prevention, aiming to reduce fear before a visit becomes necessary.

The transcripts from the interviews can be found in Appendix A.1.

Additional on-site observations were made during multiple visits to the hospital throughout the duration of this project, helping to build a comprehensive understanding of the clinical environment. Most children tend to remain close to their parents, with only a few moving around freely. Parents often take an active role in managing their child's emotional state by using food, toys brought from home, or reading books and answering questions together. Despite these efforts, the waiting area itself offers limited support for distraction or engagement. Aside from a small aquarium, a few wall stickers, and a table football setup, there are few environmental features designed to comfort or entertain children.

5.1.3 Problem Definition

The knowledge gained from the literature review, combined with insights from fieldwork at Herlev Hospital, forms the foundation of the first diamond in the Double Diamond design process. Based on these findings, a focused problem statement was developed to guide the direction of the project. This thesis aims to address the identified gaps by designing, developing, and evaluating interactive, play-based solutions specifically tailored to the PED environment, with the goal of reducing anxiety in young children during hospital visits.

Problem Statement: *How can we design an interactive solution to reduce pediatric anxiety in the waiting area of the Pediatric Emergency Department at Herlev Hospital?*

Subquestions:

1. *How can we design interactive solutions that are compatible with the spatial and procedural characteristics of the Herlev PED environment?*
2. *What different interactive solutions can be designed to reduce pediatric anxiety at Herlev Hospital and which one shows the highest potential?*
3. *How effective is the selected solution in reducing anxiety in real-life settings and how is it experienced by children and caregivers?*

5.2 Idea Generation, Concept Evaluation and Selection

5.2.1 Brainstorming

Brainstorming was conducted around four key design dimensions: Interactions, Sensors, Type (of Toy) and Feedback. The outcomes of the session, which can be found in Appendix A.9, were organized into a morphological matrix, as shown in Table 5.1.

Interactions	Sensors	Type	Feedback
Eye movement	Movement / Tilting sensor	Board game	Vibration
Magnets	Cameras	Board with things	Sounds / Music
Connecting wires	Pressure sensor	Interactive mat	Lights
Fitting things / matching	Blowing sensor	Car	Colours
Buttons / pressing	Light / IR sensor	Plush toy	Movement (e.g. shaking)

Speak / Audio Hammering things Stepping on Blowing Driving / rolling Petting / Hugging Squeezing Stacking things Wheels Tele-controlled Gears Moving Parts	Motion sensor Heart-rate sensor	Building blocks Map Puzzle Robot	Voice Images Screen

Table 5.1: Morphological Matrix of Ideas from the Brainstorming Session

5.2.2 Concept Generation

Based on the morphological matrix, six combinations were created by selecting a few elements from each dimension. In principle, any combination could be used to make an intervention. These combinations were documented on post-it notes and served as inspiration for the initial concept drafts, that can be found in Appendix A.10. This process ultimately led to the development of six distinct design concepts, as outlined in Table 5.2.

Concept	Description	Interaction	Sensors	Type	Feedback	Purpose
TaskTapper	A grid of buttons with a video and infrared hammer is used to hit the buttons that light up	Hammering	Pressure sensor	Interactive mat	Music, Lights, Sounds, Screen	Distractive
CalmBot	An interactive plush toy with different calming features and functions	Buttons, Magnets, Petting / Hugging, Squeezing	Pressure sensor, Gyro	Plush toy	Vibration, Voice, Lights, Sounds	Relaxing
Ambulance Adventure	A toy car moves across a hospital map, stopping at locations to explain the different hospital rooms and procedures	Moving parts, Buttons, Magnets	Color sensor, Contact sensor	Car, Map, Board game	Voice, Sounds, Lights	Educational

Match the (E)motion	A puzzle with gear pieces where kids connect an emotion piece to a facial piece to make a final piece	Gears, Moving parts, Fitting things, Spinning	Contact sensor	Puzzle	Sound, Lights, Movement	Distractive
Air-Balloon Ride	An interactive device where blowing and squeezing trigger visual elements and progress through cloud and air balloons	Blowing, Squeezing	Blow sensor	Board	Movement, Lights	Relaxing
Puzzle Bot	A board with missing pieces (e.g. hospital steps), where the missing pieces are provided to add them	Fitting, Matching things	Contact sensor	Puzzle	Voice, Lights	Educational

Table 5.2: Concepts generated using the Morphological Matrix

5.2.3 Concept Evaluation and Selection

To evaluate these ideas, a weighted decision matrix was constructed using the defined criteria (see Section 4.2.3). The results of this evaluation are summarized in Table 5.3.

Based on the final scores, the three highest-ranking concepts include Ambulance Adventure, Match the (E)motion and Air-Balloon Ride.

Criteria	Task Tapper	CalmBot	Ambulance Adventure	Match the (E)motion	Air-Balloon Ride	PuzzleBot
Developmental Fit	3	5	5	4	4	3
Engagement	3	4	5	4	3	2
Hospital Compatibility	3	2	5	4	4	4
Technical Feasibility	5	5	5	5	2	3
Prototyping Feasibility	3	2	3	4	5	5
Total:	3.2	3.4	4.5	4.3	3.75	3.65

Table 5.3: Concept evaluation based on criteria scores

5.3 Low-Fidelity Prototypes

5.3.1 Prototyping

The following sections provide an overview of the three low-fidelity prototypes that were developed, including their design goals, materials, and interaction flow. Additional material can be found in Appendix A.11.

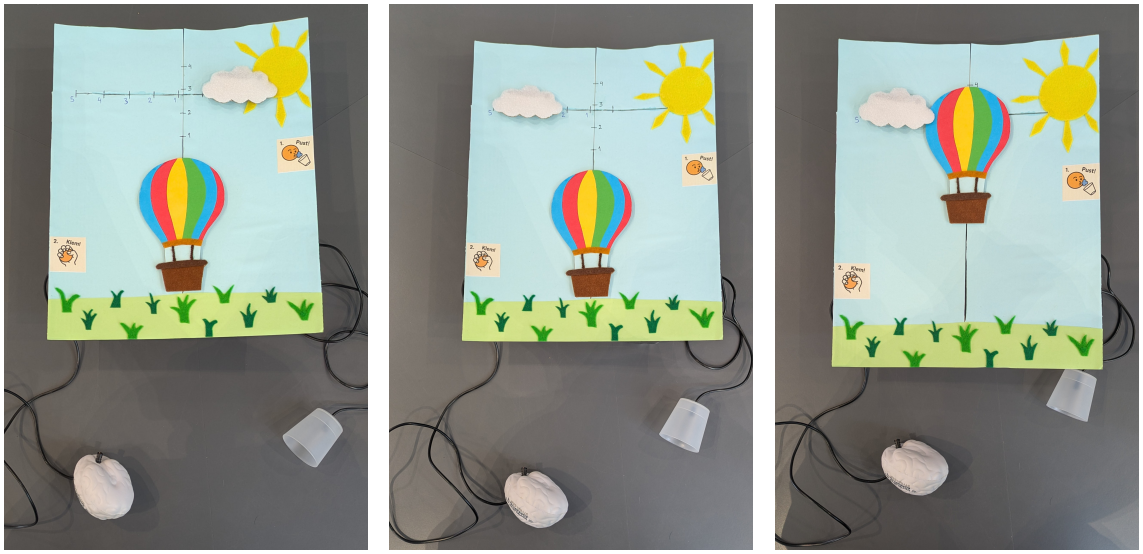
5.3.1.1 Prototype 1: Air-Balloon Ride

This concept explored the use of breathing and squeezing as calming and empowering interactions. The prototype, Figure 5.1 consisted of a cardboard board featuring two movable elements: a cloud, made of foam, and an air balloon, constructed from colored paper sheets. The board included two icons labeled with numbers: ”1” showing “Pust!” (blow) and ”2” showing “Klem!” (press), providing visual guidance for the interaction sequence. Since the prototype’s mechanics were not functional at this stage, all movements were performed by the facilitator to simulate the intended interactions.

The goal of the game was to move away the clouds and clear the sky so the air balloon could rise. The visual and tactile design aimed to engage young children through vivid colors and diverse textures, including felt details, to stimulate sensory interest.

The interactive elements were connected to the board via cables: a cup for blowing and a stress ball for squeezing. Each time the child blew into the cup, the cloud was manually moved by the facilitator one step along a numbered horizontal axis, symbolizing a gradual shift from anxiety to calm. Similarly, with every squeeze of the stress ball, the air balloon was manually moved one step upward along a vertical axis, offering a sense of progression or reward. These numbered “steps” on the board provided visual feedback and reinforced the connection between the child’s actions and the resulting movement.

The sequence was designed to support regulated breathing and focused motor control, drawing inspiration from breathing techniques used in pediatric anxiety management.



(a) Initial game setup, the air-balloon is grounded

(b) The cloud is moved away from the sun after blowing

(c) The air-balloon is lifted up after squeezing

Figure 5.1: Low-fidelity prototype of the ”Air-Balloon Ride” game

5.3.1.2 Prototype 2: Match the (E)motion

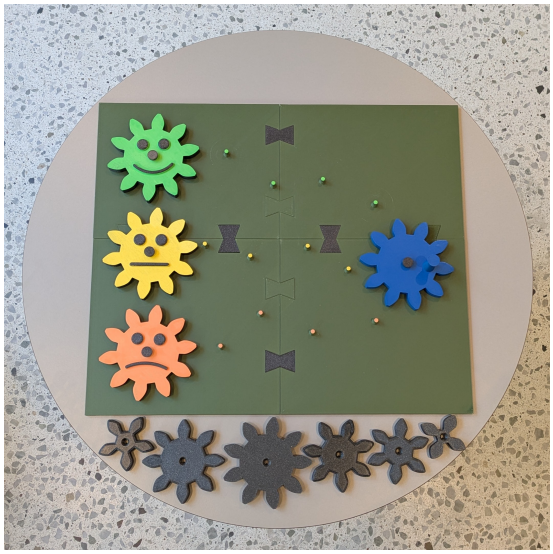
This concept explored the use of distraction through problem-solving and physical engagement as a strategy for reducing anxiety in young children. The prototype, Figure 5.2, took the form of a mechanical gear puzzle and consisted of multiple custom-designed, 3D-printed components. A board and a set of ten gear pieces, varying in size, were created. The largest gears, each with 10 teeth, served as the start and end points of the puzzle and were fixed on the board (i.e., they could rotate but their positions could not be changed).

The objective of the game was to connect one of the emotion-themed starting gears to the end gear with the crank, forming a complete mechanical chain by selecting and placing the correctly fitting gears. This process symbolized a journey from a particular emotional state toward resolution and completion.

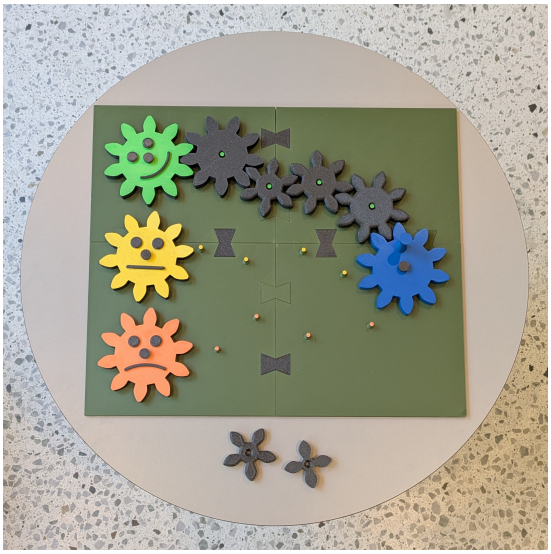
Children could choose between three emotion-themed gears: happy, neutral, and sad, which were also color-coded. These starting gears were placed at one end of the board. The child then had to complete the corresponding colored path by selecting and placing four out of the six available gears onto the color-matched pegs, linking the chosen emotion gear to the crank at the other end. When assembled correctly, turning the crank set the entire gear chain in motion, providing satisfying visual and tactile feedback. The mechanical movement reinforced a sense of accomplishment.

During early prototyping, several issues arose. The gear pieces were initially designed using an online gear generator. The original idea was to create the gears by carving them out of cork, but it became clear that for the gears to interconnect and rotate properly, there should be minimal friction, and the margin for error was very small. As a result, 3D printing was chosen instead.

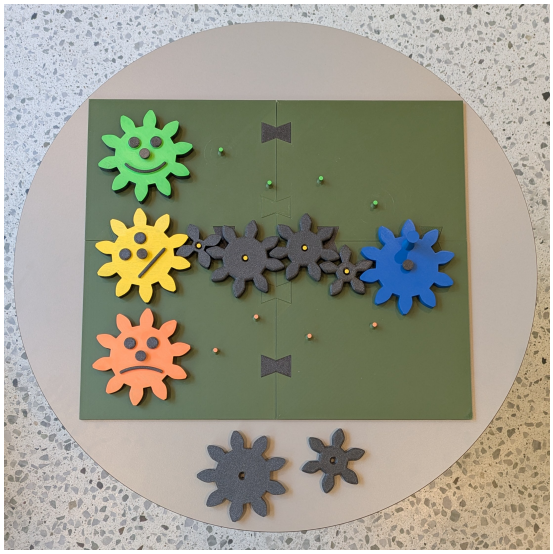
The gears generated online were created in Fusion 360, along with the board and its pegs. Printer inconsistencies led to warping and failed prints, necessitating multiple iterations to ensure the components were durable and fit together smoothly. Achieving



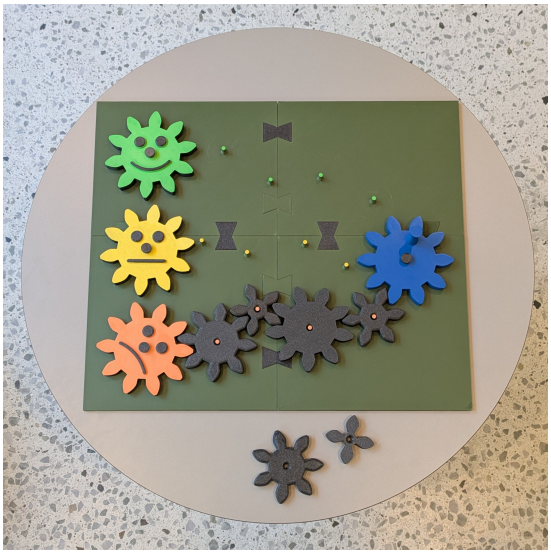
(a) Initial game setup



(b) Route completed for the ”Happy” gear



(c) Route completed for the ”Neutral” gear



(d) Route completed for the ”Sad” gear

Figure 5.2: Low-fidelity prototype of the ”Match the (E)motion” game

tight yet functional tolerances for the interlocking segments required significant trial and error. The limited size of the 3D printer bed made it necessary to split the board into four separate segments, which were later assembled. After testing different connection methods, the segments were joined using “bow-tie” connectors to create a stable play surface. Additionally, color options were restricted by the available filament. Only the board could be printed using a dark-green filament, so visual contrast for some of the other components was enhanced post-production using markers and spray paint. More details on this process can be found in Appendix A.11.1.

5.3.1.3 Prototype 3: Ambulance Adventure

This concept explored the use of educational play and narrative sequencing to reduce anxiety by familiarizing children with the hospital journey in a playful and engaging way. The prototype, Figure A.14, took the form of an interactive hospital map built from laser-cut wood, engraved with illustrations of key locations a child might encounter during a typical visit to the PED. A route was cut through the board, guiding the child from one room to the next using a movable wooden toy car attached to the track. In each room, there were icons with animated-style illustrations, mounted on small cardboard squares to give them a slight 3D effect, representing buttons for objects relevant to that specific room.

(a) Initial game setup

(b) Toy car stopped at the Reception

Figure 5.3: Low-fidelity prototype of the ”Ambulance Adventure” game

The objective of the game was for the child to drive the car around the hospital floor plan, passing through four numbered key stops: Reception, Triage Room, Waiting Area, and Examination Room, while learning information about each room along the way. The route concluded with the child “leaving” the hospital, represented by a home icon at the end of the track.

The child could start moving the car along the track and stop at pieces of tape labeled ”STOP” in each room. There, they would press the cardboard elements in that room one by one. When the child pressed one of these elements (acting like buttons), a short ”audio” explanation was triggered (the transcript was read aloud by the parents in Danish) describing the object’s purpose and use in simple, child-friendly terms. The small cardboard elements represented relevant medical items (e.g., thermometer, oximeter), objects (e.g., aquarium, sofas), and hospital staff (e.g., doctors, nurses). The specific

icons placed in each room were chosen to reflect what a child might encounter at each step of the patient journey (see *Section 2.3*) . Once the child had pressed and listened to all the information in a room, the “stop” tape was removed, allowing them to continue driving the car to the next room and repeat the process until they reached the end, marked by the home icon.

During the prototyping process, the car was designed to stay securely on the track using a 3D-printed piece glued to its bottom. The piece consisted of two parts put together and was shaped to slide along the track while preventing the car from being lifted out. Initially, the plan was to laser-cut the design into cardboard, but testing showed that it would not be stable enough to withstand the handling and movement by children. As a result, it was laser-cut from wood to ensure greater durability. Finally, the border of the board was spray-painted blue to add a touch of color and make the game visually more appealing.

The prototype aimed to support predictability and emotional preparedness. By moving through the hospital journey at their own pace and receiving explanatory input, children could build cognitive familiarity with potentially anxiety-inducing procedures and spaces.

5.3.2 User Testing and Evaluation

An overview of the user testing conducted on the three low-fidelity prototypes is provided to clarify the outcomes, while the detailed results can be found in Appendix A.12 in the form of tables.

A total of eighteen children (aged 4-7 years) participated in the testing. Each child tested one of the three prototypes (six per prototype) and all of them were accompanied by a caregiver, Figure 5.4. None reported developmental or sensory impairments that might influence play behavior.

(a) ”Air-Balloon Ride” (b) ”Match the (E)motion” (c) ”Ambulance Adventure”

Figure 5.4: Testing low-fidelity prototypes

An overview of the demographic and medical history characteristics of the 18 children who participated in the low-fidelity prototype testing can be found in Table 5.4. The table categorizes participants by age, gender, prior experience with emergency room visits and hospitalization, and it indicates their distribution across the three prototype interventions. Notably, children aged six constituted the largest age group (n=7), and boys (n=10) were more represented than girls. However, age and gender distribution were fairly balanced for each prototype. Additionally, the majority of participants had previous emergency room

experience (n=12) and previous hospitalization (n=10). This demographic data offers valuable context for interpreting children's interaction patterns and engagement levels.

Variable		Air Balloon Ride	Match the (E)motion	Ambulance Adventure	Total (out of 18 children) (%)
Age	4	2	2	1	5 (28%)
	5	2	1	1	4 (22%)
	6	1	3	3	7 (39%)
	7	1	-	1	2 (11%)
Gender	Girls	2	3	3	8 (44%)
	Boys	4	3	3	10 (56%)
Previous ER visit	Yes	3	4	5	12 (67%)
	No	3	2	1	6 (33%)
Previous Hospitalisation	Yes	3	4	3	10 (56%)
	No	3	2	3	8 (44%)
Clinic	ER	2	2	2	6 (33%)
	Outpatient	4	4	4	12 (67%)

Table 5.4: Demographic and medical background of the participating children for each prototype

To evaluate the effectiveness and appeal of the three low-fidelity prototypes, both quantitative and qualitative data were collected during the testing sessions.

An overview of the quantitative results of the testings can be found in Table 5.5. This table summarizes key metrics across the interventions, including average engagement time, changes in self-reported fear and pain levels before and after the activity, and children's willingness to play again. These indicators provide an overview of each prototype's potential impact on emotional and behavioral engagement in a pediatric emergency context.

Prototype	Average engagement time (min)	Average fear (pre → post) (difference)	Average pain (pre → post) (difference)	# of children that would play again
Air-Balloon Ride	2.2	2.0 → 1.0 (↓1.0)	3.7 → 1.0 (↓2.7)	6 out of 6
Match the (E)motion	7.3	0.7 → 0.0 (↓0.7)	1.3 → 0.0 (↓1.3)	3 out of 6
Ambulance Adventure	4.8	1.7 → 2.3 (↑0.6)	2.7 → 2.3 (↓0.4)	4 out of 6

Table 5.5: Intervention comparison: engagement time, emotion ratings, and replay preference

In addition to these measurable outcomes, qualitative observations were documented to capture children's spontaneous reactions, patterns of interaction, and parental involve-

ment. These observations, presented in Table 5.6, offer further insights into usability, playability, and areas for improvement, and inform the subsequent design reflections.

Prototype	Observations
Air-Balloon Ride	Children generally showed curiosity and engagement with the interaction of squeezing / blowing and watching the outcome of their actions. Some children tried to control the balloon by blowing harder. They needed guidance at first to understand the toy's function. Other times, they attempted to move the elements by hand. It was noted that the activity could benefit from additional interactive elements to extend playtime.
Match the (E)motion	Children showed interest in spinning the gears and building the puzzle. Parents were mostly involved by helping or making suggestions, but some of them let the child play independently. Some children started placing pieces randomly or got confused when trying to complete multiple paths simultaneously. One child played intermittently and carried gears around the waiting area. Most of the children completed more than one path.
Ambulance Adventure	Children showed interest in both interacting with the toy car and pressing the buttons to listen to the information. Parental involvement played a key role, since they were ones to read aloud the information to the children. Sometimes, they were also making sound effects and pointing out elements in the room. While some children were fully engaged and attentive, others needed encouragement or showed lower engagement. One child was distracted by their own toy.

Table 5.6: Observational notes by intervention

Additional qualitative insights were gathered from comments made by parents during the testing process. One notable remark came from a mother who mentioned that children enjoy using their whole bodies during play. Another parent, who is also a kindergarten teacher, noted that wall installations are well-received, referencing a similar play experience installed at her workplace.

Reflections

The following reflections highlight important considerations and limitations observed during the testing process. Most of the participating children were not visibly anxious, stressed, or in pain during their hospital visit, which limits the reliability of the anxiety scales as indicators of emotional impact. Additionally, all children completed the games, as each prototype featured a clear final goal. As a result, the duration of engagement may not accurately reflect the level of interest or immersion, since the tasks were structured rather than open-ended.

Furthermore, children's cognitive and interactional abilities varied considerably and did not always correspond with their chronological age. While some younger children needed more support from parents, others demonstrated skills beyond what might typically be expected for their age. This variation suggests that dividing the age group or tailoring separate interventions for narrower age ranges may not be necessary.

Specific challenges were identified in each concept. Some of these issues can be ad-

dressed through design modifications, while others are intrinsic to the game mechanics and would compromise the core experience if altered. For example, Air-Balloon Ride showed lower engagement time, which is considered fixable through added interactivity. However, the use of a blowing component raises hygiene concerns and would need to be replaced entirely. Match the (E)motion suffered from unclear game rules, which can be clarified, but its reliance on removable parts (central to its core mechanic) was found to be unchangeable without losing its value. Ambulance Adventure was described as too passive, and the layout was unclear, yet both of these aspects can be adjusted through design improvements. Table 5.7 summarizes which issues are considered fixable and which are not, based on whether they affect the fundamental purpose or experience of the game.

Prototype	Identified Issue	Fixability
Air-Balloon Ride	Low engagement time	Can be fixed (e.g., by adding more interaction)
	Cleanliness of blowing component	Cannot be fixed (must be replaced by another action)
Match the (E)motion	Use of removable parts	Cannot be fixed (core to the game concept)
	Game rules were not clear	Can be fixed (rules can be made more understandable)
Ambulance Adventure	Passive gameplay	Can be fixed (can be made more active or interactive)
	Layout was not clear	Can be fixed (can be redesigned for clarity)

Table 5.7: Prototype issues and their fixability

Based on the results, no single prototype emerged as a clear winner, and the testing did not provide definitive conclusions regarding which concept was the best fit. Throughout the testing process, it also became evident that additional evaluation criteria need to be considered. Furthermore, transitioning to a large-scale, high-fidelity prototype introduces new challenges, including increased material costs and practical concerns related to installation and maintenance in a hospital setting. Moreover, the feasibility of constructing the prototype within the limited timeframe and resources of a Master's thesis must also be taken into account. These factors must be carefully considered when selecting a concept for further development.

Comparison

It is important to acknowledge that the three prototype games differed significantly in both design and purpose, which complicates direct comparisons. Firstly, the type of gameplay varies: one game was designed primarily for relaxation, another for distraction, and the third for educational engagement. These differing intentions inherently influence how children interact with the games, affecting metrics such as engagement time, attention focus, and emotional response.

Secondly, the total play duration required to complete each game's intended interaction flow varied considerably. For example, the Air Balloon Ride game involved five blowing and five squeezing actions, resulting in a relatively short and straightforward interaction.

In contrast, the Ambulance Adventure included a navigational element and the sequential presentation of information across 11 items, leading to a significantly longer play session.

Finally, the Match the (E)Motion game featured three levels of difficulty, encouraging repeated play within a single session and potentially increasing both time-on-task and depth of engagement.

Taking all of the above into account, and in order to choose one of the prototypes for further development, especially since all prototypes performed well and received similarly high scores based on the initial evaluation criteria, newly defined criteria are needed to allow for a validated comparison of the high-fidelity solutions:

Gameplay Resilience: Evaluates whether the game can still be played as intended in cases where parts are lost, misplaced, or not used as expected.

Durability: Assesses how well the prototype withstands repeated or rough handling, including drops, pressure, or twisting.

Cleanability: Assesses how easily the prototype can be cleaned and maintained.

Wall-scale Potential: Evaluates whether the concept could be adapted into a wall-mounted or large-scale format.

Ease of Fabrication: Assesses how easily the prototype can be built using available materials, tools, and skills, considering time and resource constraints during the development phase.

Cost: Evaluates the total material cost of the prototype.

Comparative overview of the three prototypes based on decision criteria

Based on the overview provided in Table 5.8, Ambulance Adventure appears to be the strongest contestant. As previously argued, the anxiety reduction scores and engagement time should be disregarded. Focusing on the remaining criteria, Ambulance Adventure stands out with high gameplay resilience, indicating that it can maintain its intended functionality since it does not include removable parts that can be lost or misplaced. It also demonstrates high durability, as it is less affected by potential misuse of components.

Furthermore, it scores high on ease of fabrication and it shows moderate cost due to its use of basic electronic components, making it feasible to produce within the scope and time constraints of a Master's thesis. Additionally, it maintains a moderate level of wall-scale potential, as it can be scaled up and placed on a wall within the reach of a child by allowing them to extend their arms across the board. These strengths collectively support its suitability for further development.

Criterion	Air-Balloon Ride	Match the (E)motion	Ambulance Adventure
Anxiety reduction	High (fear ↓ 1.0)	Moderate (fear ↓ 0.7)	Low (fear ↑ 0.6)
Engagement time	Low (2.2 min)	High (7.3 min)	Moderate (4.8 min)
Gameplay Resilience	Moderate (kids may try to move the parts by hand if not covered)	Low (cannot be played if pieces are lost)	High
Durability	Moderate (mechanical components may wear out over time)	High	High
Cleanability	Moderate (need to pay attention to components)	Moderate (need to pay attention to components)	Moderate (need to pay attention to components)
Wall-scale potential	High (control panel can be placed somewhere low)	Moderate (size is limited to children's hand reach)	Moderate (size is limited to children's hand reach)
Ease of Fabrication	Moderate (mechanical complexity of moving parts + transforming sensor input to movement)	Moderate (design complexity of gears)	High (basic electronic components)
Cost	High (mechanical components)	Moderate	Moderate

Table 5.8: Comparison of decision criteria

5.4 High-Fidelity Prototype

5.4.1 Prototyping

The following sections provide an overview of how the high-fidelity prototype was developed, Figure 5.5, including the design process, construction steps, materials and components used, and the overall outcome. While a complete new design iteration was not conducted, several design elements were revisited and refined during the building phase as practical limitations and usability issues emerged. These adjustments were made to improve functionality and durability.

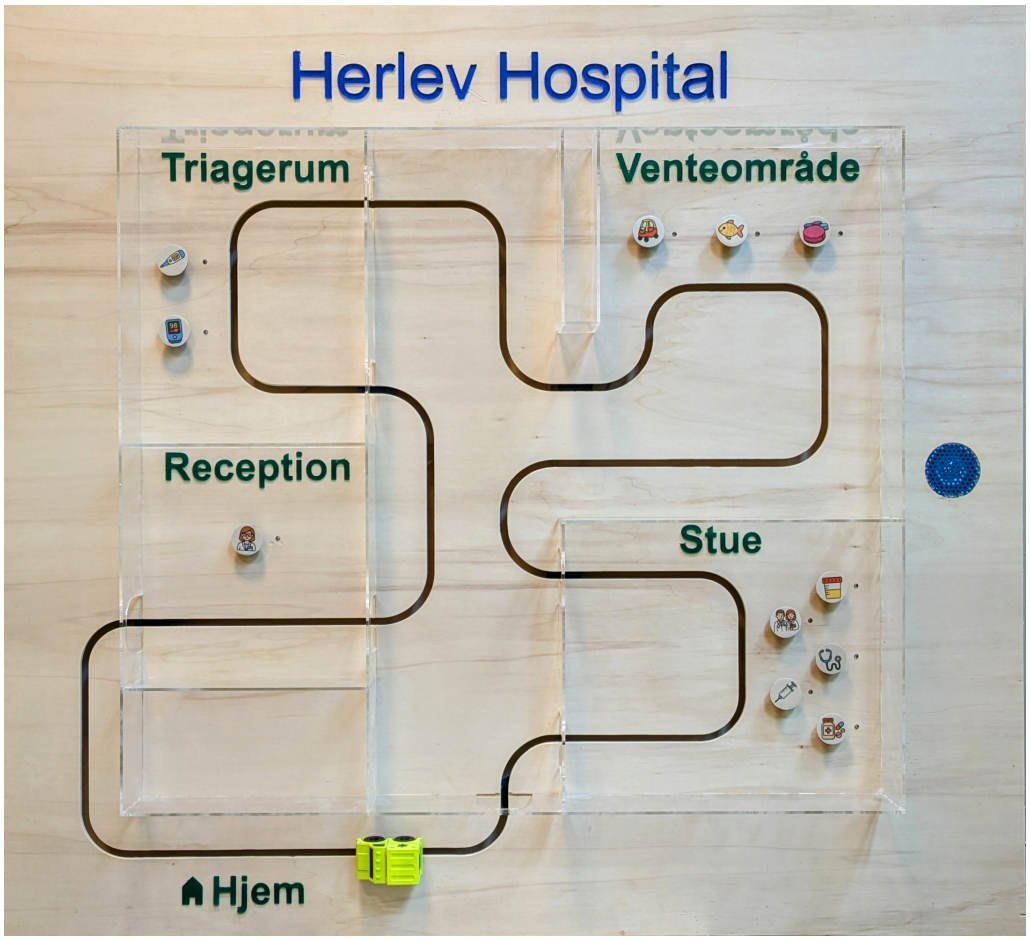


Figure 5.5: Final look of the ”Ambulance Adventure” game board

5.4.1.1 Design Board

To model the entire game board, Fusion 360 [75], a cloud-based 3D CAD, CAM and CAE software developed by Autodesk, was used. The final design of the game board was based on the initial low-fidelity prototype (see *Section 5.3.1.3*), with several improvements introduced.

Most notably, the toy-ambulance used in the interaction was designed to resemble an ambulance, reinforcing the hospital context and enhancing narrative immersion. The orientation of the layout was adjusted, and the path was redesigned to form a continuous circular route. This not only enabled uninterrupted, repeatable play without requiring manual resetting, but also ensured that if a child stopped playing midway, another child could seamlessly continue the activity. While the game still has a logical starting and ending

point at ”Home”, the circular layout avoids enforcing a strict progression, allowing children to engage with the experience in a more self-directed manner. The overall size of the board was increased to provide children with more space for movement, encouraging more embodied interaction. Additionally, 3D walls were added to separate the different rooms, clearly signaling transitions between areas of the hospital.

For the toy-ambulance, its proportions were chosen to be relative to the size of the board while also small enough to be easily grasped by a child’s hand. An approximate size of 6 cm × 4 cm × 5 cm was targeted. A design found online [76], Figure 5.6, measuring 7 cm × 3.9 cm × 4.8 cm was selected as a close fit.

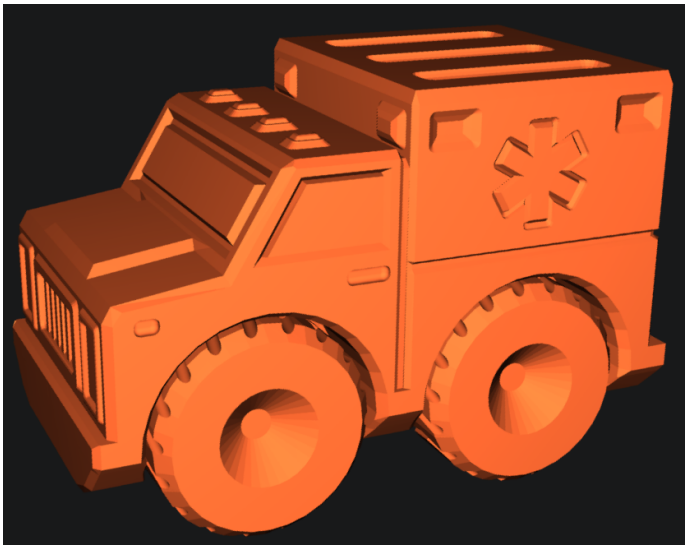


Figure 5.6: 3D render of the toy-ambulance

The base of the board was designed based on a simplified representation of the actual layout of the PED (see *Section 2.2*), including the main rooms that a patient typically visits during their time in the department, Figure 5.7. Engraved outlines were used to mark the wall positions so that vertical wall pieces could later be fitted securely into those grooves.

The walls were designed to be 8 cm tall, sufficiently high to provide clear spatial separation between rooms, yet low enough to maintain visibility of other elements on the board. Door-shaped openings were incorporated to allow the ambulance to pass easily between rooms. For structural stability and ease of assembly, finger joints were used at the corners of the outer walls, while mortise and tenon joints connected the inner walls to the external structure, Figure 5.8.

To simulate the patient journey (see *Section 2.3*), a continuous path, Figure 5.9, was modeled connecting the different rooms. The path avoided sharp 90-degree corners to support smooth movement of the ambulance. It also featured curves and twists to create a more engaging play experience and to maximize the length of the route within the given space. Adequate spacing between the path and the walls was ensured to allow the ambulance to pass unobstructed.

Further details were added to enhance usability and visual clarity. The names of the rooms and the hospital were designed to be engraved using font sizes and styles that could be read from a distance. A hole for a speaker was positioned at the mid-height of the board’s right side, approximately aligned with the average height of a child’s head to optimize audio directionality. Additional holes were included for buttons and corresponding LEDs

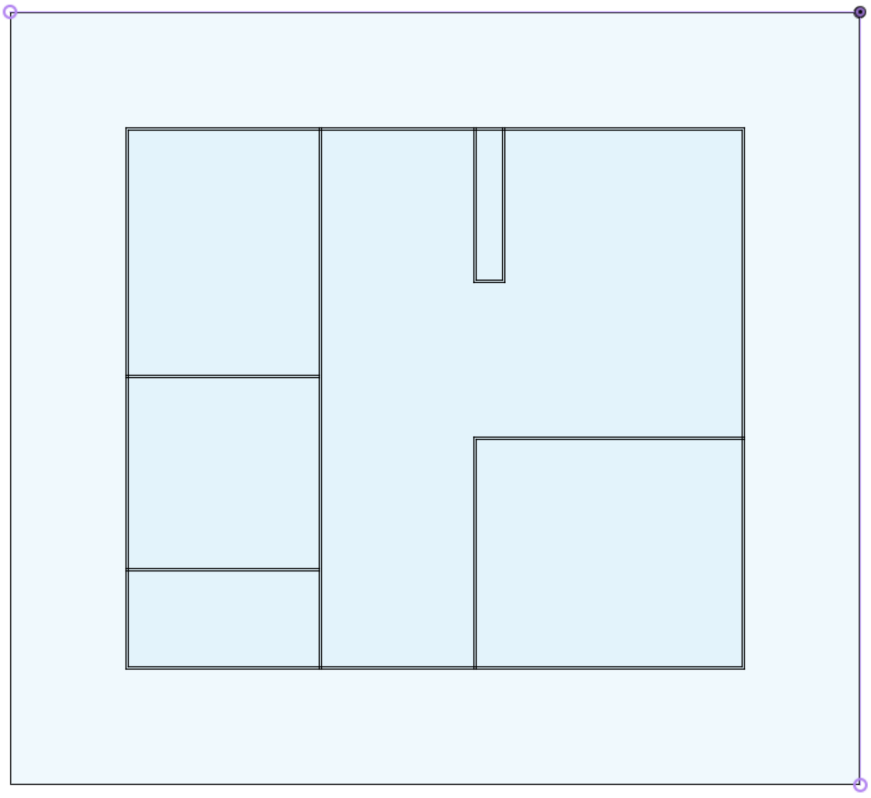
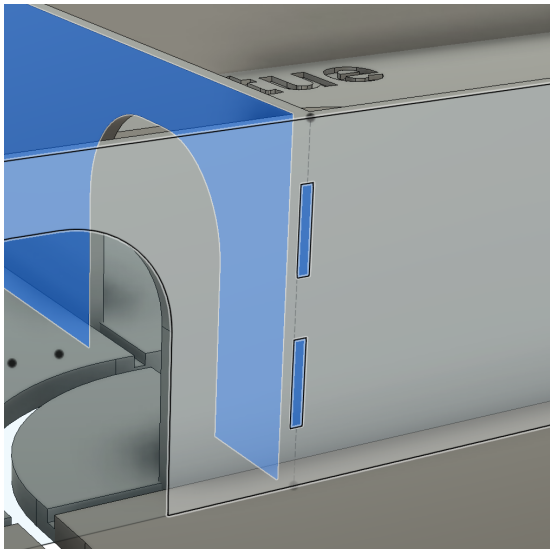
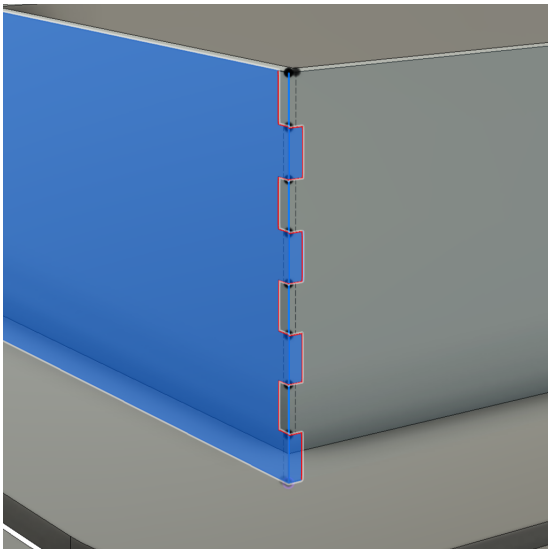


Figure 5.7: Design of the layout on the board



(a) Mortise and Tenon type joint



(b) Finger type joint

Figure 5.8: Types of joints used to connect the walls

completing the design of the game board, Figure 5.10.

As a general note, while some dimensions were defined during the planning phase (see *Section 4.3.2.2*), based on ergonomic considerations and design intentions, many others (such as wall thickness and length and hole sizes for the buttons, LEDs and speaker) were dictated by the sizes of the available materials and components.

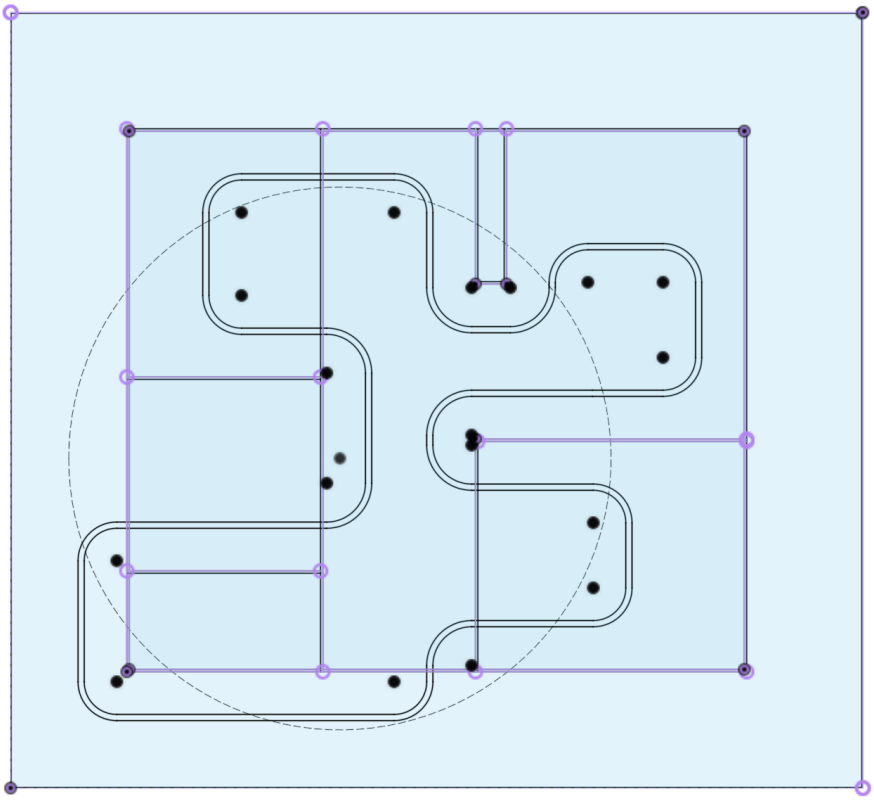
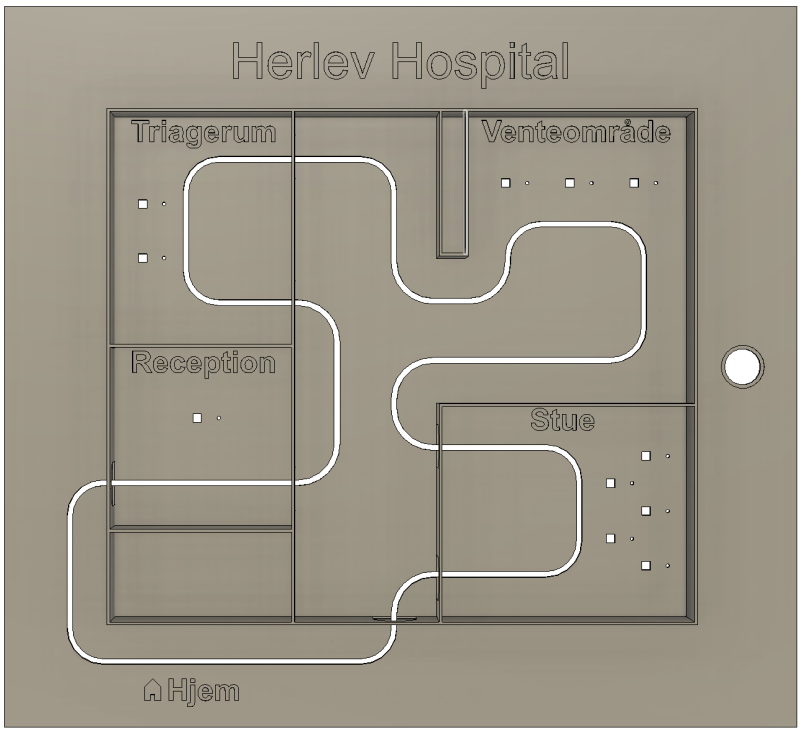
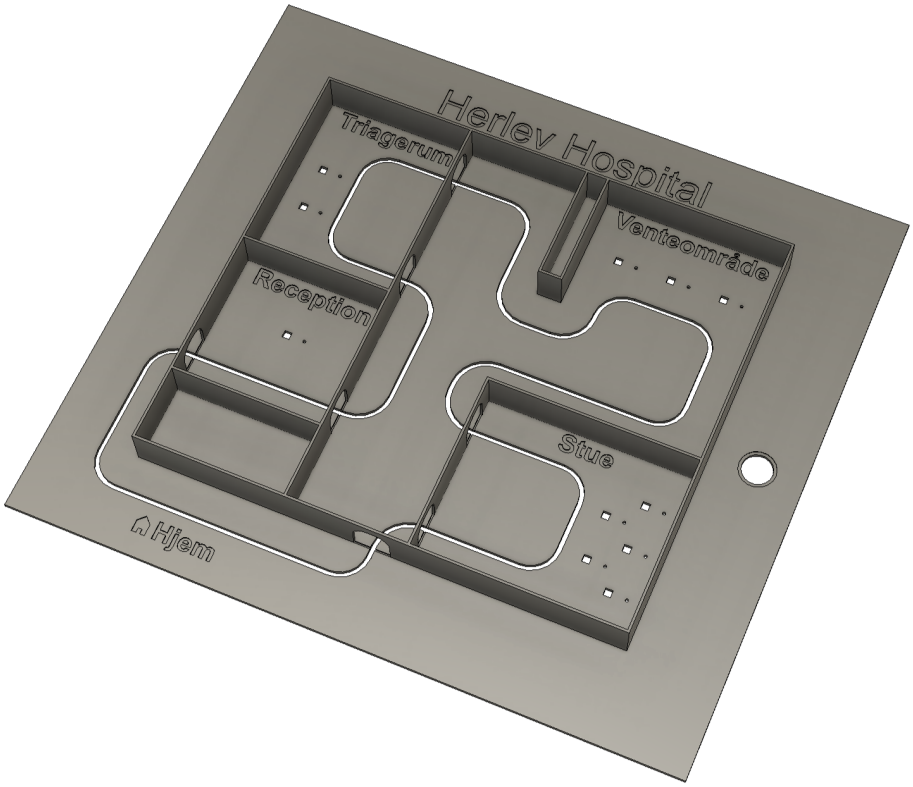


Figure 5.9: Design of the path



(a) Top-down view



(b) Axonometric view

Figure 5.10: 3D render of the game board

Electronics

To make the game functional, the system was powered using Arduino boards. Arduino boards were chosen due to their suitability for rapid prototyping, as they offer a low-cost, user-friendly, and highly customizable environment for building interactive systems. The system schematics shown in this and subsequent sections, were developed using Fritzing [77], an open-source electronics design software known for its ease of use and extensive component library.

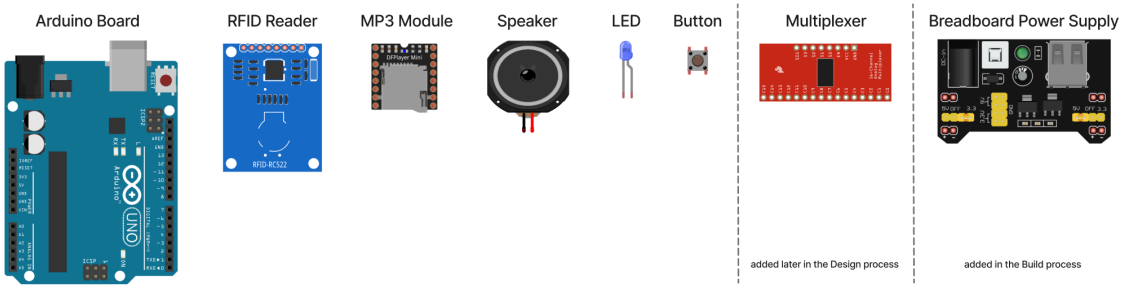


Figure 5.11: Overview of system's components

The system's main electronic components included RFID readers, an MP3 module, a speaker, buttons, and LEDs, Figure 5.11. The initial concept involved placing a single RFID reader on the ambulance and embedding RFID tags at the entrances of the rooms. This setup allowed the reader to scan tags upon entering a room and detect its corresponding ID. However, this approach presented mechanical challenges: due to the circular route and the presence of supports underneath the board, the wires from the RFID reader would get entangled. An alternative design, attaching the board's "island" to the main structure via the walls without supports, was also considered but was ultimately deemed insufficiently stable.

To address these challenges, the system was redesigned to invert the RFID logic. Instead of placing a reader on the ambulance, five RFID readers were mounted on the underside of the board, each associated with a room. The ambulance itself carried a tag, allowing the system to identify the room it entered by detecting which reader was triggered as the ambulance passed by.

The complete system design required 5 RFID readers, an MP3 module, a speaker, 11 buttons, and 11 LEDs, Figure 5.12. A single Arduino board could not accommodate all necessary components, so the design incorporated two Arduino boards to expand pin availability and separate system responsibilities. Even with the distribution of components across two microcontrollers, the number of available pins remained limited. To resolve this, a multiplexer was used to manage the button inputs, reducing the number of required pins from 11 to 4.

As shown in Figure 5.12, the system utilizes two Arduino boards. Arduino A, positioned on the left side of the schematic, is responsible for managing the RFID readers and the MP3 module. Arduino B, located on the right, controls the LEDs and buttons. This division of tasks allows for better distribution of processing load and simplifies wiring by grouping related components under each microcontroller.

To facilitate communication between the two Arduinos, several methods were considered (Serial, I2C, and SPI). Serial communication was selected due to its simplicity and ease of implementation, as system scalability (that I2C could offer) was not a primary concern.

The finalized design includes all component connections, appropriate resistors for LEDs and buttons, and a voltage divider to protect the RX pin of the MP3 module.

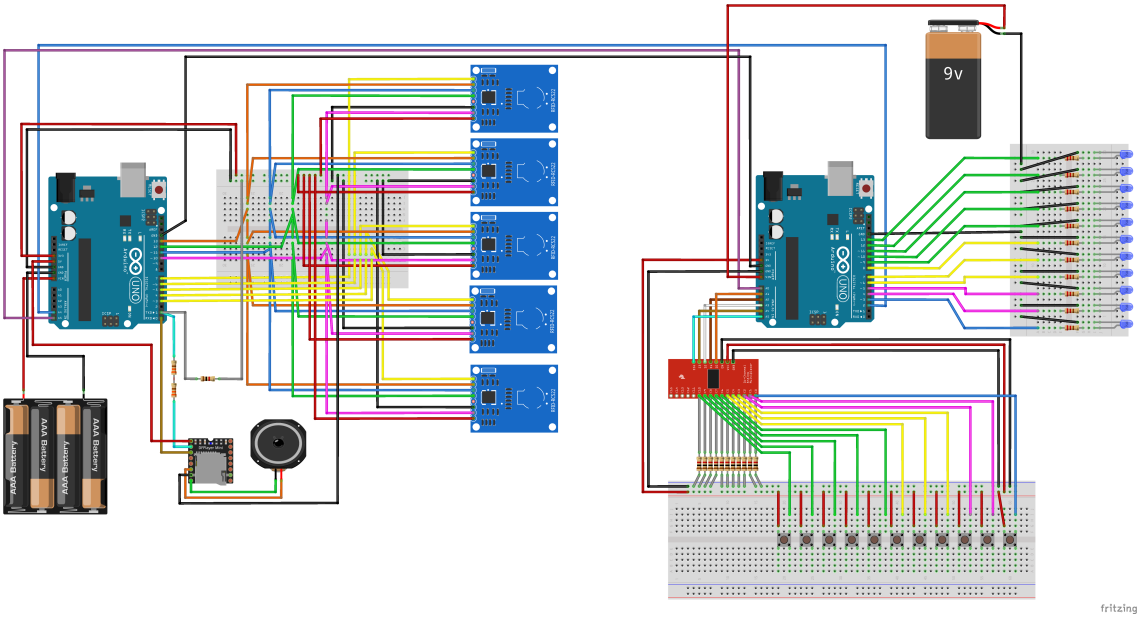


Figure 5.12: Overview of system schematic

The audio files that play when the button is pressed were created by asking one of the student nurses at the hospital to read and record the transcripts, which can be found in Appendix A.11.2. Since the content is in Danish, a native speaker was chosen instead of an AI voice to ensure a more natural delivery and a warmer, more engaging tone for children to listen to.

The logic of the game was translated into code for the two Arduinos, Figure 5.13. Arduino A continuously monitors its five RFID readers and when an RFID tag is detected, it identifies which room it corresponds to (e.g., ”Room 3”) and sends this room name to Arduino B. Once Arduino B receives the room message, it activates the corresponding LEDs to reflect that the current room is activated. It then monitors whether a button that belongs to that room is pressed and, if so, sends the button index (e.g., ”3”) back to Arduino A. Upon receiving this value, Arduino A plays the associated audio file.

The complete Arduino code can be found in Appendix A.13.

Overall, the design of the board and electronics was carried out with the intention of complying with Norman’s Principles, (*Section 4.3.2.1*):

1. **Visibility**: When the child drives the ambulance into a room, the corresponding buttons light up, clearly signaling that they are active and ready to be pressed. Additionally, the spatial layout of the game (including 3D walls, icons, and the ambulance track) enhances spatial understanding and makes the structure of the hospital environment understandable.

2. **Feedback**: The lights in the room light up when the ambulance enters, giving visual confirmation that the room is active and responsive. When a child presses a button in a room, an audio message plays, offering information about a hospital object or person. These responses help the child understand that their actions are having a direct effect.

```
// Arduino A

SETUP:
  Start Serial communication with DFPlayer
  Start SoftwareSerial communication with Arduino B

  Initialize DFPlayer
    If DFPlayer not found, stop program

  Set DFPlayer volume

  Start SPI communication for RFIDs
  Initialize all 5 RFID readers

LOOP:
  FOR each RFID reader (1 to 5):
    IF a new card is detected AND read successfully:
      SEND the corresponding "Room X" name to Arduino B via SoftwareSerial
      Halt RFID communication and reset UID data
      Wait briefly to prevent multiple reads

  IF a message is received from Arduino B:
    READ the message (button index)
    CONVERT the button index to an integer
    INCREMENT track number by 1 (button 0 → track 1, etc.)
    PLAY the corresponding track on DFPlayer
```

(a) Pseudocode of Arduino A

```
// Arduino B

SETUP:
  Start SoftwareSerial communication with Arduino A
  Set multiplexer control pins (S0–S3) as OUTPUT
  Set all LED pins as OUTPUT

LOOP:
  IF a message is received from Arduino A:
    READ the message (room name)
    Store as currentRoom

    TURN OFF all LEDs

    SELECT which LEDs to turn ON based on currentRoom:
      Room 0 → No LEDs ON
      Room 1 → LED 1
      Room 2 → LEDs 2 and 3
      Room 3 → LEDs 4, 5 and 6
      Room 4 → LEDs 7 to 11

  FOR each channel (0 to 10) on the multiplexer:
    SELECT the channel using control pins
    WAIT briefly for signal to stabilize
    READ analog value from signal pin

    IF signal is above threshold (button pressed):
      IF pressed button is in the currentRoom:
        SEND channel number to Arduino A (as string)
        Wait briefly to debounce
```

(b) Pseudocode of Arduino B

Figure 5.13: Pseudocodes

3. **Constraints**: The physical track constrains the ambulance's movement to a predefined path, guiding the child around the board and limiting where they can go. Additionally, only the buttons in the room where the ambulance is currently located are activated, which constrains the interaction space and minimizes potential confusion. While the system allows freedom of exploration in terms of room order and pacing, these embedded constraints help ensure that interactions remain meaningful and context-specific.

4. **Mapping**: The layout of the hospital on the board mirrors a real-world hospital environment, with buttons in each room designed as visual icons representing medical staff, equipment or objects.

5. **Consistency**: All rooms share the same interaction pattern, with buttons that are visually and physically consistent in size and shape, helping children predict what to expect in each space. Additionally, the style of icons and the tone of the audio explanations remain uniform across the game.

6. **Affordance**: The buttons invite physical interaction, as their design clearly suggests they should be pressed. The toy ambulance on the track naturally encourages movement along the path, since children easily recognize it as a drivable object. Additionally, the layout of the board, along with the 3D walls and openings, clearly communicates that the toy is intended to be explored.

5.4.1.2 Build
Board

For the construction of the board, the design was precisely cut using a 5-axis CNC machine [78] on a 6 mm plywood sheet.

Since the board features a circular path, this creates an "island" in the center that is not physically connected to the rest of the board. To support this isolated section and ensure the structural integrity of the overall design, a layered construction was implemented. Specifically, a backboard was added and foam spacers were used between the front board and the backboard to provide the necessary depth for housing the electronics on the reverse side of the front board. This layered structure also helped keep the central "island" in its intended position. The entire assembly was built like a sandwich, Figure 5.14, consisting of a plywood front, a middle foam layer, and a plywood back. Wooden blocks were placed within the foam layer to act as anchors, allowing all three layers to be securely screwed together.

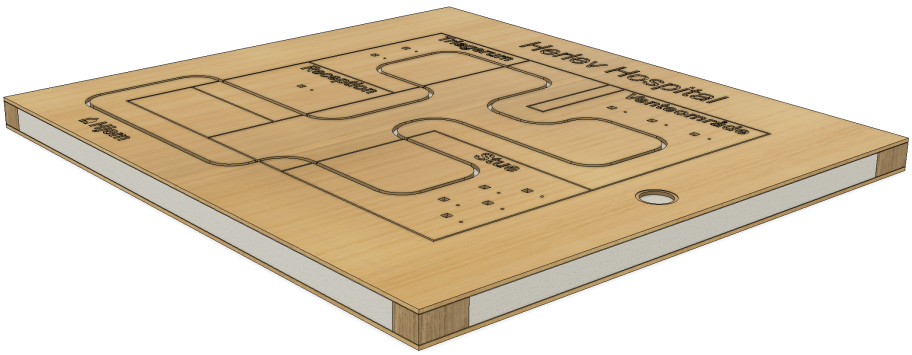


Figure 5.14: 3D render of the layered board construction

The foam layer was designed to include cutouts and cavities that allow space for mount-

ing the electronics and routing the wires. Additionally, care was taken to keep the foam layer at a distance from the path along which the ambulance moves. This spacing was necessary to ensure proper operation of the RFID system, allowing the tag mounted on the ambulance to be detected by the RFID readers positioned beneath the surface. The foam layer was carved using the 5-axis CNC machine and then glued to the front board, along with several wooden blocks that were placed in the corners of the board and on the ”island”, Figure 5.15.

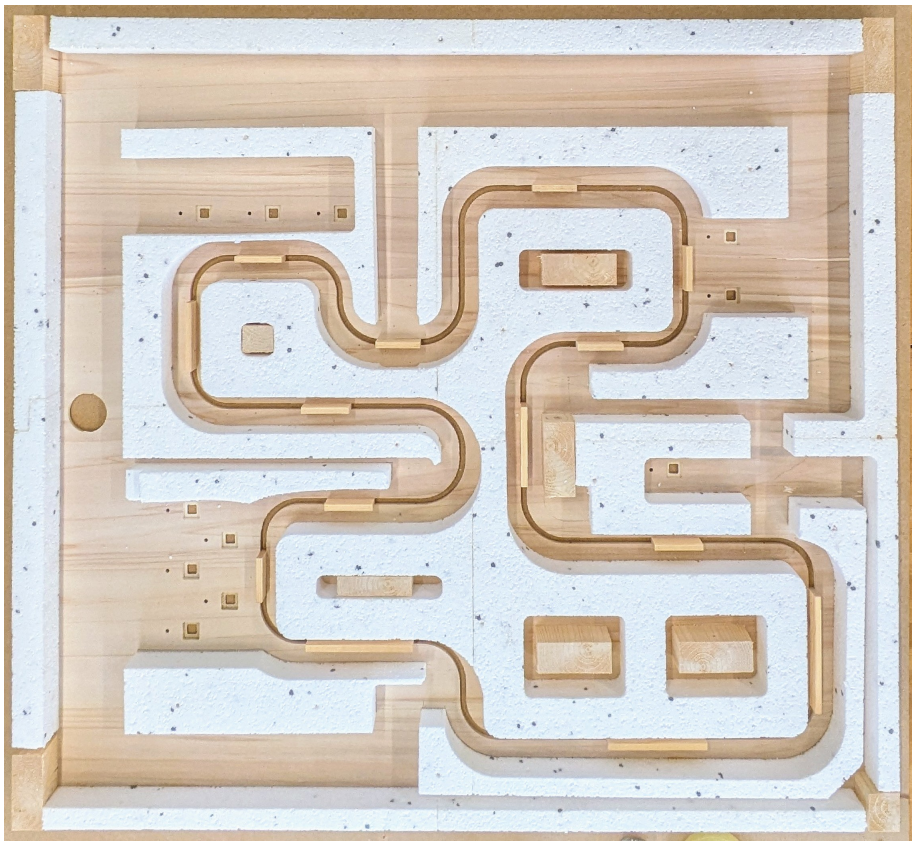


Figure 5.15: Foam layer and wooden blocks attached to the front board

The ambulance was 3D printed using black PLA. Some parts of it, like the tyres and windows, were covered with masking tape to preserve their color. The remaining surface was then spray-painted a fluorescent yellow, the headlights were painted orange, and the hospital symbol on the side was painted blue, all to resemble the appearance of Danish ambulances, Figure 5.16. Finally, it was spray-painted with a clear top coat to protect it from wear due to frequent handling by children and ensure it could be easily cleaned.

A hole was drilled on the underside of the toy-ambulance to fit a screw that served as an axis, allowing the attachment of an RFID tag beneath the vehicle. Before attaching the screw to the ambulance, it was passed through a 3D-printed base with a central hole. This base acted as an extension of the screw head, providing a wider surface onto which the RFID tag could be glued securely. In this setup, the ambulance was positioned on top of the front board, with the screw extending down into a cut-out path. On the underside of the board, the 3D-printed base with the RFID tag secured the structure. This design ensured that the ambulance stayed aligned with the path while maintaining a fixed distance between the RFID tag and the underlying readers, allowing for consistent and reliable tag detection.

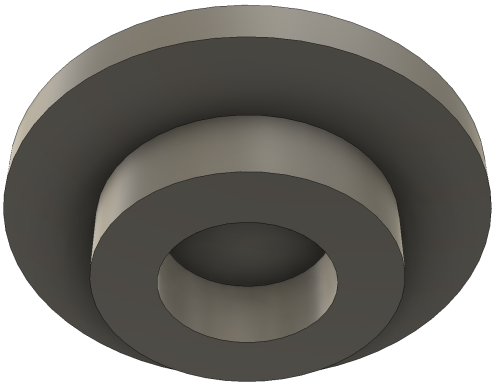
(a) Front view

(b) Back view

Figure 5.16: Toy-ambulance equipped with RFID tag

A cover for the speaker was cut out of perforated metal and was placed over it to protect the speaker membrane from being pressed by children. It was also spray-painted blue to add a touch of color.

Since the button caps were small and icons needed to be added, a custom attachment was 3D-printed, Figure 5.17. The printed icons were cut out, glued onto the attachment and then covered with clear sticker paper to protect them from fading due to frequent handling by children and to allow for easy cleaning.



(a) 3D render of the button cap

(b) Physical version of the button cap

Figure 5.17: Custom-made button caps

The letters and wall pieces were laser-cut from acrylic. The room labels were made in green, while the hospital name was cut in blue to match the branding of Herlev Hospital. The walls were made from transparent acrylic to avoid blocking the view of the board. Both the letters and the walls were placed into their corresponding engraved slots on the board and secured in place with glue.

After all these steps, the prototype was ready for final assembly. Once the electronics

were installed on the back of the front board, the back board could be positioned and secured using screws that fit into threaded inserts embedded in the wooden blocks. This design allowed for easy attachment and removal of the back board when needed. Once assembled, the entire board could be placed on two rectangular bases that supported it in an upright position against the wall, ensuring it stood vertically at the appropriate height (see *Section 4.3.2.2*).

An overview of all materials used in the prototype is provided in Table 5.9.

Part	Material and Details
Board	1.00m x 1.10m 6mm plywood
Walls	3mm transparent acrylic sheets
Letters	3mm blue and green acrylic sheets
Speaker Cover	1mm perforated metal sheet
Button addons	11 x 3D printed caps
Support for the board	4cm Expanded Polystyrene (EPS 80), 4cm wood
Base for the board	50cm x 4cm Extruded Polystyrene (XPS300)
Toy-ambulance	3D printed, spray painted
Toy-ambulance axis	M8 Hex socket cap screw
RFID tag base	3D printed
Mounts for electronics	3D printed, 5 for RFID readers, 2 for Arduino boards

Table 5.9: Materials used in the system

Electronics

The development of the electronic system began with testing the components (including the MP3 module, the multiplexer, the RFID readers and the communication between the two arduino boards) individually, using small breadboard circuits. This helped verify their functionality and allowed for an understanding of their behavior prior to full system integration.

Following successful individual tests, a proof-of-concept circuit was built using all essential components and two RFID readers. Standard Arduino jumper wires (maximum 20 cm) were used. The successful operation of this prototype validated the approach and confirmed readiness for scaling up to the full version.

Once the layout of the board and its build process were done, assembly of the system on the physical board began. The primary elements, two Arduino boards and two breadboards along with the battery packs, were positioned according to the planned layout, Figure 5.18. Assembly started with fixing the buttons and LEDs on their specified places onto the board, trimming wires to optimal lengths for neat routing.

Buttons and LEDs were secured using a hot glue gun. The wires were stabilized using paper tape. The Arduino boards and RFID readers were mounted onto 3D-printed holders and fastened with screws. Breadboards and mounts were attached to the baseboard using double-sided adhesive tape.

During the first test of the fully assembled system, none of the RFID readers responded. Investigation revealed that signal degradation occurred due to excessive wire length. The

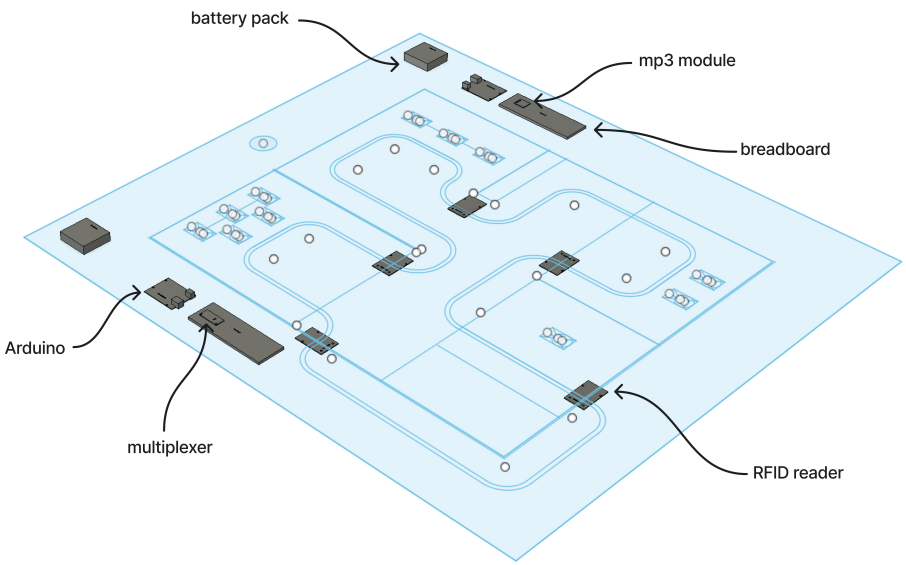


Figure 5.18: Blueprint of the position of key components on the back side of the board

MFRC522 RFID reader uses the SPI communication protocol, which is highly sensitive to signal integrity over longer distances. It was found that SPI communication became unreliable when wire lengths exceeded 75 cm. This required a redesign of the wire routing to keep connections within this functional limit.

Even after adjusting wire lengths, system stability remained an issue. The RFID readers would intermittently fail to initialize or respond to scans. After further research, it became apparent that power instability was a major cause. The MFRC522 module is particularly sensitive to fluctuations in the 3.3V supply. Voltage noise or sagging can cause SPI communication errors, microcontroller crashes, or silent failures of the RFID module.

To resolve this, the power strategy was revised. The RFID readers were decoupled from the Arduino's onboard 3.3V regulator and instead powered via an external regulated 3.3V source. A breadboard power supply module was introduced for this purpose. Additionally, decoupling capacitors (220 µF) were placed between the 3.3V and ground pins of each RFID reader to suppress high-frequency noise. A larger bulk capacitor (1000 µF) was also added to the power rail to buffer current surges. This significantly improved system reliability.

Further challenges arose with the DFPlayer Mini MP3 module and its speaker. One issue was incorrect audio playback order, even though the filenames appeared correctly sorted on the SD card. This occurred because the DFPlayer does not use filenames for playback sequencing. Instead, it relies on the FAT filesystem's internal file index, which is determined by the order in which files are copied to the card.

To fix this, the SD card was reformatted using the official SD Card Formatter, then populated with correctly named files (e.g., 0001.mp3, 0002.mp3, etc.) and finally loaded with files in the intended sequence by dragging them all at once into the card's root directory. This ensured consistent indexing and fixed the audio order.

Another problem was insufficient speaker volume. This was addressed by processing the audio files in Audacity [79], an open-source audio editor. Dynamic range compression was applied to reduce the volume difference between loud and quiet sections of speech. Additionally, a makeup gain of 10 dB was applied during compression to boost overall

loudness without distorting the audio.

Although the system was now mostly functional, intermittent audio cutouts appeared during playback. These were traced back to brownout conditions, a drop in voltage when the DFPlayer module experienced sudden current spikes, causing it to reset or stop playback. This issue was mitigated by adding a decoupling capacitor (220 µF) between the power and ground pins of the DFPlayer module, absorbing transient current spikes, ensuring a more stable voltage supply during audio playback.

Finally, two toggle switches were added to the battery power sources supplying the Arduinos, allowing the game to be turned off, since the breadboard power supply already includes a built-in switch.

After implementing all the above fixes, Figure 5.19, and all the electronics were placed on the back side of the front board, Figure 5.20, the system was able to perform all intended tasks.

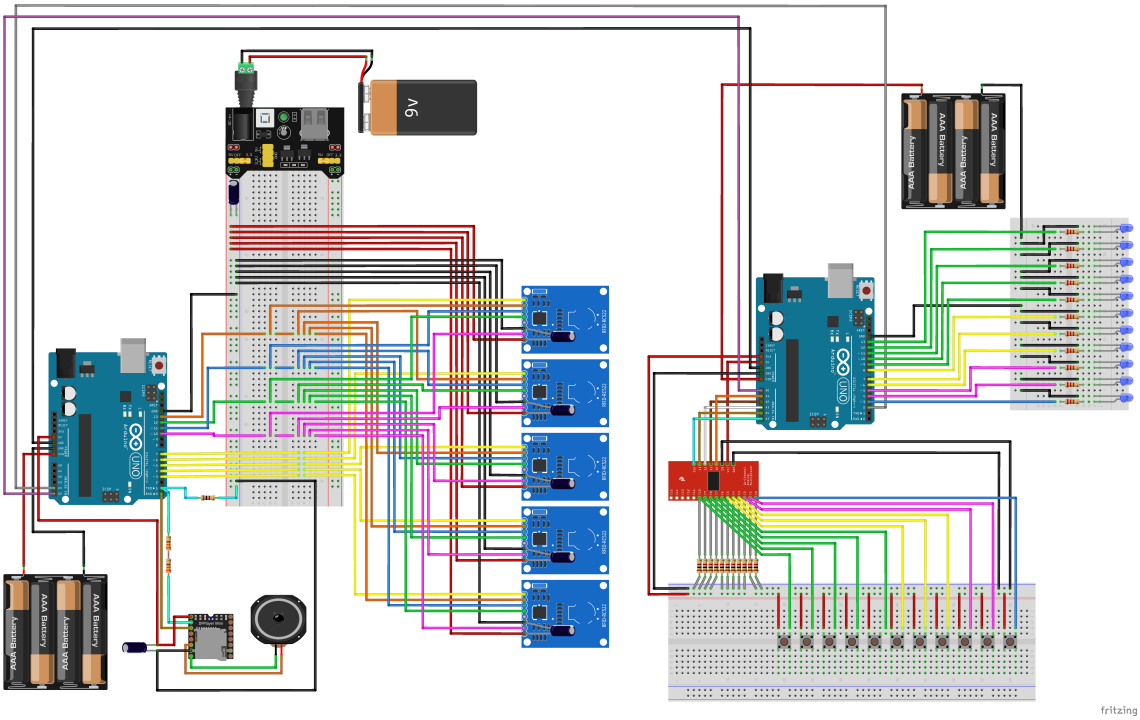


Figure 5.19: Final system schematic

An overview of all electronic components used in the system, along with their specifications and quantities, is provided in Table 5.10.

Figure 5.20: View of the electronics on the back side of the front board

Component	Quantity	Specifications
Arduino boards	2	Arduino UNO R3
MicroSD card	1	32GB, FAT32 format
MP3 module	1	DFPlayer Mini (MP3-TF-16P)
Speaker	1	4Ω 3W 50mm mini speaker
RFID chip	1	RFID key tag (T5577/EM4305 125khz)
RFID readers	5	RFID-RC522
Push buttons	11	SMD switches
LEDs	11	LED 5mm, clear lens, Blue
Multiplexer	1	16-channel (CD74HC4067)
Resistors	25	11 x 220Ω, 12 x 1kΩ, 2 x 330Ω
Capacitors	8	6 x 220μF, 2 x 1000μF
Ethernet wires	5	75cm
Single-core wires	-	Varying length based on usage
Switches	2	Toggle switch with 2 pins (soldered ears)
Power sources	3	2 x 6V battery (4x1.5V AA pack), 1 x 9V PP3 battery
Breadboard Power Supply	1	ELEGOO module with 3.3V/5V output

Table 5.10: Electronic components used in the system

5.4.2 User Testing and Evaluation

A total of thirteen children (aged 4-7 years) participated in the testing of the high-fidelity prototype, each accompanied by a caregiver, Figure 5.21.

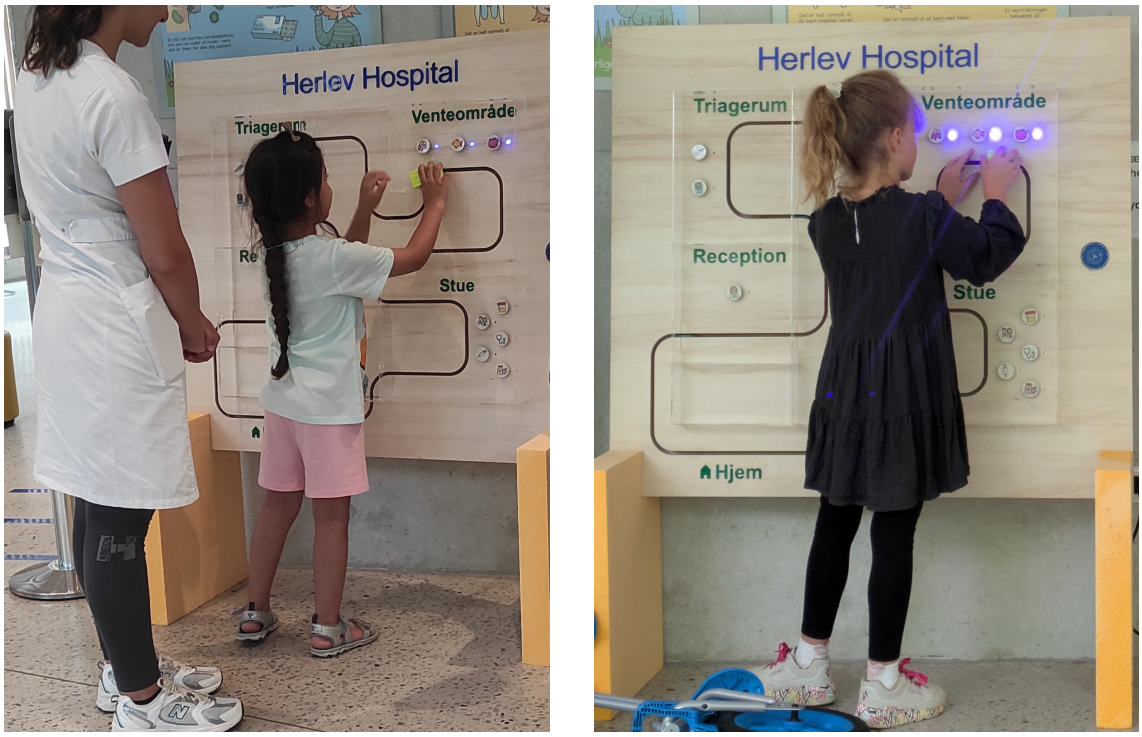


Figure 5.21: Testing “Ambulance Adventure” in the waiting area of Herlev Hospital’s PED

An overview of the demographic and medical history characteristics of the 13 children who participated in the high-fidelity prototype testing is provided in Table 5.11. The table categorizes participants by age, gender, prior experience with emergency room visits, and hospitalization. Notably, children aged five constituted the largest age group (n=7). Gender distribution was fairly balanced, with 7 boys and 6 girls. Additionally, the majority of participants had previous emergency room experience (n = 10), with six having also been hospitalized at some point, and seven reporting no history of hospitalization.

From the quantitative and qualitative measures of the engagement section of the testing, summary statistics are provided in Table 5.12. Children spent on average approximately 5 minutes playing and interacting with the game. On average, they pressed 9 out of the 11 buttons and listened to 7 out of the 11 audio clips in full. All participants completed the full route of the game and many continued playing, repeating additional routes during the session.

The intuitiveness and ease of use of the prototype were assessed through direct observation based on four predefined questions, and the results are provided in Table 5.13. A considerable number of children did not initially understand the game mechanics, primarily because they did not recognize the buttons as interactive elements. In most cases, children only began pressing the buttons after being explicitly told they could do so. It was also observed that parents frequently engaged with their children during the activity, either by explaining, helping or playing with the child, resulting in a high level of parent-child interaction throughout the session.

From an ease-of-use perspective, the findings were clear. All children within the target

Variable		Number (out of 13 children) (%)
Age	4	2 (15%)
	5	7 (54%)
	6	1 (8%)
	7	3 (23%)
Gender	Girls	6 (46%)
	Boys	7 (54%)
Previous ER visit	Yes	10 (77%)
	No	3 (23%)
Previous hospitalisation	Yes	6 (46%)
	No	7 (54%)

Table 5.11: Demographic and medical background of the participating children

Average engagement time	Average buttons pushed	Average audios listened	Completed full route
4.54 min	8.77 (79.7%)	7.15 (65%)	13 (100%)

Table 5.12: Summary of user engagement statistics

age group were able to reach every area of the board without tiptoeing, indicating that the physical layout was accessible. A few children aged 6 or 7 chose to kneel down to move the ambulance along the lower part of the route, but they were still able to do so with ease. On the other side, none of the children found it easy to move the ambulance along the track, as it frequently became stuck.

Did they understand the game mechanics?	Are the parents helping?	Can they reach all places on the board?	Is it easy to move the ambulance around the path?
7 out of 13 (53.8%)	9 out of 13 (69.2%)	13 out of 13 (100%)	0 out of 13 (0%)

Table 5.13: Observational insights for intuitiveness and ease of use

To assess knowledge retention after the session, a set of three multiple-choice questions was presented to the children, as shown in Appendix A.8.2. The results of their performance on the quiz are provided in Table 5.14. The highest performance was observed in Quiz Question 3, with 9 out of 10 children answering correctly (90%). Quiz Question 1 had a slightly lower success rate, with 8 out of 11 correct responses (72.7%), while Quiz Question 2 had the lowest correct response rate at 66.7% (8 out of 12). These results suggest that the majority of children were able to recall key information from the experience. It should be noted that some children did not answer all questions, but unanswered questions were not included in the analysis in order to focus on the accuracy of responses when an answer was given.

However, no apparent correlation between participants' ages and quiz performance was found within the sample, as no clear pattern or trend was observed, Figure 5.22. For

Quiz Question 1	Quiz Question 2	Quiz Question 3
8 out of 11 (72.7%)	8 out of 12 (66.7%)	9 out of 10 (90%)

Table 5.14: Children's performance on the quiz questions

example, both high and low scores were recorded among 5-year-olds, and older participants (e.g., 7-year-olds) did not consistently achieve higher scores. For this analysis, any unanswered quiz question was marked as incorrect (if no answers were given, quiz score is 0).

Figure 5.22: Relationship between children's age and quiz scores

When the children were asked whether they would play again following the high-fidelity prototype session, a generally positive reception of the experience was indicated, Figure 5.23. The majority of children (n=7) responded positively and another two said "Maybe". This suggests that most children found the prototype enjoyable or engaging to consider replaying it. Only three participants responded negatively, and one was uncertain and answered "Don't know".

The parents' responses to how likely they were to recommend the intervention to others on a scale from 1 (very unlikely) to 10 (very likely) suggest a favorable reception of the prototype, Figure 5.24. The majority of parents rated the experience positively, with 6 out of 13 giving a score of 8. Two parents gave the highest possible score of 10, while scores below 6 were given by only two parents.

When parents were asked if they had any additional comments or feedback to capture relevant reflections, they provided a variety of responses, but some recurring themes were identified. A summary of the thematic coding of parents' comments is provided in Table 5.15. The most frequently mentioned theme was Ease of Movement (n=5), with parents noting that children had difficulty moving the ambulance. Content Expansion (n=4) was another common suggestion, with parents expressing interest in increasing the num-

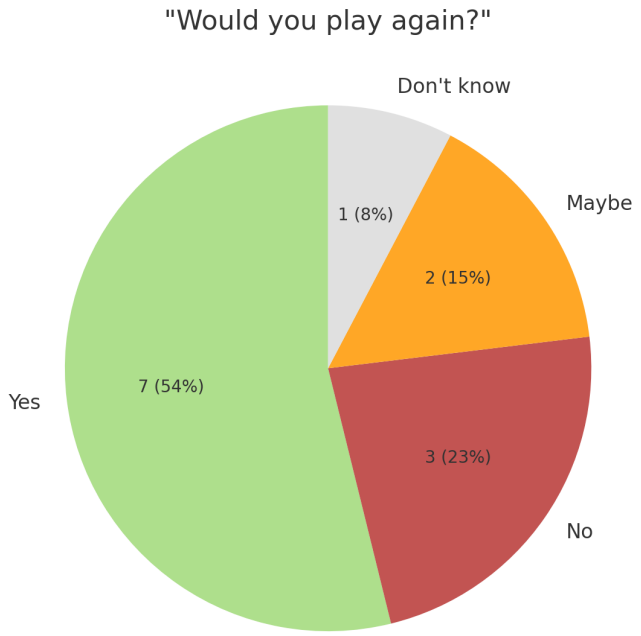


Figure 5.23: Distribution of children's responses to "Would you play again?"

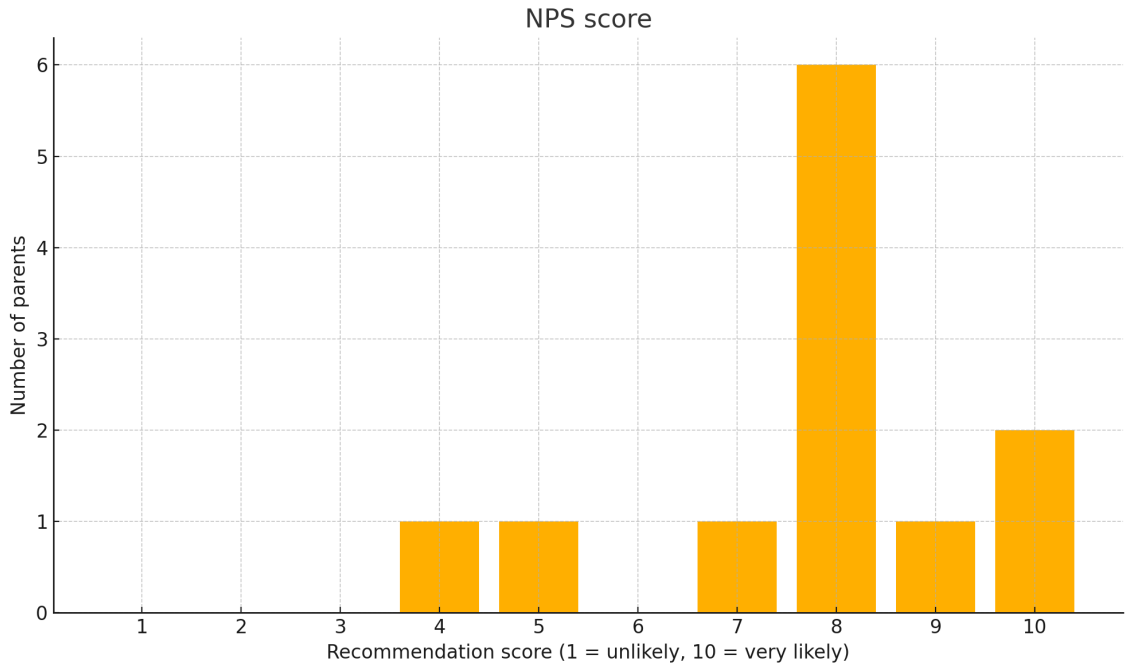


Figure 5.24: Distribution of Net Promoter Scores based on parents' responses

ber of interactive elements. Issues with Removable Buttons (n=2) were also reported negatively, as some children removed the buttons during play. The Interactive/Visual/Fun nature of the prototype was highlighted again (n=2), suggesting that the design was visually appealing and engaging. Additionally, the suggestion to include Headphones (n=2) was mentioned, likely reflecting a desire to improve audio clarity or reduce environmental noise.

Theme	Count	Sentiment	Overview
Ease of Movement	5	Negative	The kids had trouble moving the ambulance
Content Expansion	4	Neutral	Add more buttons, colours, lights and/or pictures
Removable Buttons	2	Negative	Many kids removed the buttons
Interactive / Visual / Fun	2	Positive	It looks fun
Headphones	2	Neutral	Add headphones

Table 5.15: Thematic coding of parents' comments

The anxiety scores measured before and after the intervention include data from the Wong-Baker FACES Pain Rating Scale (WBF) and the modified Yale Preoperative Anxiety Scale (m-YPAS). Each child's m-YPAS score was independently assessed by two observers, and the average of their ratings was used as the final score per time point. From these values, the group-level mean values were calculated and used in the plots.

Table 5.16 summarises participants' scores on the two scales before and after playing the game. For each measure it reports the mean ± standard deviation (SD) at both time points, the average paired difference (Δ), and the paired-sample t-test results (t(12), p-value), providing a compact snapshot of the intervention's impact on anxiety levels.

Measure	Mean ± SD Before	Mean ± SD After	Δ	t(12)	p
WBF (0-10)	2.46 ± 2.47	1.54 ± 2.03	0.92	2.52	0.027*
m-YPAS (23.33-100)	28.39 ± 6.18	26.60 ± 5.22	1.79	1.52	0.152

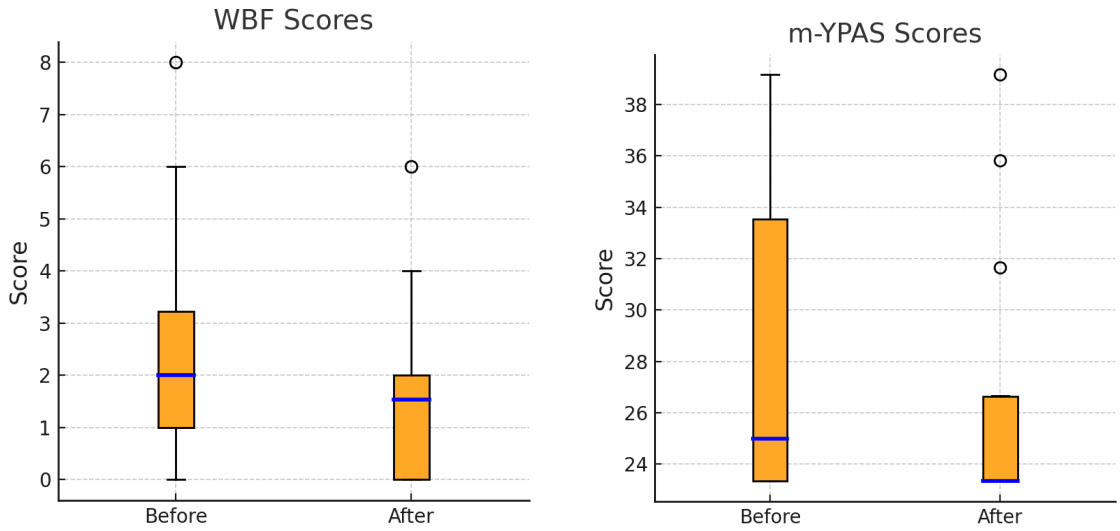
Table 5.16: Pre- and post-intervention scores on WBF and m-YPAS.

As shown in the table, the WBF scores dropped from a mean of 2.46 to 1.54, while m-YPAS scores decreased from 28.39 to 26.60. For a better understanding of the table the following explanations are given:

- Δ is the mean paired difference (Before - After), computed by subtracting the post-intervention score from the pre-intervention score and then averaging those differences across all 13 participants. Positive values indicate a reduction in anxiety after playing the game.
- t(12) denotes the paired-sample t statistic which evaluates whether the mean of the paired differences (Δ) is significantly different from zero, with 12 (N-1) degrees of freedom (N = 13). Larger absolute t values provide stronger evidence that the pre- and post-scores differ.

- p is the probability of obtaining a t value at least as extreme as the one observed if, in reality, there were no difference between pre- and post-scores (the null hypothesis). p values < .05 are marked with an asterisk, indicating statistical significance. In this table, the WBF change reaches that criterion, whereas the m-YPAS change does not.

To complement the statistical overview provided in Table 5.16, Figure 5.25 illustrates the distribution of individual WBF and m-YPAS scores before and after the intervention using boxplots. These plots show the median (blue line), interquartile range (box), full data range (whiskers), and any outliers (circles). A downward shift in both medians and interquartile ranges suggests a general trend toward lower anxiety scores following the intervention, with the WBF scores showing a more consistent reduction across participants. A few children still registered relatively high anxiety (outliers) on both scales, showcasing that the prototype did not benefit every participant equally.



(a) Wong Baker FACES scores (0-10)

(b) m-YPAS scores (23.33-100)

Figure 5.25: Anxiety scores pre- and post-intervention

It is noteworthy that the WBF scale was administered immediately after the intervention, capturing the child's immediate emotional response, whereas the m-YPAS was completed slightly later, once the child had returned to a more neutral or uninterrupted state.

The detailed results of the high-fidelity prototype testing can be found in Appendix A.14.

6 Discussion

The final prototype, Ambulance Adventure, was developed to explore how interactive, play-based systems can reduce pediatric anxiety in the waiting area of the Pediatric Emergency Department at Herlev Hospital. The following discussion interprets the testing outcomes in greater depth, outlines the main contributions of the project in response to the initial research questions, addresses the limitations and proposes directions for future work and further development of the concept.

6.1 Interpretation of Results

Looking more closely, beyond the numbers and statistics collected during testing of the high-fidelity prototype, can offer insights into how children experienced and understood the intervention. Interpreting these observations helps uncover the underlying factors that shaped their engagement, behaviors and performance, as well as provide indications of whether and how the intervention may have contributed to reducing their anxiety in the hospital setting.

Initially, when it comes to the children's engagement with the game, all participants completed a full route. In general, the children pressed most, if not all, of the buttons and most of those times stayed to listen to the entire audio before pressing the next button or moving along. This behavior indicates that the narration and explanations were effective in capturing and maintaining their attention.

Regarding the intuitiveness of the intervention, all children appeared to understand that they could drive the ambulance around the board and began doing so independently, without the need for explanation. However, this was not the case for the buttons. A number of participants did not recognize the buttons as interactive components and only pressed them after prompted by either their parents or by the facilitators.

In addition to providing such guidance, parents often supported their children by responding to their questions. When children encountered unfamiliar or intriguing audio content, many turned to their parents for clarification or to share their curiosity, resulting in moments of joint engagement. In general, when parents were physically close, they tended to participate in the experience much like they would in any other play activity. However, there were also cases where parents allowed their children to explore the intervention independently. This range of involvement reflects common patterns in how children interact with toys and games and suggests that the intervention remains functional and engaging both with and without adult participation.

Another relevant observation concerning parents that can be noted is that when the game was placed in the waiting area, some parents passing by either alone or with younger children, outside the targeted 4-7 age group, briefly stopped to interact with it. In the latter instances, the parents often took the lead, engaging with the game while their children observed or participated minimally. This suggests that for younger age groups, the intervention may become a shared experience, with the parent guiding the interaction, explaining what is happening and using the opportunity to initiate a conversation that supports the child's understanding of the hospital environment.

From an ease-of-use perspective, all participating children in this age group were able to physically access the entire game board. Some of the older and taller children even chose

to kneel in order to better reach the bottom areas, suggesting that the game could also be accessible for slightly older children who may choose to interact with it. For example, when a 12-year-old boy passing by began interacting with the game, he remarked that it had caught his attention and that he would be willing to play with it in a hospital setting.

However, all participants, regardless of age, experienced difficulty when attempting to move the toy-ambulance along the track as it frequently became stuck. This mechanical issue may undermine the intended enjoyable nature of the experience and could potentially lead to disengagement, particularly if a child becomes tired or irritated by repeatedly attempting to slide a component that does not function as expected.

When assessing knowledge retention following interaction with the game, participants performed notably well on the post-intervention questions. Particularly Question 3, which was about which object (oximeter) performs which function (showing pulse rate). The high accuracy in responses suggests that participants retained information presented during gameplay. Notably, the wording of the question closely mirrored the phrasing used in the corresponding audio when the oximeter button was pressed, indicating that verbal cues may have played a significant role in supporting memory. Nevertheless, it cannot be excluded that some children used a process of elimination, selecting the correct answer by ruling out the more familiar items (thermometer and syringe, which served as the other multiple-choice options) that they knew did not match the described function.

Similarly, performance was strong on Question 1, which assessed the ability to match an object (the aquarium) to the room (the waiting area) where it can be found. Some participants had not yet learned to read, which likely contributed to difficulties in interpreting the written labels on both the board and the answer sheet. As a result, some children gave incorrect or seemingly random answers, while others, despite selecting the correct location, pointed to the icon on the game board or even to the actual aquarium in the room instead of marking the answer on the sheet. This behavior suggests a reliance on visual recognition and spatial memory rather than reading comprehension.

Question 2 focused on conceptual understanding of spatial layout and sequencing in the hospital setting by asking how many rooms (4) the patient passes through during the journey. Most participants answered correctly. Among those who selected the option with one more room than the correct number, it appears that the ”home” icon on the board was mistakenly included in their count as part of the hospital path. For those who selected the option with one less room than the correct number, the reasons are less clear, but it is possible that they failed to count a room where no audio was played, perhaps because they did not press the button in that room or due to confusion or inattention.

It is also worth noting that a few children did not provide answers to certain questions. In some cases, this was expressed through a verbal response such as “I don’t know” or by nodding. For example, one seven-year-old child with ADHD did not answer any of the questions and his play session was noticeably more rushed and less structured than those of other participants. In other instances, such as with the oximeter question, non-responses appeared to be linked to the fact that the children had not pressed the corresponding button during gameplay and therefore had not heard the relevant audio information.

Overall, no clear correlation could be observed between participants’ ages and their performance on the quiz. This may be attributed to the varying developmental levels among children, which are influenced by factors beyond age. For instance, some younger children demonstrated reading abilities, while some older participants had not yet learned to

read. Additionally, a few children spoke multiple languages, which may have influenced both their cognitive development and their ability to understand or interact with different aspects of the intervention. These variations highlight that developmental differences within this age group can be shaped by a range of individual factors such as the family environment.

When asked whether they would like to play the game again, the majority of children responded positively. This indicates a general willingness to repeat the experience, which is a promising indicator of the prototype's perceived playability and acceptance. Interestingly, even among the few children who responded negatively, some had already completed more than one route through their play session, suggesting that their decision may have been influenced by having already explored the content rather than a lack of interest.

Notably, it was observed that all children enjoyed moving the ambulance around the track. So in cases where a child has already pressed all the buttons and listened to the corresponding audio content, they could possibly continue to engage with the game by sliding the vehicle along the track and through the doors resembling the kind of tactile play seen with bead maze toys, where the satisfaction comes from the movement itself rather than achieving a specific outcome. This suggests that the physical interaction component of the prototype holds standalone play value, which may help sustain engagement even after the primary informative elements have been explored.

Parents' general satisfaction was reflected in the high Net Promoter Scores (NPS) they provided, indicating that they found the intervention interesting, appropriate for the hospital environment, and a promising concept overall. These impressions were further supported by the optional feedback they were invited to share at the end of the session. One mother, whose child participated in the testing, noted that she believed the intervention could also be beneficial for her son, who is on the autism spectrum. She explained that he prefers to explore things at his own pace, is drawn to tactile and interactive experiences, and feels somewhat uncomfortable with social interactions. In this context, she felt that receiving information through the game, rather than directly from a nurse, for example, could be more suitable and supportive for him.

Regarding the pre- and post-intervention anxiety measurements, the results were modest but encouraging. Both the WBF scale and the m-YPAS indicated a decrease in anxiety levels. Although the small sample size limits the strength of statistical conclusions, the consistency across both measures suggests a potential calming effect of the prototype.

Notably, the WBF scale revealed a statistically significant reduction in self-reported anxiety, whereas the observational decrease measured by m-YPAS did not reach statistical significance. This discrepancy may be attributed to the difference in timing between the two assessments: the WBF scale was administered immediately following the play session, while m-YPAS observations were conducted a couple of minutes later, once the child had returned to their pre-intervention context. Additionally, potential ceiling effects may have contributed to the limited change in m-YPAS scores, as baseline anxiety levels on this scale were already relatively low. It is noteworthy that on several occasions, the m-YPAS indicated no observable anxiety, while children self-reported anxiety levels above the lowest possible score on the WBF scale.

6.2 Main Contributions

The main contributions of this thesis include answering the problem statement and subquestions.

1. *How can we design interactive solutions that are suitable for young children in the context of Herlev's PED?*

To gain a comprehensive understanding of the pediatric patient journey and the procedures that children undergo in the emergency setting, observational studies and semi-structured interviews were conducted with medical staff at Herlev Hospital. Additionally, literature and market research were carried out to identify developmentally appropriate toys for children aged 4 to 7 years.

These efforts informed the creation of specific criteria used to evaluate and select potential solution concepts suited to the hospital context. The selected evaluation criteria included: Developmental Fit referring to cognitive, emotional, and physical appropriateness of the solution for the target age group, Engagement, defined as the solution's ability to sustain attention and encourage curiosity and a sense of control through play, and Hospital Compatibility, encompassing practical factors such as portability, ease of cleaning, durability, low noise output, and minimal setup time.

Accordingly, the interactive solution to be developed should fulfill all three criteria to ensure it is both effective in reducing anxiety and feasible for use in a pediatric emergency environment.

2. *What different interactive solutions can be designed to reduce pediatric anxiety at Herlev Hospital and which one shows the highest potential?*

Literature review revealed that there are numerous types of interventions capable of reducing pediatric anxiety. Building on these insights, a brainstorming session was conducted, followed by an evaluation of the generated concepts based on the previously defined criteria. As a result, three low-fidelity prototypes were selected for development and testing: AirBalloon Ride, a concept that explored the use of breathing and squeezing as calming and empowering interactions, Match the (E)motion, which explored the use of distraction through problem solving and physical engagement and Ambulance Adventure, which incorporated educational play and narrative sequencing as a means of familiarizing children with medical procedures.

To assess the effectiveness of these prototypes, user testing was carried out. Although the results were inconclusive with regard to anxiety reduction, the process informed the need for additional evaluation criteria to guide the selection of the most promising concept for further development. Based on this extended evaluation, Ambulance Adventure emerged as the strongest candidate for continued exploration.

3. *How effective is the selected solution in reducing anxiety in real-life settings and how is it experienced by children and caregivers?*

Testing of the high-fidelity prototype indicated that the solution led to a significant reduction in self-reported anxiety among participating children. However, it did not produce satisfying results regarding observational indicators of anxiety. Despite this limitation, the prototype was positively received and successfully captured the attention and interest of both children and caregivers in the waiting area, including those who were not directly involved in the testing. Overall, the findings suggest that the prototype holds promise and warrants further exploration and refinement.

Considering the problem statement:

How can we design an interactive solution to reduce pediatric anxiety in the waiting area of the Pediatric Emergency Department at Herlev Hospital?

The process followed in this thesis resulting in the development of the Ambulance Adventure prototype, offers a response to the identified challenge. The findings suggest that even a brief interaction with a simple, interactive hospital map can engage preschool-aged children and lead to a statistically significant reduction in self-reported anxiety.

6.3 Limitations

Several limitations should be acknowledged in relation to both the testing process and the prototype itself.

Although testing was conducted over multiple days, it took place during the summer, a period when fewer children typically visit the Pediatric Emergency Department. As a result, the available sample was limited in both size and diversity. This reduced the likelihood of including children who were experiencing elevated levels of anxiety, which may have affected the evaluation of the prototype's effectiveness in reducing distress. Furthermore, the nature of this thesis project imposed time constraints that limited the overall duration of data collection. While behavioral observations and self-report methods were employed, these approaches may not have captured more subtle or internalized expressions of anxiety, especially in children who appeared calm or were not particularly anxious during their visit.

The high-fidelity prototype also presented some technical limitations. While the system was generally functional, minor instability was observed during testing. This was likely caused by the combined power demands of the RFID readers and the MP3 module, both of which can draw high peak currents. These demands occasionally resulted in brief performance issues, which were resolved by rebooting the game. Fortunately, these interruptions did not significantly affect the testing sessions.

6.4 Future Work

The primary aim of this prototype was to help reduce anxiety in children visiting the Pediatric Emergency Department. To address the current limitations, future studies should involve a larger and more diverse sample, with particular emphasis on including children who exhibit higher levels of anxiety prior to hospital visits. Additionally, incorporating physiological measures such as heart rate monitoring or eye-tracking could offer a more objective assessment of emotional responses and engagement during gameplay.

Also, building on the insights gained during testing, several improvements and extensions could be made to the prototype. First and foremost, the prototype's minor power-related issues should be addressed by optimizing power distribution, possibly through the use of more stable power supplies or lower-energy components.

Additionally, the button interface could be refined to feel more intuitive. Making the buttons non-removable and visually more button-like would improve durability and recognition. Additionally, integrating a blinking effect around the pressed icon (e.g., a light ring) while the audio is playing, could provide children with clearer feedback.

To support multisensory engagement, incorporating audio cues throughout the experience is recommended. These could include a bell sound when the child "arrives home," as well as an engine sound while the ambulance is moving. Furthermore, when the ambulance enters a room, a short audio clip could play that announces the room name, particularly beneficial for children who cannot yet read.

In terms of navigation mechanics, first and foremost, the ambulance should glide smoothly along the track, providing a satisfying and seamless experience. To enhance physical in-

teraction, adding a magnet-based stopping mechanism could help position the ambulance in front of buttons. Additionally, placing RFID scanners at room exits would allow children to re-enter rooms if they wish to go back.

In terms of localization, introducing a language selection option (e.g., Danish/English) would increase accessibility for families with different language backgrounds.

Finally, the scope of the play environment could be expanded by adding new areas, such as the garden, to enrich the narrative and provide further opportunities for exploration.

7 Conclusion

This thesis explored the design and evaluation of interactive, play-based interventions aimed at reducing anxiety in children aged 4-7 in the Pediatric Emergency Department (PED) at Herlev Hospital. Recognizing the limitations of passive or pharmacological strategies, the project followed a human-centered design approach grounded in the Double Diamond model, emphasizing empathy, iteration, and real-world testing.

A review of existing literature revealed a gap in interactive solutions suited to emergency settings. Observations and interviews with hospital staff highlighted that pediatric anxiety often goes unaddressed early in the patient journey due to systemic and time-related constraints.

In response, the project introduced Ambulance Adventure, a wall-mounted interactive board game informed by developmental psychology and embodied interaction principles. Through tactile play and audio feedback, the intervention familiarizes children with the hospital journey. Two testing rounds, low- and high-fidelity, demonstrated strong engagement and a statistically significant reduction in self-reported anxiety, as measured by the Wong-Baker FACES scale. Although observational measures (m-YPAS) did not yield significant changes, caregiver feedback confirmed the intervention's relevance, and potential value in a clinical setting.

This work shows that interactive, developmentally appropriate tools can enrich pediatric emergency environments, offering children agency, comfort, and emotional support. It contributes to the growing body of research at the intersection of interactive user interfaces, pediatric healthcare, and affective design, and provides a scalable foundation for future interventions.

In conclusion, this project demonstrates that thoughtfully designed interactive experiences can support young patients' emotional needs in acute care settings, contributing to child-friendly hospital environments.

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A Appendix

A.1 Interviews with Medical Personnel

Date: February 28, 2025

A.1.1 General Information

During conversations with Gitte, a researcher and Clinical Nursing Specialist that works in Herlev Hospital, several information about the hospital were extracted:

- Children arrive at the hospital from the GP or from 1813.
- When children arrive at the hospital the available information is: name, age, where they live, and why they are coming.
- Children 0-4 years old are treated here for everything. The older children, and cases with burns and broken bones, go to the adult clinic. Apart from that, the department does not see injuries. They see headaches, earaches, throat, and stomach issues.
- Process: children arrive at emergency care → go to secretary → triage (within 10min of coming in): here they get temperature, breathing is checked, and they are asked about their pain level → get a single room: height, weight, and maybe some additional examinations like a urine sample.
- If the child has a fever, they are given paracetamol which lowers fever and pain.
- Follow primary care: this means that after triage, one nurse is dedicated to each patient.
- From triage: green - 2 hours, yellow - 1 hour, orange - 15min, red - immediately. But being in the ER, children may wait for 4-5 hours before they are seen by a doctor. So sometimes they go for a walk, and the nurse communicates with parents when the time has come for them to see the doctor.
- Department homepage mentions they treat 12000 children per year.

A.1.2 Interviews on Anxiety Reduction

Questions to Gitte (Researcher and Clinical Nursing Specialist):

What strategies do you use now to reduce anxiety? Are there any digital tools used?

In cases of procedural pain, they numb the skin and sometimes give sedatives, use virtual reality solutions, or use the screen in the room. Otherwise, we just sing and try to distract the children. Sometimes, clowns come in.

It has become very common to sedate the children when we think they are scared. This is because, for example, if we use laughing gas with a mask, then 2 nurses are needed per child. This makes it a resource-intensive solution.

How much of a problem is anxiety for nurses/doctors?

Anxiety is a problem because we would like to do the best for the child, give them the best experience. But we are time-constrained because we might need the room for another patient. So we cannot give all children all the time they need to relax before treating them.

Studies show that if you come to the hospital multiple times, your anxiety level is higher after the first visit.

Children can be anxious or fearful about not knowing what is going to happen. In this case, nurses assure them: “Nothing bad is going to happen to you” or “We are not going to do anything right now.”

Does anxiety cause a delay in medical procedures?

Sometimes fear causes a delay in medical procedures, and there is sometimes a need to restrain the children. It is not easy to give sedatives to children above the age of 8-9 because it numbs their awareness. The older the child, the more difficult it is to reach this state of mind.

Do you think that most nurses can recognize and address anxiety? What are some signs?

Sometimes nurses come in after being with the child and say: “Oh, this child is very anxious.” There are some things that can be noticed to reach that assumption: Is the child crying? (It could also be fear, but sometimes, with experience, you can tell.) Is the child saying ”No”? Is the child looking down? Can I calm the child in any way? Recognizing anxiety is a skill you have to learn.

Maybe if the child rates 10 for pain and 8 for fear, and we work on the fear, then the pain level will go down.

What aspects of the hospital experience trigger anxiety in young children?

What children fear the most is getting blood samples or other stitches. Another thing is the ”white coat syndrome”: being afraid of the clothes nurses wear at the hospital. (Maybe in the US there have been studies about clothing color.)

When/if/how much do the kids interact with doctors?

A doctor sees the family once or twice. Sometimes the nurse communicates the problem to the doctor without the need for them to see the child. They might only see the child after the samples are taken. They are in the room for 10-15 minutes doing an additional examination. Then they leave to plan further processes (e.g., X-ray, ultrasound), and the nurses arrange it, but the doctor informs the family. Also, the doctor talks to the nurse before seeing the child.

More comments from Gitte:

Children come to the hospital with some kind of pain, which is why they are asked about their pain level. The nurse listens to what the child says and assesses the situation (e.g., if the child says pain is 7-8, the nurse might think the pain is around 5 but that the child is afraid) → We want to separate pain and fear. The term ‘anxiety’ is used interchangeably with fear.

Nurses try to explain the scale to children by asking questions. → Gitte’s process: Ask at the beginning, half an hour after they arrive, after any event (if they are given medicine, then they should be asked again half an hour to one hour later), and at the end. → Common process: Ask once in the triage room.

Getting specific biometric measurements may not be helpful since, in cases such as increased heart rate, the first instinct is to medically treat the child, not consider anxiety as the cause.

The parents' emotional state affects the children. Sometimes mothers cry and fathers get upset, which also affects the children.

A hospital in Jutland invited a kindergarten group and showed them all the departments to help familiarize them with the environment. Children's TV shows the "teddy bear doctor": you bring your teddy bear who is ill and show the children what is going to happen. There are also some cartoons, short videos, about coming to the hospital.

Questions to another nurse (currently working at Herlev Hospital for 8 months since finishing her degree):

How much of a problem is anxiety for nurses/doctors?

I would not describe anxiety as a problem. It's just that it makes our job take longer. The kids don't want to get their blood taken, so the process is delayed.

Do you think that most nurses can recognize and address anxiety? What are some signs?

Nurses can understand the problem of anxiety. You can see that children withdraw a bit or get closer to their parents. Some kids become more verbal and say things like "I'm nervous" or "I don't want to do this." For some children, you can just tell from their facial expressions.

What aspects of the hospital experience trigger anxiety in young children?

We think the uniforms are a problem that causes anxiety in children, and also how white the environment is. That's why we've incorporated posters and butterflies. Same for the rooms: we've tried to contact and ask for permission to get the walls painted, and we've gotten permission for one room so far, but not more.

What strategies do you use now to reduce anxiety?

To reduce anxiety, we incorporate children's play or use distractions. We try to get down to their level. We also let them watch TV, listen to music, and try to involve the parents. We talk to them about everyday stuff or things they like. Some things that have previously been used in the hospital include playing with bubble wrap and using a VR headset.

More comments from the nurse:

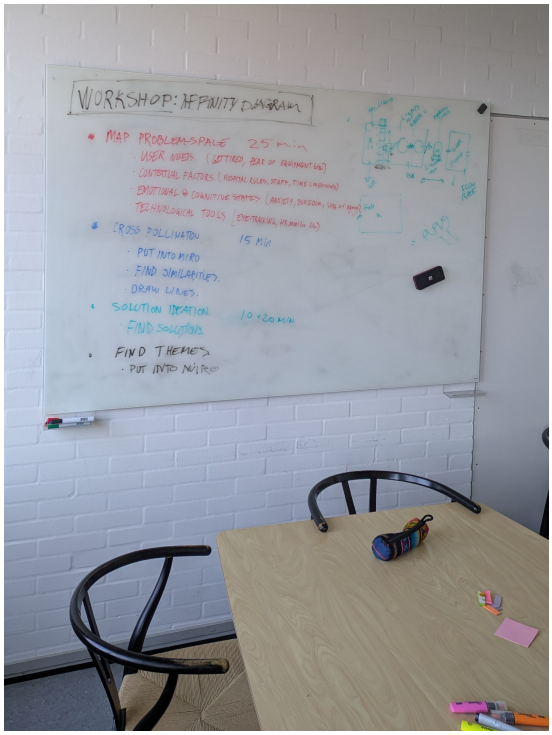
A game intervention could work for some kids, probably the older ones, but usually, the anxiety takes over, and they are more focused on that than on playing.

Younger children get the most scared, and when we try to incorporate such games, it's 50/50 whether it will help or not.

Subjective assessment from kids is not viable.

A.2 Affinity Diagram Workshop Session

An Affinity Diagram Workshop was held together with other thesis students collaborating with Herlev Hospital. The goal of the session was to align across teams, gain insight into each other's findings, and inspire new ideas through shared reflection.



(a) Plan of the Workshop

(b) Clustering of insights

Figure A.1: Workshop plan and group work

The workshop began with a 25-minute session focused on mapping the problem space. Each participant wrote post-it notes based on their individual research, aiming to capture observations and insights related to user needs, contextual factors, emotional and cognitive states, and technological tools. These notes were then grouped and categorized into thematic clusters.

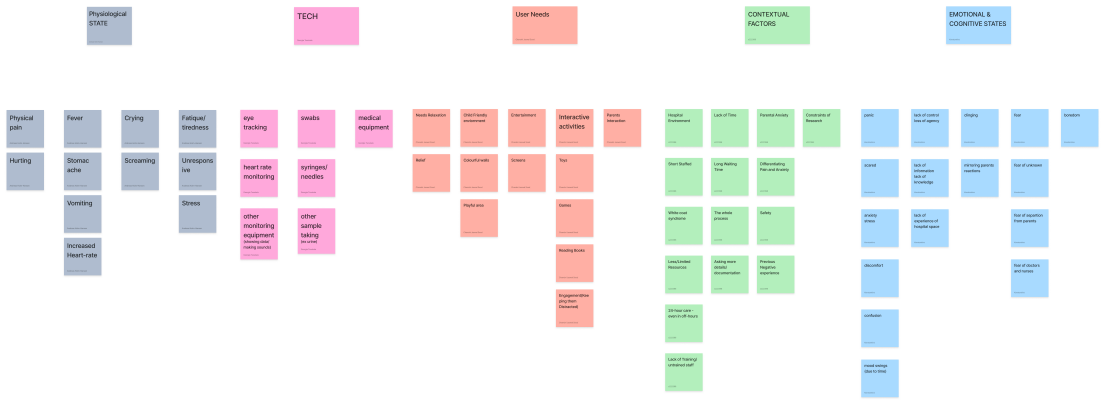


Figure A.2: Mapping of Problem Space

Following this, a 15-minute cross-pollination session took place. Similar ideas were identified, overlapping ideas were connected and relationships between items were discussed. All the clustered notes were transferred into a shared Miro board, where it was easier to explore each other's categories in detail.

In the next part of the workshop, the focus shifted to solution ideation. This was done in two rounds, starting with a 10-minute individual brainstorming session, followed by a 20-minute group discussion. Based on the insights that had been collected, participants generated potential solutions and discussed them in relation to the earlier findings. These ideas were then categorized into broader themes and documented on the Miro board.

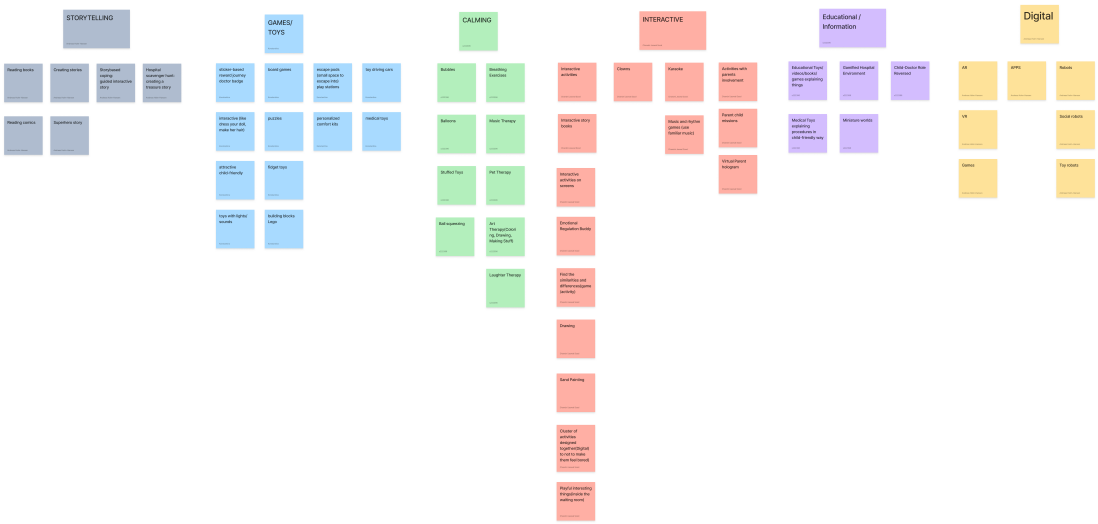
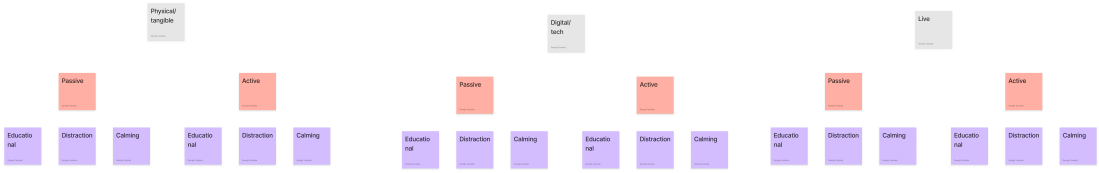


Figure A.3: Mapping of Solution Space

Lastly, there was also a discussion about how the generated solutions could be categorized. Some overarching categories were identified, and different tree-structured categorizations of the ideas were sketched based on combinations of these categories.

Figure A.4: Identified Categories (interaction-based, medium-based, goal-based) based on Solution Space



(a) Example 1: medium → interaction → goal

(b) Example 2: interaction → medium → goal

Figure A.5: Examples of different combinations of categories

A.3 Implemented Interventions Full Table

Author & Year	Study Title	Short Title	Intervention Type	Intervention Description	Age Range	Sample Size	Anxiety Measurement Method	Results	Context (Hospitalization/Other)
Abdi et al. (2025)	Effect of play therapy and storytelling on the anxiety level of hospitalized children: a randomized controlled trial	Storytelling	Storytelling vs. Play Therapy	Storytelling with hospital-related stories vs. patient-doctor roleplay	3-10	75	Spence Children's Anxiety Scale (SCAS), Visual Facial Anxiety Scale (VFAS)	Storytelling significant (p=0.03), play therapy not significant	Hospitalization
Andi et al. (2023)	The Effectiveness of Puzzle Play Therapy in Reducing Anxiety Due to Hospitalization in Preschool Age Children (3-6 Years) in the Sakura Room at Tenriawaru Bone Regency Hospital	Puzzle Play Therapy	Puzzle Play Therapy	Children solved puzzles designed for anxiety reduction	3-6	24	Hamilton Rating Scale for Anxiety (HARS)	Significant reduction (p=0.000)	Hospitalization
Arbianingsih et al. (2021)	BRAIN GYM EFFECTIVELY REDUCES ANXIETY IN SCHOOL AND PRESCHOOL AGED CHILDREN IN HOSPITALS	Brain Gym Effectively Reduces Anxiety in Children	Brain Gym	PACE model exercises: brain buttons, cross crawl, positive relax + other brain gym exercise: pressing the earth button, the balance button, the space button, the thinking cap, and the energetic yawn	3-12	32	Modified Hamilton Anxiety Rating Scale / Zung Self-Rating Anxiety Scale	Significant reduction (p=0.006 preschool, p=0.016 school-age)	Hospitalization
Bernaerts et al. (2022)	Virtual Reality for Distraction and Relaxation in a Pediatric Hospital Setting: An Interventional Study With a Mixed-Methods Design	Virtual Reality for Distraction and Relaxation	VR Relaxation App	VR breathing exercises, meditation exercises and mini games	4-16	51	Visual Analog Scale and Revised Faces Pain Scale (FPS-R)	Significant reduction (p<0.001)	Both (Hospitalization/Procedure)
Castiglioni et al. (2022)	Play-Based Activities with a CoderBot Robot on a Pediatric Ward: A Case Study	CoderBot Robot Play	Robot Play Therapy	Children played interactive games with robot: guiding the robot through an obstacle course	4-14	61	Likert Scale, Visual Analog Scale	Improved mood and well-being (p<0.05)	Hospitalization
Dian & Mariyani (2023)	THE EFFECT OF COLORING PLAY THERAPY ON REDUCING STRESS IMPACT OF HOSPITALIZATION IN PRE-SCHOOL AGE CHILDREN	Coloring Play Therapy	Coloring Play Therapy	Children colored drawings to reduce hospitalization stress	4-6	32	Questionnaire refering to the HRS-A component	Significant reduction (p=0.000)	Hospitalization
Hikmah Nanda et al. (2023)	The Effect of Play Therapy on Children's Anxiety Level Age 4-6 years During Hospitalization at the Kronjo Health Center	Animal Image Recognition Play	Animal Recognition Game	Children identified animals during the game	4-6	30	? Not mentioned	Significant reduction (p=0.003)	Hospitalization

Author & Year	Study Title	Short Title	Intervention Type	Intervention Description	Age Range	Sample Size	Anxiety Measurement Method	Results	Context (Hospitalization/Other)
Jeong (2017) [Thesis]	The Impact of Social Robots on Young Patients' Socio-emotional Well-being in a Pediatric Inpatient Care Context	Social Robots for Pediatric Well-being	Social Robot (Huggable) vs Plush Toy vs Virtual Avatar	Children interacted with a robotic teddy bear guided by a Child Life Specialist, compared to plush toy and tablet-based virtual character.	3-10	54	Facial Affective Scale, PANAS, STAIC, EDA sensor, video analysis	Robot group showed longest engagement, most positive affect, and highest emotional and social interaction.	Hospitalization
Kulal & Ray (2020)	A Quasi-Experimental Study To Assess The Effectiveness Of Art Therapy On Level Of Anxiety Among Hospitalized Children In Selected Hospitals Of Pune City	Effectiveness of Art Therapy	Art Therapy	Children engaged in free drawing and coloring	3-6	60	Five Facial Anxiety Scale	Significant reduction ($p<0.001$)	Hospitalization
Lawrence & Lazer (2024)	Effective reduction of anxiety in hospitalised children through bibliotherapy	Bibliotherapy reduces anxiety in hospitalised children	Bibliotherapy	Age-appropriate activities: mage completion and object identification, reading comics and interpreting proverbs, puzzles and word rearrangements	5-12	60	Modified Spence Children Anxiety Scale	Significant reduction ($p=0.001$)	Hospitalization
Li et al. (2016)	Play interventions to reduce anxiety and negative emotions in hospitalized children	Play interventions to reduce anxiety	Hospital Play Program	Structured play (medical, preparation, distraction, developmental)	3-12	304	Visual Analogue Scale (VAS)(3-7), Chinese version of the State Anxiety Scale for Children (CSAS-C)(8-12)	Significant reduction ($p<0.001$)	Hospitalization
Mahimai Jacquline Josephine et al. (2022)	Effectiveness of origami on stress and anxiety of hospitalized children	Effectiveness of origami on stress and anxiety	Origami Play Therapy	Children folded colorful origami animals and shapes	6-12	50	Stress assessment scale & Anxiety assessment checklist (unspecified)	Significant reduction ($p<0.001$ stress, $p=0.002$ anxiety)	Hospitalization
Naning Puji et al. (2019)	"PLAYDOUGH TO REDUCE ANXIETY": Alternative Therapy in Pre-School Children with Hospitality	Playdough to reduce anxiety	Playdough Therapy	Preschoolers molded playdough freely	3-6	20	Modified Yale Preoperative Anxiety Scale (mYPAS)	Significant reduction ($p=0.000$)	Hospitalization
Nisa et al. (2023)	The Effect of Building Block Therapeutic Play Program on Preschooler's Anxiety Levels in Indonesia	Building Block Play Therapy	Building Block Play	Children created structures using blocks and plasticine	2-6	40	Taylor's Manifest Anxiety Scale (T-MAS)	Significant reduction ($p=0.000$)	Hospitalization
Novita Dewi Kok et al. (2024)	Anxiety Levels of Preschool Children on the Effect of Play Therapy Due to Hospitalization at Makassar City Hospital	Anxiety Levels of Preschool Children on the Effect of Play Therapy	Coloring Play Therapy	Preschoolers colored pictures with crayons/pencils	3-6	20	Faces Anxiety Scale (FAS)	Significant reduction ($p=0.008$)	Hospitalization
Padila et al. (2022)	Educational Play Snakes and Stairs Can Overcome Anxiety in Children's Hospitalization	Snakes and Stairs Can Overcome Anxiety	Educational Snake & Ladder Game	Children played a modified snakes & ladders game for interaction	Preschool	15	Hamilton Anxiety Rating Scale (HARS)	Significant reduction ($p=0.000$)	Hospitalization

Author & Year	Study Title	Short Title	Intervention Type	Intervention Description	Age Range	Sample Size	Anxiety Measurement Method	Results	Context (Hospitalization/Other)
Pita et al. (2023)	The Application of Playing Therapy with Video Media on The Anxiety of Pre-School Age Children Due to Hospitalization in Regional Hospital dr. Soeratno Gemolong	Video Play Therapy (Si Kancil)	Storytelling Video Play	Animated video story shown to children	5-6	2	Spence Children's Anxiety Scale (SCAS)	Reduction observed, one mild, one reduced but moderate	Hospitalization
Siti Fadhila Sepfiani (2023)	The Application Of The Intervention "Puzzle Play Therapy" To Anxiety Levels In An. E Who Was Hospitalized At Bantul Hospital	Puzzle Play Therapy (Case Study)	Puzzle Play Therapy	One-on-one puzzle play sessions	3-6	1	Preschool Anxiety Scale (PAS)	Anxiety reduced from moderate to mild	Hospitalization
Stein Duker et al. (2020)	Use of Audiobooks as an Environmental Distractor to Decrease State Anxiety in Children Waiting in the Pediatric Emergency Department: A Pilot and Feasibility Study	Audiobooks as Distractors in PED	Audiobook Distraction	Children listened to age-appropriate audiobooks	5-13	131	Children's Fear Scale (CFS), modified State-Trait Anxiety Inventory for Children (m-STAIC)	Small but significant reduction	Pediatric Emergency Department
van der Heijden et al. (2019)	Children Listening to Music or Watching Cartoons During ER Procedures: A RCT	Music vs. Cartoon for Procedural Pain	Music Distraction vs Cartoon Watching	Children listened to relaxing music or watched cartoon during procedures	3-13	191	Alder Hey Triage Pain Score, Faces Pain Scale-Revised (FPS-R), Observational Scale of Behavioral Distress-revised (OSBD-r)	Music reduced pain (p=0.003), cartoon not effective	Pediatric Emergency
Yildirim et al. (2025)	Effect of toys made from medical materials on anxiety among hospitalized children: A randomized controlled trial	Toys made from medical materials	Medical Material Toys	Children created toys (rabbit, cat, airplane) from syringes, gloves	4-6	90	Children's State Anxiety scale (CSA)	Significant reduction (p≤0.000)	Hospitalization
Yilmaz & Demir (2024)	The effect of animal-assisted intervention on fear in children in the emergency department: A randomized controlled trial	Goldfish Animal-Assisted Intervention	Animal-Assisted Therapy (Goldfish)	Children interacted with and fed goldfish placed at bedside	5-7	70	Children's Fear Scale (CFS)	Significant fear reduction (p=0.001)	Pediatric Emergency Department

A.4 PRISMA Worksheet

Research Question: *What non-pharmaceutical **interventions** have been implemented to **reduce children**'s **anxiety** in **healthcare** settings?*

Keywords and synonyms: (brainstorming)

- anxiety, stress, distress, fear
- reduce, mitigate
- children, kids, pediatric
- intervention, solution, program, technique
- healthcare, hospital, emergency room/department

Filters applied:

English, since 2015

Common topics removed:

dentist, dental, adults, anxiety disorder, covid, pregnancy

Search string:

To refine the search process, a search string was developed by incorporating synonyms for key terms such as children and healthcare, while also excluding unrelated topics such as covid, pregnancy, dentistry and other irrelevant subjects.

(anxiety OR anxious) AND (child* OR pediatric* OR paediatric*) AND (hospital* OR "emergency room" OR "emergency department*" OR PED OR "pediatric department") AND (reduce OR mitigate) AND (intervention* OR treatment* OR therapy OR program* OR management OR protocol OR technique*) AND (effect* OR outcome* OR result* OR efficacy OR impact OR evaluation OR assessment OR success* OR improvement*) NOT (disorder OR covid OR pregnant OR depression OR dentist OR dental OR burn*)

Results:

PubMed: 964 (directly through Silvi.ai)

DTUFindIt: 1907 (1000 of which were imported on Silvi - the first 1000 based on relevance)

Process:

From the initial 1,964 studies imported into Silvi.ai, we first removed 503 duplicate entries. The remaining references then underwent multiple screening stages.

The first screening involved reviewing the titles and abstracts to exclude studies that were clearly irrelevant to our research focus. A total of 1,281 studies were excluded at this stage. Studies were removed if they focused on critically ill or neonatal patients, parental anxiety (including parental presence and caregiver stress), anesthesia-related effects, specific medical procedures, or nurse training. Additional exclusions included studies centered on mothers (e.g., breastfeeding, recent labor, Cesarean sections), research involving medical or nursing students, post-operative conditions, vaccination, psychiatric care, or pharmaceutical interventions.

While most exclusions were based on relevance, some studies that were slightly outside our primary scope were retained if they presented innovative interventions or offered valuable experimental insights related to our target age group of children aged 4-7.

In the next stage, we re-screened the titles and abstracts of the remaining studies to refine the selection further. The exclusion criteria applied during this stage are described in Table A.1. During this step, we chose to include studies involving hospitalized children, as the context of a pediatric emergency department (PED) waiting room shares similarities with the experience of children waiting in private hospital rooms.

Exclusion criteria	**Description**
Not PED	Does not refer to the Pediatric Emergency Department
Not anxiety	Focuses on mitigating other negative emotions, such as fear and pain
Wrong age group	Involves children outside the target age range of 4-7 years old
Surgery	Addresses pre-, peri- or post-operative anxiety
Specific procedure	Focuses on reducing anxiety during specific medical procedures (such as venipuncture, anaesthesia induction, wound repair, etc.)
Review	Literature reviews or studies summarizing other research

Table A.1: Exclusion criteria and their descriptions

Following this re-screening, 63 studies were identified as relevant for full-text assessment. In the final screening phase, we reviewed the full texts of these studies. Additional papers were excluded based on the earlier criteria. Furthermore, we excluded studies for which the full text was not available, was not in English, or where the publication presented only a study protocol with no results. Studies reporting insignificant results were also excluded.

The literature review concluded with 22 studies that met all inclusion criteria, providing valuable insights into anxiety mitigation strategies for children aged 4-7 in pediatric care settings.

Prisma Flow Diagram:

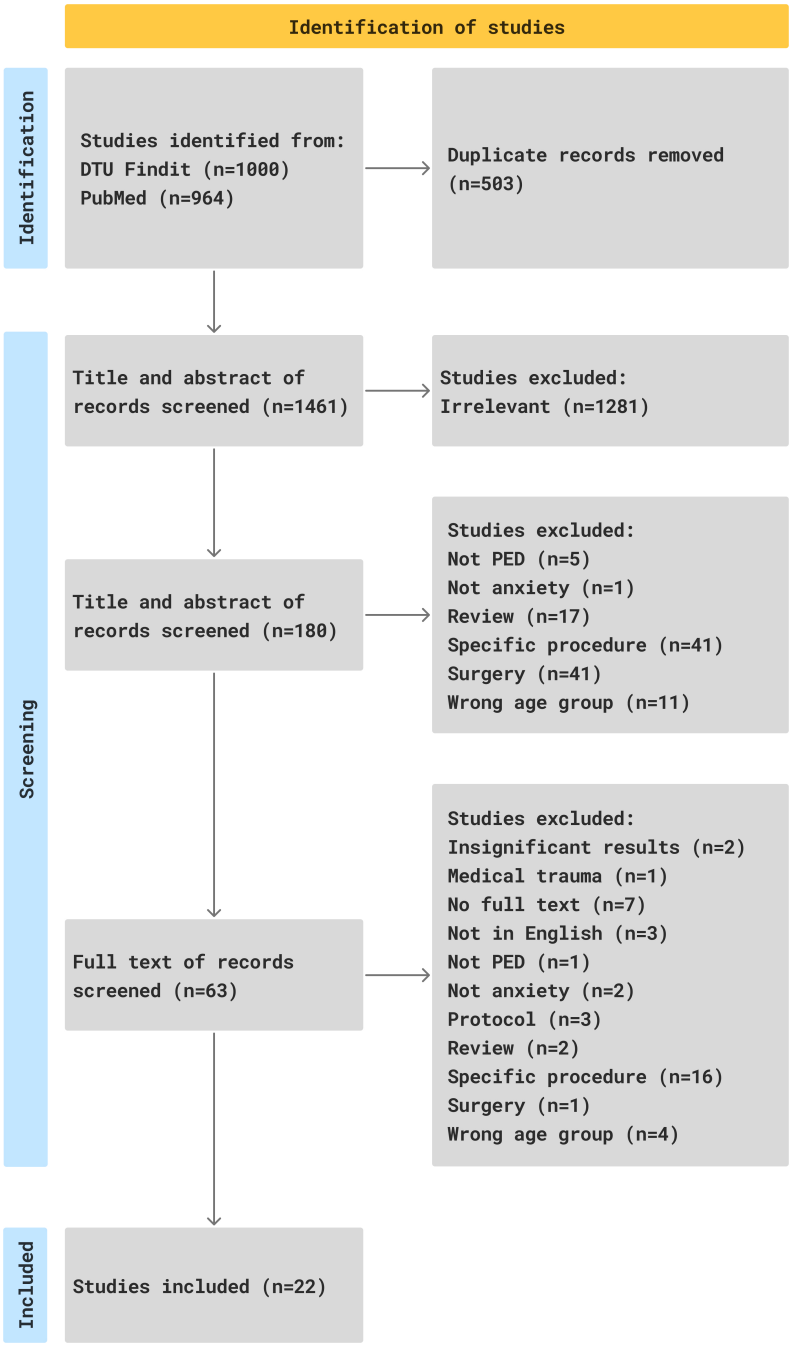


Figure A.6: PRISMA Flow Diagram

A.5 Low-Fidelity Prototype Plan

A.5.1 Prototype: Ambulance Adventure

1. **Concept Summary:**

   Children move an ambulance on a simplified hospital map to simulate a visit to the Pediatric Emergency Department. At each stop (reception, triage, waiting room, single-patient room), they receive visual and audio feedback that explains the role of that space, what happens, and what is there in a child-friendly way.

2. **Purpose / Hypothesis:**

   Familiarity with the hospital journey will reduce anxiety by making the environment more predictable and less threatening for children through a fun and playful process.

3. **Interaction Overview:**

Interaction Type	Description
Input	Child moves the car to different spots along a path.
Output	Audio clips play at each stop when the buttons next to the images are pressed.
Materials	Board with drawn hospital map, small toy car with magnet, audio clips played via smartphone, buttons.

4. **Storyboard / Steps of Use:**

   The board is placed on a surface in front of the child.

   (a) The child is introduced to the board and map.

   (b) They are asked to drive the car from the entrance along the stops.

   (c) At each stop, they press the buttons next to the images and hear audio feedback explaining the stop.

   (d) The child reaches the final stop and completes the journey by reaching their "home."

5. **Testing Questions:**

   - Does the child understand what they have to do?
   - Do they understand what each stop represents?
   - Do they hear the whole audio for the info before moving to the next stop?
   - Can they recall some of the info after the game?

6. **Notes for Final Prototype:**

   When the buttons are active, they light up. While the audio is playing, the buttons blink.

A.5.2 Prototype: Match the (E)motion

1. **Concept Summary:**

   A gear puzzle where children match and assemble gear pieces. There are multiple initial gear pieces that resemble emotions, and there is one final gear. Once the puzzle is fully assembled, a crank allows the child to move the entire mechanism, leading to the rotation of the corresponding emotion gear.

2. **Purpose / Hypothesis:**

   Building the gear system engages problem-solving. Seeing the final motion offers emotional closure, reinforcing a sense of control and completion. By choosing a specific emotion at the start of the game, the child is given the chance to express their emotional state. Also, this game acts as a form of distraction that requires the child's engagement to complete the mission.

3. **Interaction Overview:**

Interaction Type	Description
Input	Child places gears in position to complete a pathway.
Output	Final gear triggers visual motion - the emotion gear rotates.
Materials	Plastic gears, board with predefined gear positions.

4. **Storyboard / Steps of Use:**

   The board is placed on a surface in front of the child.

   (a) The child is introduced to the board and gears.

   (b) They are asked to choose an emotion.

   (c) They place the gears on the corresponding path to complete the puzzle.

   (d) Once the path is complete, turning the last gear triggers all to move, rotating the initial emotion gear.

5. **Testing Questions:**

   - Does the child understand the goal of completing the gear system?
   - Are they curious about what will happen at the end?
   - Do they express satisfaction upon completing the puzzle?

6. **Notes for Final Prototype:**

   Light up the emotion once the path is complete and moving.

A.5.3 Prototype: Air Balloon Ride

1. **Concept Summary:**

   A breath-controlled and squeeze-activated game where the child interacts with physical objects to make other objects move. For example, they can light up a 'sun' by blowing away a 'cloud', and they can fly an 'air balloon' by squeezing a ball.

2. **Purpose / Hypothesis:**

   By controlling their breath, children can practice calm breathing techniques in a fun way. Also, by squeezing a stress ball, children can release their anxiety creatively. Visual feedback reinforces the effect of their actions, creating a sense of empowerment and control.

3. **Interaction Overview:**

Interaction Type	Description
Input	Child blows into a nozzle or squeezes a stress ball.
Output	Cloud moves away from the sun, clearing the sky. The air balloon rises.
Materials	Cardboard, yarn, nozzle, stress ball, coloured sheets of paper.

4. **Storyboard / Steps of Use:**

   The board is placed on a surface in front of the child.

   (a) The child is shown the setup and asked to help clear the sky and raise the air balloon (they can also look at the instructions on the side of the board).

   (b) They blow into the nozzle to trigger the motion of the cloud.

   (c) If the cloud does not reach the end of its route and the child stops blowing, the cloud returns to its original position.

   (d) When the cloud is moved away and the sky is 'clear', the air balloon can take off.

   (e) The child moves the air balloon by squeezing the ball.

   (f) The game ends when the goal is reached (the cloud and air balloon are moved fully).

5. **Testing Questions:**

   - Is the breathing action intuitive and engaging?
   - Does the child repeat the action voluntarily?
   - Do they associate the action with calming or fun?
   - Does the visual feedback reinforce the effort?
   - Is the structure/timeline of the game clear? (e.g., understanding they need to move the cloud first)

6. **Notes for Final Prototype:**

   Add lights to the fire of the air balloon and the sun.

A.6 Testing Consent Form

Consent Form

Please fill out the following form regarding your child's participation.

Photos may be taken during the activity, however, your child's face will not be visible in any images. These photos will be used solely for the purpose of illustrating the results in a Master's thesis report at DTU.

Your participation is voluntary, and you can withdraw your consent at any time.

Sign in to Google to save your progress. Learn more

* Indicates a required question

Child's name or initials: *

Your answer

Child's age? *

- 4
- 5
- 6
- 7

Child's gender: *

- Male
- Female
- Other
- Prefer not to say

Previous visits to the ER (Akutmodtagelse): *

- Yes
- No

Previous hospitalization: *

- Yes
- No

I consent to my child's participation: *

- Yes
- No

Submission

Clear form

A.7 Low-Fidelity Testing Observation Sheet

Prototype Testing Observation Sheet

Prototype Name: _____

Session Date and Time: _____

Observer Name: _____

Testing Location: Waiting area / Single room

About the Child

Child ID / Initials: _____

Age: 4 5 6 7

Gender: M F

Initial Anxiety Scale Measurements

Self reported

- Pain: 1 2 3 4 5 6
- Fear: 1 2 3 4 5 6

Final Anxiety Scale Measurements

Self reported

- **Pain:** 1 2 3 4 5 6
- **Fear:** 1 2 3 4 5 6

Engagement Time:

Testing Questions

Did the child understand the goal?

Did you like it? / Would you play again?

What did you like more about it?

Was it hard to complete?

Additional Notes or Reflections

A.8 High-Fidelity Testing Materials

A.8.1 High-Fidelity Testing Observation Sheet

Prototype Testing Observation Sheet

Session Date			**Child Initials**	
Session Time			**Child Age**	4 5 6 7
Observer Name			**Child Gender**	M F

Engagement:

Time	
Buttons pressed	/ 11
Number of audios listened	/ 11
Completed full route	Yes No
Times of parent/child interaction	

Intuitiveness:

Does the kid fully understand the game mechanics?	Yes No
Are the parents explaining/helping?	Yes No

Ease of use:

Can they reach all the places on the board?	Yes No
Is it easy to move the ambulance around the path?	Yes No

Learning:

Question 1	A B C
Question 2	A B C
Question 3	A B C

WBF Scale before: _____ **WBF Scale after:** _____

Questions to Children:

Would you like to play again?

Questions to Parents:

On a scale from 1 to 10, how likely would you be to talk about this game or recommend it to other parents whose children are visiting the hospital?

Do you have any other comments that you think might be important to us?

Other notes:

A.8.2 Quiz Items

Which room has an aquarium you can look at while you wait?

TRIAGERUM **STUE** **VENTEOMRÅDE**

How many different rooms can you visit in the hospital with the ambulance?

3 **4** **5**

Which of these do they put in your finger to see how fast your heart beats?

A.8.3 Observational Anxiety Questionnaire

Modified Yale Preoperative Anxiety Scale

(m-YPAS)

Child's initials: _____ **Observer Name:** _____

Timepoint: _1. Before Intervention _2. After Intervention

Activity

_1. Looking around, curious, playing with toys, reading; moves around waiting area to get toys or go to parent.

_2. Not exploring or playing, may look down, may sit close to parent while waiting.

_3. Moving around in unfocused manner, non-activity derived movements; frenetic/frenzied movement or play; squirming, clinging to parent.

_4. Actively trying to get away, pushes with feet and arms, may move whole body, not looking at toys or will not separate from parent; desperate clinging.

Vocalizations

_1. Reading, asking questions, making comments, babbling, laughing, readily answers questions but may be generally quiet.

_2. Responding to adults but whispers, "baby talk," only head nodding.

_3. Quiet, no sounds or responses to adults.

_4. Whimpering, moaning, groaning, silently crying.

_5. Crying, or may be screaming "No".

_6. Crying, screaming loudly sustained.

Emotional Expressivity

_1. Manifestly happy, smiling, or concentrating on play.

_2. Neutral, no visible expression on face.

_3. Worried, frightened, sad or tearful eyes.

_4. Distressed, crying, extremely upset, may have wide eyes.

Modified Yale Preoperative Anxiety Scale

(m-YPAS)

State of Arousal

_1. Alert, looks around occasionally, notices people around.

_2. Withdrawn child sitting still and quiet, may be sucking on thumb, or face turned into adult.

_3. Vigilant, looking quickly all around, may startle to sounds, eyes wide, body tense.

_4. Panicked, whimpering, may be crying or pushing others away, turns away.

Use of Parent

_1. Busy playing, sitting idle, or engaged in age-appropriate behavior and doesn't need parent; may interact with parent if parent initiates the interaction.

_2. Reaches out to parent (approaches parent and speaks to otherwise silent parent), seeks and accepts comfort, may lean against parent.

_3. Looks to parent quietly, doesn't seek contact or comfort, accepts it if offered or clings to parent.

_4. Keeps parent at distance or may actively withdraw from parent, may push parent away or desperately cling to parent and will not let parent go.

Score: _____

Notes: Each time point is scored separately. Typical administration is 4 time points. For this thesis, 2 time points are used.

Scoring: Divide each item rating by the highest possible rating (i.e., 6 for the "vocalizations" item and 4 for all other items), add all of the produced values, divide by 5, and multiply by 100. This produces a score ranging from 23.33 to 100, with higher values indicating higher anxiety.

Reference: Kain, Z. N., Mayes, L. C., Cicchetti, D. V., Bagnall, A. L., Finley, J. D., & Hofstadter, M. B. (1997). The Yale Preoperative Anxiety Scale: How does it compare with a "gold standard"? *Anesthesia & Analgesia*, *85*(4), 783-788. https://doi.org/10.1213/00000539-199710000-00032

A.9 Idea Generation Brainstorming Session

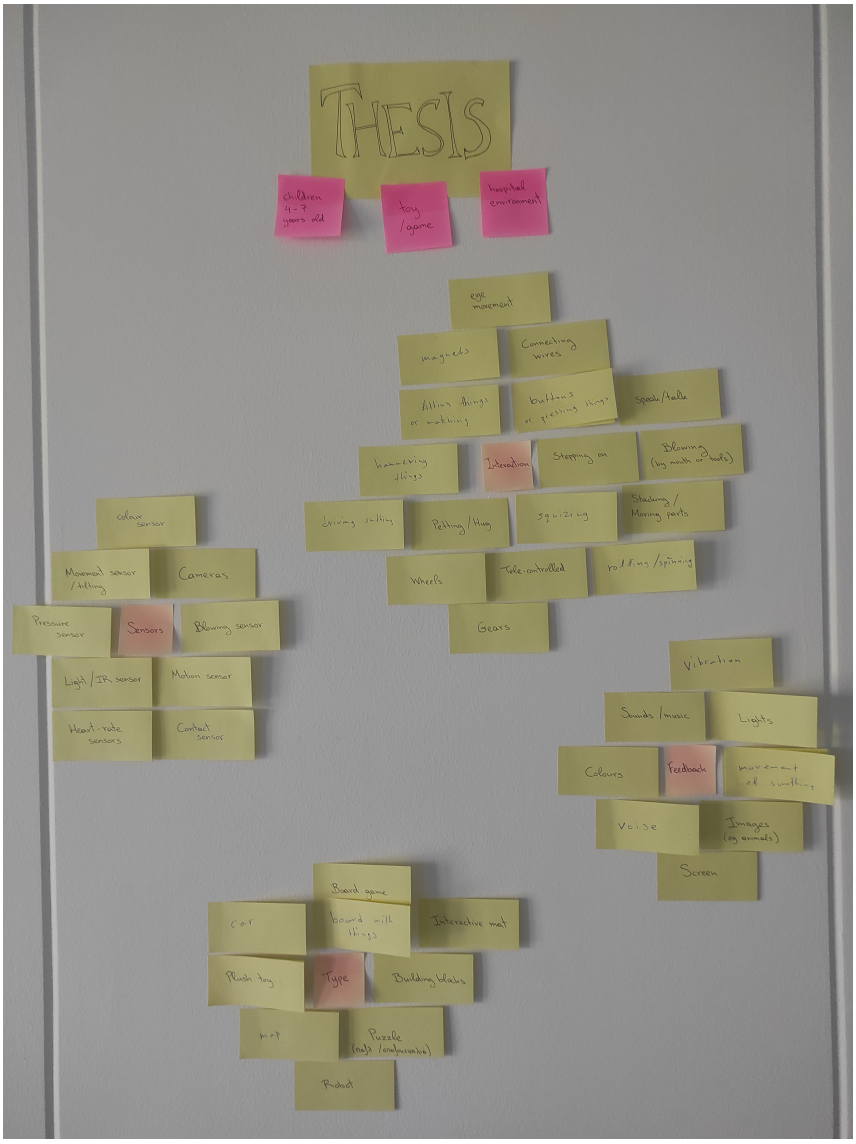


Figure A.7: Brainstorming Session

A.10 Initial Concept Notes

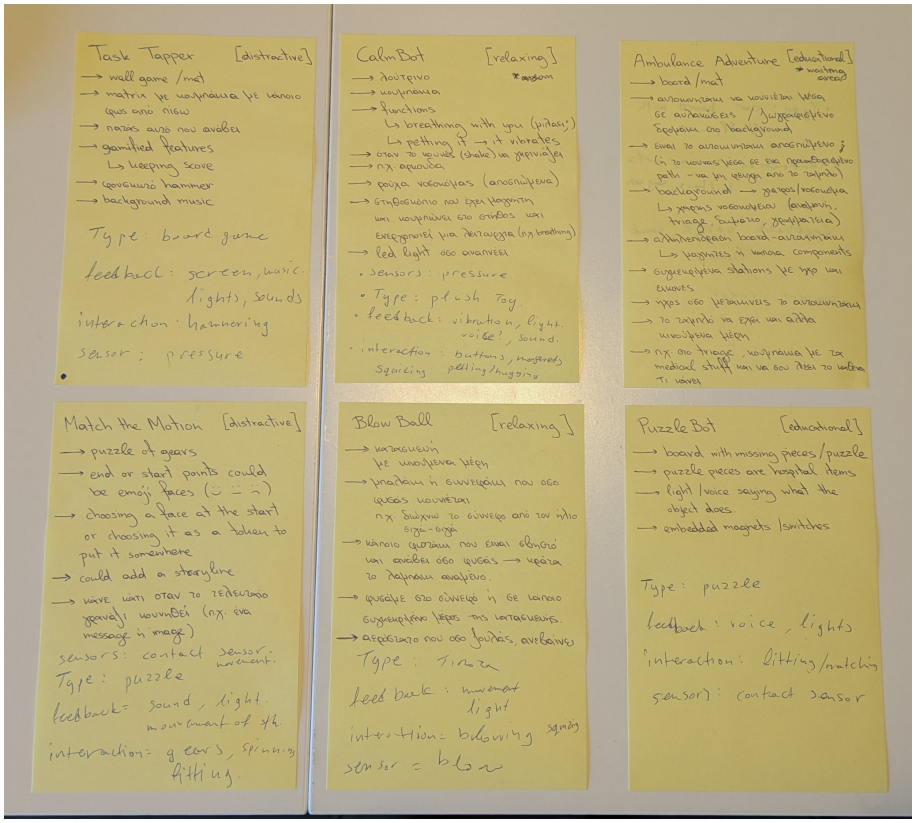
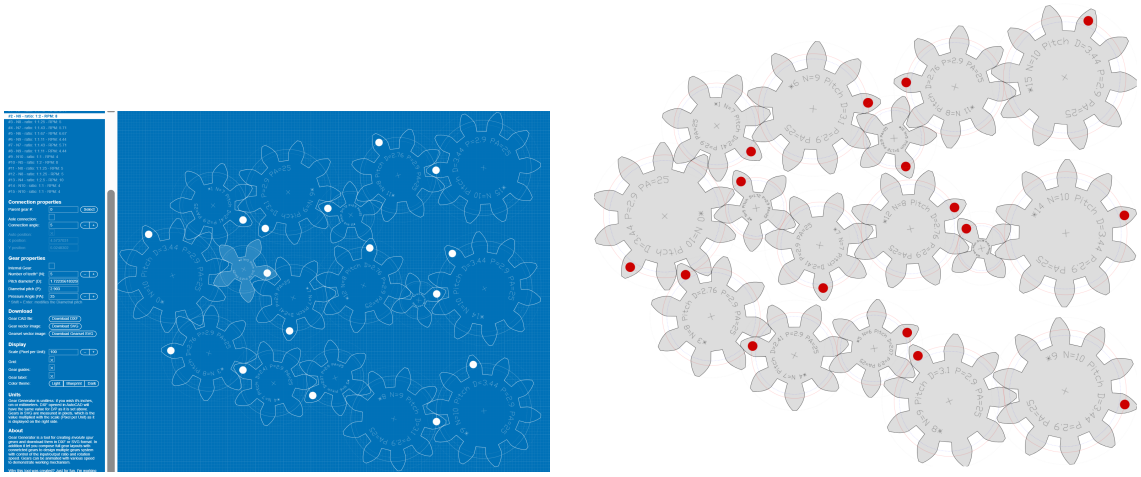


Figure A.8: Post-it notes of the different low-fidelity concept descriptions

A.11 Low-Fidelity Prototypes Material

A.11.1 Construction of Match the (E)motion

To construct the mechanical system of Match the (E)motion, an online gear generator tool (https://geargenerator.com/) was used. The design concept involved three independent starting gears following different paths that converge on a single final gear. This structure was first developed digitally in the gear generator tool, Figure A.9a and it was then exported in svg format, Figure A.9b.



(a) Screenshot from the gear generator tool

(b) Exported SVG gear system

Figure A.9: Overview of the gear generation tool and outcome

The SVG file exported from the gear generator was imported into Autodesk Fusion 360, where the 3D models of the gears were designed and refined, Figure A.10.

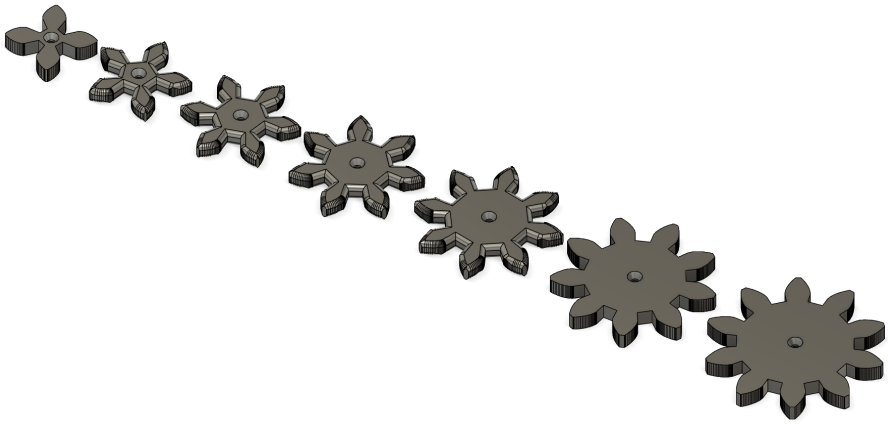


Figure A.10: 3D designed gears

Subsequently, the game board was designed. The SVG layout of the gear system was reused to accurately mark the placement of pegs for the rotating components.

Due to printer size limitations, the board (43.8 cm × 37.5 cm) was divided into four separate pieces, Figure A.11.

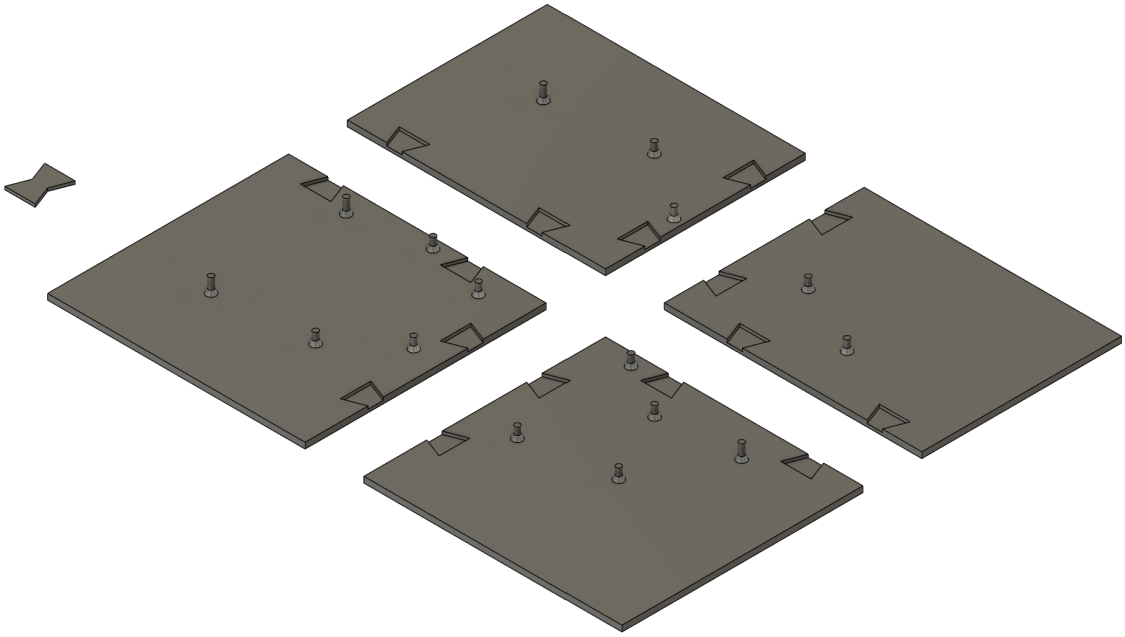
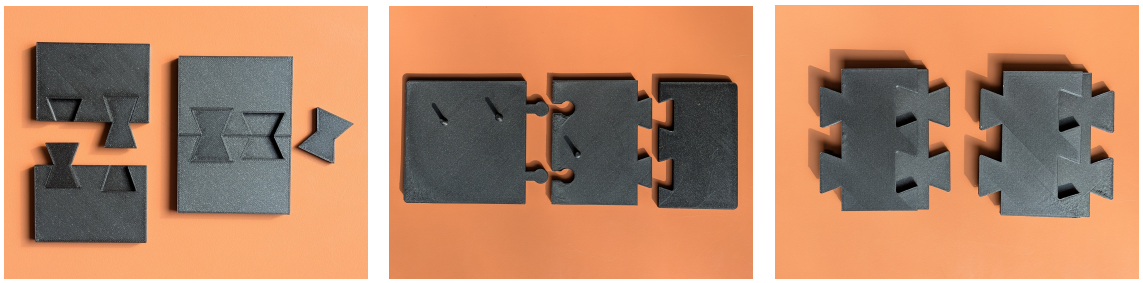


Figure A.11: 3D design of the pieces of the board

To assemble the board seamlessly, various connection mechanisms were prototyped and tested, Figure A.12.



(a) Bowtie connections (b) Slots connections (c) Puzzle connections

Figure A.12: Testing different connections for assembling the board

The final board was printed using child-friendly colored PLA filament, and some of the gears were later painted with markers to make them more fun, Figure A.13.

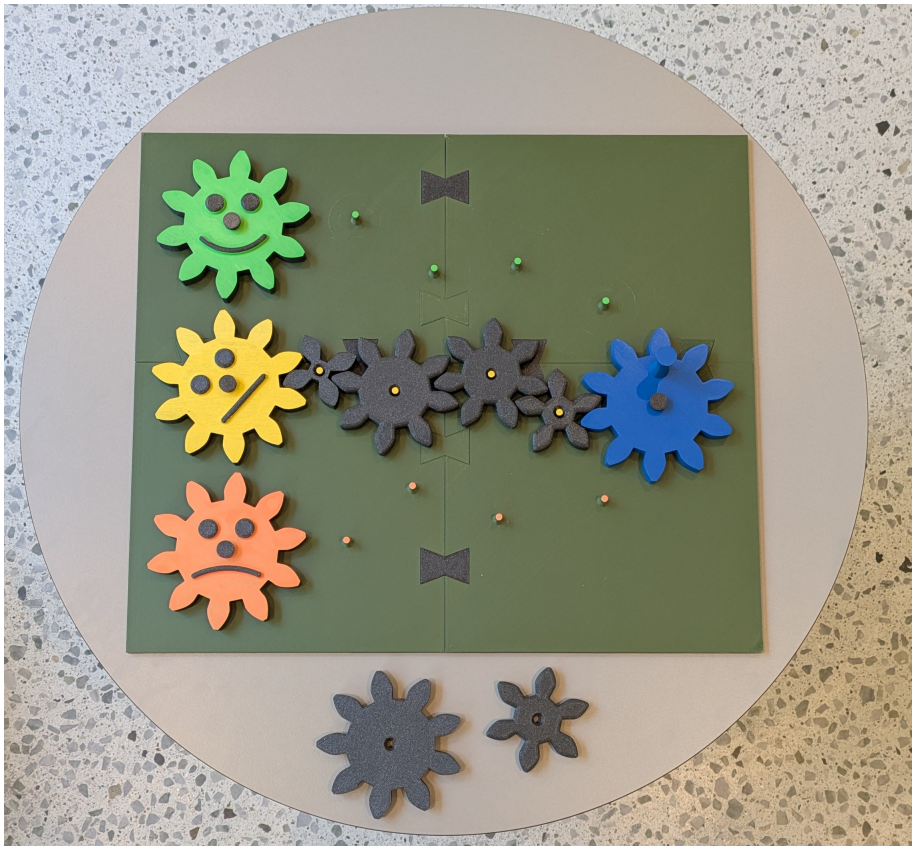


Figure A.13: Final outcome of Match the (E)motion

A.11.2 Ambulance Adventure Material

A.11.2.1 Audio Transcripts

English version

Reception

Item - Secretary:

"This is the secretary, she helps get everything ready so the doctors and nurses know you're here and can take good care of you!"

Triage Room

Item - Oximeter:

"The SAT-meter is a small clip that you put on your finger and shows how you're breathing and how fast your heart is beating."

Item - Thermometer:

"The thermometer shows if your body is warm or cold."

Waiting Area

Item - Couches:

"There are couches where you can sit and wait with your parents."

Item - Fish (Aquarium):

"There's a big fish tank. You can watch the fish swim around while you wait!"

Item - Toy Car:

"There are little cars you can drive around and play while you wait."

Examination Room

Item - Doctor and Nurse:

"Doctors and nurses are the people who take care of you. They wear white coats or blue shirts."

~~**Item - Scale:**~~

~~*"They'll ask you to stand on the scale to see how big and strong you are."*~~

Item - Syringe:

"They'll use a syringe to take a tiny bit of blood and see how your body is doing. It's just a little pinch!"

Item - Cup for Urine Sample:

"They might give you a little cup to pee in. That helps them see what's going on inside your body."

Item - Stethoscope:

"This is a stethoscope. The doctor will put it on your chest and back to listen to your heart and lungs."

Item - Medication: (only used for the high-fidelity prototype)

"The doctor/nurse will give you some medicine to make you feel better."

Danish version

Reception

1 Item - Sekretær:
”Det her er sekretæren, hun hjælper med at gøre alting klar, så lægerne og sygeplejerskerne ved, at du er her og kan passe godt på dig!”

Triagerum

2 Item - SAT-måler:
”SAT-måleren er en lille klemme, der sættes på din finger og viser, hvordan du trækker vejret og hvor hurtigt dit hjerte slår.”

3 Item - Termometer:
”Termometeret viser, om din krop er varm eller kold.”

Venteområde

4 Item - Sofaer:
”Der er sofaer, hvor du kan sidde og vente med dine forældre.”

5 Item - Fisk (Akvarium):
”Der er et stort akvarium. Her kan du se fiskene svømme rundt, mens du venter!”

6 Item - Legebil:
”Der er små biler, du kan køre rundt på og lege med, mens du venter.”

Stue

7 Item - Læge og sygeplejerske:
”Lægerne og sygeplejerskerne er dem, der passer på dig. De har hvide kitler eller blå trøjer på.”

8 ~~Item - Vægt~~:
~~”Sygeplejersken beder dig stå på vægten for at se, hvor stor og stærk du er.”~~

9 Item - Sprøjte:
”Dette er en sprøjte! Måske sygeplejersken har brug for, at tage en lille smule blod for at se, hvordan din krop har det. Det er bare et lille prik!”

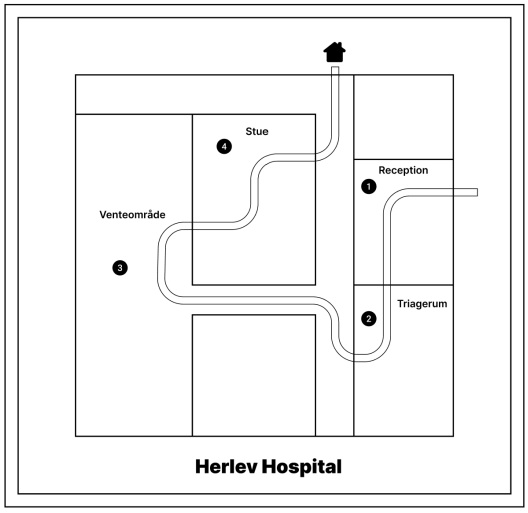
10 Item - Kop til urinprøve:
”Du får måske en lille kop til at tisse i. Sådan kan lægen finde ud af, hvad der sker inde i din krop.”

11 Item - Stetoskop:
”Dette er et stetoskop. Lægen sætter det på din brystkasse og ryg for at lytte til dit hjerte og dine lunger.”

12 Item - Medicin: (only used for the high-fidelity prototype)
”Sygeplejersken vil måske give dig noget medicin, så du kan få det lidt bedre.”

A.11.2.2 Construction Process

For the construction of the low-fidelity prototype of Ambulance Adventure, the layout of the hospital was designed in Figma, a collaborative web application for interface design, Figure A.14a. Then, cardboard was used first in order to check that the design can be printed correclty using the laser-cutters, Figure A.14b.

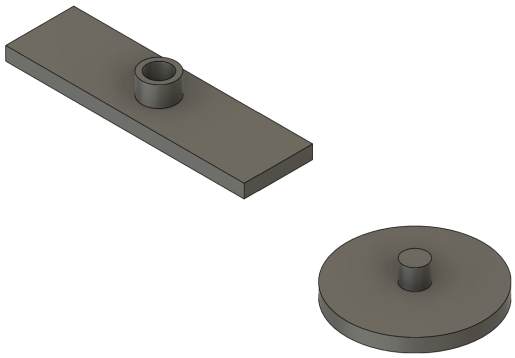


(a) Design of the PED layout using Figma

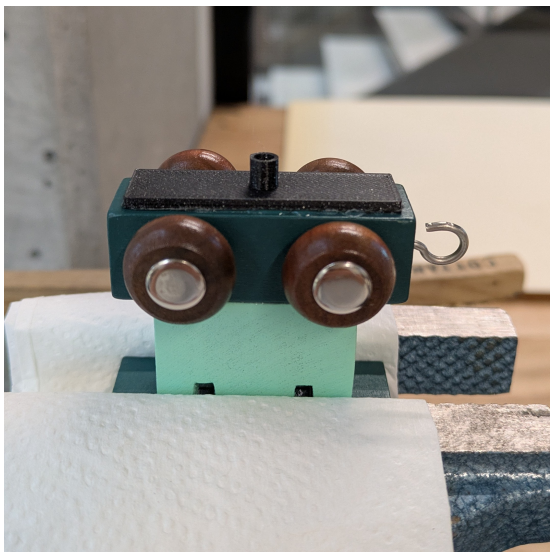
(b) Printed layout on cardboard

Figure A.14: Board design and construction of low-fidelity Ambulance Adventure

For the attachment of the car on the board, a two-part car base was designed and 3D printed, Figure A.15a. One part of the base (top part) was attached on the bottom of the car, Figure A.15b, sitting on top of the board, and the other part (bottom part) was attached to the top part from across the board (between the top and bottom wooden boards). So the car cannot be removed from the board but it can still move around its surface.



(a) Design of the ambulance base using Fusion 360



(b) 3D printed ambulance base (top part)

Figure A.15: Ambulance base design and construction

The final board was made of wood and laser-cut on the same printers. After attaching the car, the icons that were designed with the help of chatGPT, Figure A.16 were also printed and added mounted on small pieces of cardboard so that they resemble buttons.

Figure A.16: Icons used for the buttons

The end result can be found in Figure A.17.

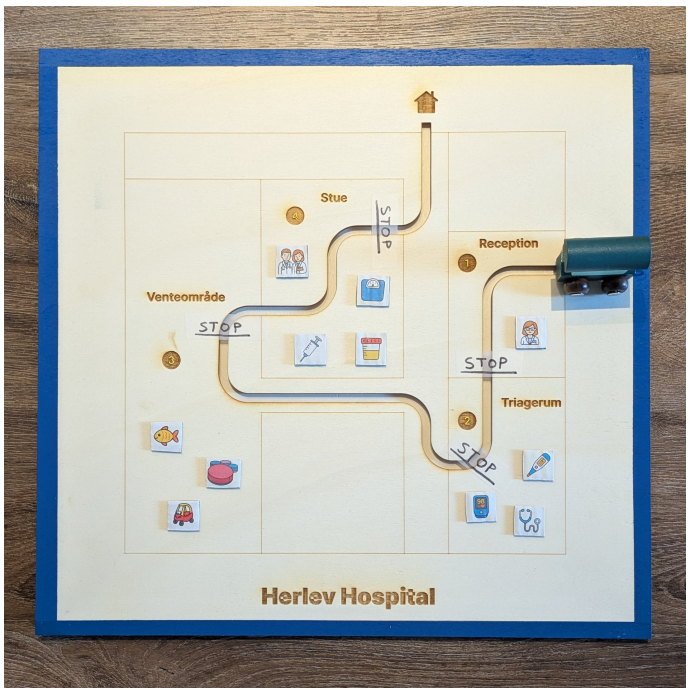


Figure A.17: Final Ambulance Adventure low-fidelity prototype

A.12 Low-Fidelity Testing Results

Air_Balloon_Ride

Χρονική σήμανση	Child's name or initials:	Child's age:	Child's gender:	Previous visits to the ER (Akutmodtagelse):	Previous hospitalization:	I consent to my child's participation:	Engagement Time (min)	Fear (before)	Fear (after)	Fear dif	Pain (before)	Pain (after)	Pain dif	Did you like it?	Would you play again?	What did you like most?	Observations
08/04/2025 1:29:53 μ.μ	FJBN	4	Male	Yes	Yes	Yes	3	0	0	0	10	0	10	Yes	Yes	the balloon	The child was uncomfortable (maybe because of previous bad experience: last time he had a blood test). The parent was really friendly - helped the child and explained how to do it. The kid was smiling and tried to interact with the toy. They squeezed the toy together. Mainly the parent played and tried to entertain the kid.
08/04/2025 1:40:50 μ.μ	Luisa	5	Female	Yes	Yes	Yes	1	6	6	0	4	4	0	Yes	Yes	the air balloon and squeezing	The child tried to physically move the cloud. She interructed with the toy and engaged but at the end she did not feel any better.
08/04/2025 2:33:36 μ.μ	Wc	7	Male	No	Yes	Yes	2	2	0	2	0	0	0	Yes	Yes	to squeeze	The parent explained the game. Neede the parent's help to figure it out. The child looked to have fun. Squeezed the ball really hard.
08/04/2025 3:26:45 μ.μ	Hussain	5	Male	No	No	Yes	2	0	0	0	2	2	0	Yes	Yes	the cloud / to blow	The child tried to move the clouds and the air balloon physically. Smiled while blowing and squeezing (when seeeing the items moving).
08/04/2025 3:27:39 μ.μ	Umer	6	Male	No	No	Yes	2	4	0	4	6	0	6	Yes	Yes	the air balloon	The child looked interested. He needed a bit of help to understand. He liked it but it needed to have more stuff to do to make it longer. Tried to move the balloon by blowing harder.
08/04/2025 3:44:11 μ.μ	Alda Pultz Larsen	4	Female	Yes	No	No	3	0	0	0	0	0	0	Yes	Yes	blowing and squeezing	The kid was excited to play. Got help from the parent at the start but then she understood and got the order. She played three times, got more excited each time and cheered at the end.
							2,166666667	2	1		3,666666667	1					

Match_the_EMotion

Χρονική σήμανση	Child's name or initials:	Child's age:	Child's gender:	Previous visits to the ER (Akutmodtagelse):	Previous hospitalization:	I consent to my child's participation:	Engagement Time (min)	Fear (before)	Fear (after)	Fear dif	Pain (before)	Pain (after)	Pain dif	Did you like it?	Would you play again?	What did you like most?	Observations
29/04/2025 1:58:36 μ.μ.	Mateo	6	Male	Yes	Yes	Yes	10	0	0	0	2	0	2	Yes	No	that you can spin it	Started placing gears randomly. Places all of the pieces and then tries to change them (not one at a time). Completes the second route, goes ahead and chooses a new path.
29/04/2025 2:34:04 μ.μ.	Mia Sloth	6	Female	Yes	No	Yes	6	0	0	0	0	0	0	Yes	No	don't know	The child was really smart - placing pieces correctly very fast. Completed all routes by herself without help. Parents left the child to play alone and were on their smartphones.
29/04/2025 3:19:27 μ.μ.	Other	6	Male	Yes	Yes	Yes	6	0	0	0	2	0	2	Yes	No	to build it	The child looked interested. Tried to put different gears in a position and each time tried if it spins. Tried to put gears on other paths - using the second path to complete the first - got confused and asked parent.
02/05/2025 10:50:15 π.μ.	Naia Ipsen	4	Female	No	No	Yes	8,5	0	0	0	0	0	0	Yes	Yes	spinning the last gear	Needed help from mum to explain but she did it mostly by herself. Played again.
02/05/2025 11:50:16 π.μ.	Yassine	5	Male	Yes	Yes	Yes	6	0	0	0	4	0	4	Yes	Yes	the gears	Really energetic. Played for a route then left and kept coming back - interrupted game session. Took some gears and was running around with them. Finished two routes.
02/05/2025 1:23:26 μ.μ.	Alberte	4	Female	No	Yes	Yes	7	4	0	4	0	0	0	Yes	Yes	that it spins	The parent made comments and recommendations through the game.
							7,25	0,6666666667		0	1,333333333		0				

Ambulance_Adventure

Χρονική σήμανση	Child's name or initials:	Child's age:	Child's gender:	Previous visits to the ER (Akutmodtagelse):	Previous hospitalization:	I consent to my child's participation:	Engagement Time (min)	Fear (before)	Fear (after)	Fear dif	Pain (before)	Pain (after)	Pain dif	Did you like it?	Would you play again?	What did you like most?	Observations
05/05/2025 11:05:34 π.μ.	Johannes	7	Male	Yes	Yes	Yes	5	0	0	0	0	0	0	Yes	Yes	the waiting area and to hear about the fish	The child was playing with the car as he was listening to the info. He knew all information. Kept pressing buttons to learn more.
05/05/2025 11:19:10 π.μ.	Muhammed	6	Male	Yes	Yes	Yes	5	0	0	0	0	0	0	Yes	Yes	toy car	Looked to enjoy it. Parent explained and the nurse that helped made sounds to make it more interactive.
05/05/2025 11:26:06 π.μ.	Olivia	6	Female	No	No	Yes	4,5	8	8	0	0	0	0	Yes	Yes	to hear about the urine test	The parent helped the child and made a sound in every stop. The girl is patient, presses the buttons and listens to parent.
05/05/2025 12:56:52 μ.μ.	Aria Degweker	6	Female	Yes	No	Yes	4,5	2	2	0	0	0	0	Yes	No	the fish	Tried to stop in the middle of the route and press buttons beside it of another room. Patiently hears the info. Was unexpressive.
05/05/2025 1:42:39 μ.μ.	Josef Essam Al-Jaberi	4	Male	Yes	Yes	Yes	5	0	0	0	8	8	0	Yes	No	the road and moving the car	The child was not engaged - played with his own toy car at the same time. The parent was helping out and urge the child to keep playing. Was also showing the items around the room.
06/05/2025 10:31:25 π.μ.	Hurry	5	Female	Yes	No	Yes	5	0	4	-4	8	6	2	Yes	Yes	toy car	The child pressed the buttons and smiled. The parent was pointing out things in the room. The parent was trying to take over and rush it.
							4,833333333	1,666666667	2,333333333		2,666666667	2,333333333					

A.13 Arduino Code

```
#include <SPI.h>
#include <MFRC522.h>
#include <DFRobotDFPlayerMini.h>
#include <SoftwareSerial.h>

// RFID pin definitions
#define SS0_PIN 4 // room 0: Home
#define SS1_PIN 7 // room 1: Reception
#define SS2_PIN 6 // room 2: Triage
#define SS3_PIN 5 // room 3: Waiting Area
#define SS4_PIN 3 // room 4: Patient Room
#define RST_PIN 10 // Reset

// RFID reader instances
MFRC522 rfid1(SS0_PIN, RST_PIN);
MFRC522 rfid2(SS1_PIN, RST_PIN);
MFRC522 rfid3(SS2_PIN, RST_PIN);
MFRC522 rfid4(SS3_PIN, RST_PIN);
MFRC522 rfid5(SS4_PIN, RST_PIN);

DFRobotDFPlayerMini myDFPlayer; // DFPlayer instance

SoftwareSerial mySerial(A0, A1); // SoftwareSerial instance

void setup() {
  // Start communication with DFPlayer on hardware Serial
  Serial.begin(9600);
  delay(1000);

  // Start communication with the other Arduino on Software Serial
  mySerial.begin(9600);

  // Initialize DFPlayer
  if (!myDFPlayer.begin(Serial)) {
    while (true);
  }

  // Set audio volume
  myDFPlayer.volume(18);

  // Start SPI communication for RFID
  SPI.begin();

  // Initialize RFID readers
  rfid1.PCD_Init();
  rfid2.PCD_Init();
  rfid3.PCD_Init();
  rfid4.PCD_Init();
  rfid5.PCD_Init();
}

void loop() {
  // === RFID Reader 1 check ===
  if (rfid1.PICC_IsNewCardPresent() && rfid1.PICC_ReadCardSerial()) {
    mySerial.println("Room 0"); // Send message to the other Arduino
```

```
    rfid1.PICC_HaltA();
    rfid1.PCD_StopCrypto1();
    rfid1.uid.size = 0;
    memset(&rfid1.uid.uidByte, 0, sizeof(rfid1.uid.uidByte));

    delay(200); // Prevent double reads
  }

  // === RFID Reader 2 check ===
  if (rfid2.PICC_IsNewCardPresent() && rfid2.PICC_ReadCardSerial()) {
    mySerial.println("Room 1"); // Send message to the other Arduino

    rfid2.PICC_HaltA();
    rfid2.PCD_StopCrypto1();
    rfid2.uid.size = 0;
    memset(&rfid2.uid.uidByte, 0, sizeof(rfid2.uid.uidByte));

    delay(200); // Prevent double reads
  }

  // === RFID Reader 3 check ===
  if (rfid3.PICC_IsNewCardPresent() && rfid3.PICC_ReadCardSerial()) {
    mySerial.println("Room 2"); // Send message to the other Arduino

    rfid3.PICC_HaltA();
    rfid3.PCD_StopCrypto1();
    rfid3.uid.size = 0;
    memset(&rfid3.uid.uidByte, 0, sizeof(rfid3.uid.uidByte));

    delay(200); // Prevent double reads
  }

  // === RFID Reader 4 check ===
  if (rfid4.PICC_IsNewCardPresent() && rfid4.PICC_ReadCardSerial()) {
    mySerial.println("Room 3"); // Send message to the other Arduino

    rfid4.PICC_HaltA();
    rfid4.PCD_StopCrypto1();
    rfid4.uid.size = 0;
    memset(&rfid4.uid.uidByte, 0, sizeof(rfid4.uid.uidByte));

    delay(200); // Prevent double reads
  }

  // === RFID Reader 5 check ===
  if (rfid5.PICC_IsNewCardPresent() && rfid5.PICC_ReadCardSerial()) {
    mySerial.println("Room 4"); // Send message to the other Arduino

    rfid5.PICC_HaltA();
    rfid5.PCD_StopCrypto1();
    rfid5.uid.size = 0;
    memset(&rfid5.uid.uidByte, 0, sizeof(rfid5.uid.uidByte));

    delay(200); // Prevent double reads
  }

```

```
  // Check for incoming messages (number of pressed button) from other Arduino
  if (mySerial.available()) {
    String msg = mySerial.readStringUntil('\n');
    msg.trim();

    int trackNumber = msg.toInt() + 1; // Convert message to track number
    myDFPlayer.play(trackNumber); // Play corresponding track
  }
}
```

Listing A.1: Code of Arduino A

```
#include <SoftwareSerial.h>

const int controlPins[] = {A1, A2, A3, A4}; // Multiplexer control pins (S0-S3)
const int signalPin = A5; // Multiplexer signal output pin (SIG)
const int threshold = 500; // Button press detection threshold
const int numButtons = 11; // Number of multiplexed buttons

// LED pins
const int ledPins[11] = {3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13};

SoftwareSerial mySerial(2, A0); // SoftwareSerial instance

String currentRoom = ""; // Stores name of currently active room

void setup() {
  // Start communication with the other Arduino on Software Serial
  mySerial.begin(9600);

  // Initialize mux control pins
  for (int i = 0; i < 4; i++) {
    pinMode(controlPins[i], OUTPUT);
  }

  // Initialize all LED pins as outputs
  for (int i = 0; i < 11; i++) {
    pinMode(ledPins[i], OUTPUT);
  }
}

void loop() {
  // Check for incoming messages (number of entered room) from the other Arduino
  if (mySerial.available()) {
    currentRoom = mySerial.readStringUntil('\n');
    currentRoom.trim();

    // Turn off all LEDs
    turnOffAllLEDs();

    // Turn on LEDs based on current room
    if (currentRoom == "Room 1") { // Reception
      digitalWrite(ledPins[0], HIGH);
```

```
    } else if (currentRoom == "Room 2") { // Triage
      digitalWrite(ledPins[1], HIGH);
      digitalWrite(ledPins[2], HIGH);
    } else if (currentRoom == "Room 3") { // Waiting Area
      digitalWrite(ledPins[3], HIGH);
      digitalWrite(ledPins[4], HIGH);
      digitalWrite(ledPins[5], HIGH);
    } else if (currentRoom == "Room 4") { // Patient Room
      for (int i = 6; i <= 10; i++) {
        digitalWrite(ledPins[i], HIGH);
      }
    }
  }

  // Read the mux buttons
  for (int channel = 0; channel < numButtons; channel++) {
    selectChannel(channel); // Select button via mux
    delay(3); // Allow signal to stabilize
    int value = analogRead(signalPin); // Read value from selected button

    if (value > threshold) { // Check if button is pressed
      // Send button press only if it matches the current 'rooms active buttons
      if ((currentRoom == "Room 1" && channel == 0) ||
          (currentRoom == "Room 2" && (channel >= 1 && channel <= 2)) ||
          (currentRoom == "Room 3" && (channel >= 3 && channel <= 5)) ||
          (currentRoom == "Room 4" && (channel >= 6 && channel <= 10)) {
        mySerial.println(channel); // Send button number to the other Arduino
        delay(300); // Debounce delay
      }
    }
  }
}

// Selects a channel (0-15) on the multiplexer
void selectChannel(int channel) {
  for (int i = 0; i < 4; i++) {
    digitalWrite(controlPins[i], bitRead(channel, i));
  }
}

// Turn off all LEDs
void turnOffAllLEDs() {
  for (int i = 0; i < 11; i++) {
    digitalWrite(ledPins[i], LOW);
  }
}
```

Listing A.2: Code of Arduino B

A.14 High-Fidelity Testing Results

Ambulance Adventure

Χρονικό σήματος	Child's name or initials:	Child's age?	Child's gender:	Previous visits to the ER (Ακτινοσταφείες):	Previous hospitalization:	I consent to my child's participation:	Engagement Time (min)	Buttons pushed	Audios Listened	Completed full route	Parent Interaction	Engagement Notes	Did they understand the game mechanics?	Are the parents helping?	Can they reach all places on the board?	Is it easy to move the ambulance around the path?	Quiz Question 1	Quiz Question 2	Quiz Question 3	Quiz Comments	WBF Scale before	WBF Scale after	m-YPAS before - observer 1	m-YPAS before - observer 2	m-YPAS before average	m-YPAS after - observer 1	m-YPAS after - observer 2	m-YPAS after average	Would you like to play again?	On a scale from 1 to 10, how likely would you be to recommend this game?	Do you have any comments that you think might be important for us?	Notes
03/07/2025 12:25:13 μ.μ.	Carl S	5	Male	Yes	No	Yes	4	7	6	Yes	Explained at the start and when he needed to	Pressed some buttons in Waiting area and Examination room.	No	Yes	Yes	No	C (✓)	B (✓)	-	They did not listen to the audios	4	4	23,33	23,33	23,33	23,33	23,33	23,33	Yes	5	Needs to be robust. The kids are wild. It needs more cars and colours. Make sure that they cannot remove things and put them in their mouths.	Parent starts by explaining. We told him to press one button, then he pressed more.
03/07/2025 2:58:25 μ.μ.	Lana	5	Female	Yes	No	Yes	10	11	11	Yes	No interaction	Started a second round to listen to the audios she did not listen at the start.	Yes	No	Yes	No	B	A	A (✓)		0	0	23,33	23,33	23,33	23,33	23,33	23,33	Yes	-	-	The parent did not speak english. They did not interact with us or the toy. A nurse helped with introducing the game. The kid speaks english. She is having difficulties moving the car. She is pointing the car toward the button to press. Presses the buttons so hard that they play twice. She asks more questions about the things she hears. 'Triage room was fun, I want to go there again'. Keeps playing with the car after testing finishes. She played 3 times.
05/07/2025 10:40:08 π.μ.	HODP	5	Male	Yes	Yes	Yes	4	10	10	Yes	Parent asked at the end of the route if the kid would like to listen to more things, so the kid kept playing	Pressed buttons and listened to things on the second route.	No	Yes	Yes	No	C (✓)	C	A (✓)		0	0	33,33	43,33	38,33	23,33	23,33	23,33	Yes	8	It should get cleaned. Maybe it is not a good idea to have them touch the same things.	The child has difficulty moving the car. He is told he can press the buttons by his dad. Completed a full route without pressing buttons, then dad asked him if he wants to listen to more audios and he did another route pressing all buttons.
05/07/2025 10:48:54 π.μ.	Sebastian	5	Male	Yes	No	Yes	5	10	5	Yes	Helps/explains/plays with the kid	He pressed all buttons on the second route. He listened to all audios patiently inside the Stue.	Yes	Yes	Yes	No	C (✓)	B (✓)	A (✓)	Dad helped him count in Q2	2	2	43,33	28,33	35,83	43,33	28,33	35,83	No	10	Compared to other toys this is interactive and fun. If you can squeeze in some more buttons and lights that would be great. The car did not move very well.	Understands the buttons but presses them repeatedly. Holds the car beside each button.
05/07/2025 11:22:12 π.μ.	S D	6	Female	Yes	Yes	Yes	4	10	10	Yes	Only helped out with the quiz	She got all buttons and audios on the second route	Yes	No	Yes	No	C (✓)	B (✓)	A (✓)		2	2	23,33	23,33	23,33	23,33	23,33	23,33	Yes	9	Make the car easier to move,because it was easy to see she had trouble moving it. As long as there are buttons, kids are happy.	She tried to remove a button. She moved the car at the place of the button. Listened patiently. Started the second route so that she could listen to what she could not before.
05/07/2025 2:00:18 μ.μ.	Younas	4	Male	No	Yes	Yes	3	4	4	Yes	Interacted with parents constantly.	-	No	Yes	Yes	No	-	B (✓)	B	Cannot read	0	0	26,66	26,66	26,66	26,66	26,66	26,66	Maybe	4	It has potential. Liked it that the lights went off when you leave a room. But the storytelling is a bit monotone for younger ages. Too much info for a 4 year old. You need a lot of energy to play with it as it is mounted on the wall (compared to if it was on the floor).	The kid played with his bike while playing. Tried to have the car beside the button pressed. Started going the opposite way but dad told him to move around. There was noise on the background from some other kids playing with their bikes.
06/07/2025 10:54:56 π.μ.	LOM	7	Male	No	Yes	Yes	4	11	11	Yes	Helped to start pressing buttons	At the start, he ignored the buttons. Buttons and audios played only on the second round.	No	Yes	Yes, but sits on the floor to move the car while at the bottom of the route.	No	C (✓)	C	A (✓)	Q1 pointed to the fish tank in the room	2	2	23,33	23,33	23,33	23,33	23,33	23,33	Don't know	8	It is a good idea. "I give it an 8 only because it was hard to move the car." The buttons should not be removeable. It can give the parents some ideas of what to do in the waiting area while you wait. Add more buttons (more ideas).	Tried to remove buttons. Did the route the opposite way. Moves the car and presses buttons aggressively. Presses buttons multiple times. Got bored at the end.
06/07/2025 1:53:27 μ.μ.	Joanna	5	Female	Yes	No	Yes	4	11	11	Yes	Tried to make objects come to life by making sounds and gestures.	She got called in after the 4 minutes.	Yes	No	Yes	No	C (✓)	B (✓)	A (✓)	Q1 pointed to the fish tank on the map	2	0	23,33	23,33	23,33	23,33	23,33	23,33	Yes	10	It is very visual and fun. Great product. I think it could also help children that are in the spectrum like her brother. I think after playing with it they would not be that fearful.	She said (when asked about the WBF scale pre intervention) she is a bit anxious that it is going to hurt, but she feels good. Looked happy and listened patiently, excited. Tried to hold the car in front of the buttons.
06/07/2025 3:41:36 μ.μ.	Andrea	5	Female	Yes	Yes	Yes	3	11	11	Yes	Helped to not be shy	She completed the route but stopped at the last room, without returning home.	Yes	Yes	Yes	No	C (✓)	B (✓)	A (✓)		2	0	36,66	31,66	34,16	28,33	23,33	25,83	Yes	8	Adding headphones would be a good idea, kids need to focus. I think it would be more fun.	Moves the car fast. Does not talk at all throughout the game.
07/07/2025 12:13:24 μ.μ.	Sofia	5	Female	Yes	No	Yes	4	11	0	Yes	No help	On the second route she heard all of the 5 audios she pressed.	Yes	No	Yes	No	B	B (✓)	A (✓)		4	0	23,33	23,33	23,33	23,33	23,33	23,33	Yes	8	Make it easier with the car. More stable. Add more pictures.	She could not move the car. She did not listen to any of the audios.
11/07/2025 5:33:33 μ.μ.	Valdemar	4	Male	No	Yes	Yes	2	4	1	Yes	No interaction	The sound cut off after the first audio.	No	Yes	Yes	No	C (✓)	A	-	He answered 'I don't know' in Q3	6	4	23,33	23,33	23,33	23,33	23,33	23,33	Maybe	7	Use headphones. We have a similar toy at home, where you move a car around. If kids think it is something they like, they will come around and try to play with it again.	There is noise on the background. He has issues with moving the car. The sound cut off. He was pressing the LEDs, not the buttons.
12/07/2025 10:43:53 π.μ.	allan	7	Male	Yes	No	Yes	5	5	4	Yes	Explains and helps throughout	Parent urged him to listen to play more, otherwise he would have stopped.	No	Yes	Yes	No	-	-	-	He ran away right after finishing the game. Did not answer any questions.	0	0	23,33	40	31,665	23,33	40	31,665	No	8	It is okay because it is simple. He likes simple, otherwise he gets distracted.	He has been diagnosed with ADHD. Removed a button. Started driving the car even before the testing started. Pressed on the LED. Moves the car fast and aggressively presses buttons. He comments on the syringe: "I don't like this". He run away right after playing, returned back to his tablet.
12/07/2025 12:50:00 μ.μ.	Israa	7	Female	Yes	No	Yes	7	9	9	Yes	Help from older brother.	Completed the route each time and was pressing different buttons in each route.	Yes	Yes	Yes	No	B	B (✓)	A (✓)		8	6	36,66	41,66	39,16	36,66	41,66	39,16	No	8	I think someone in my age (12 years old) maybe would play, it looks interesting.	Parents did not speak english - the older brother answered the questions. The kid carefully moved the car. Her brother helped her with playing. Neutral expression, looks uninterested. She is shy. Completed three routes pressing different buttons each time.
							4,538461538	8,769230769	7,153846154	13 out of 13			7 out of 13 (53.8%)	9 out of 13 (69.2%)	13 out of 13 (100%)	0 out of 13 (0%)	8 out of 11 (72.7%)	8 out of 12 (66.7%)	9 out of 10 (90 %)		2,462	1,538			28,393			26,599		7,75		

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