Developing a solution for sleeping problems encountered by deaf and hard of hearing children

Bachelor Graduation Project

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ABSTRACT

This thesis addresses the significant sleep challenges faced by deaf and hard-of-hearing children by designing solutions aimed at improving their sleep quality. The project was initiated by Ability Tech, a student-run citizen science hub at the University of Twente, following a request from a mother of a child with a hearing disability. The primary research question guiding this study is: ”How to design a solution that aims to improve the sleep quality of deaf and hard-of-hearing children who experience sleeping difficulties?”

To answer this, a comprehensive literature review identified anxiety and poor sleep hygiene as key factors contributing to sleep problems in these children. An online questionnaire was also conducted, revealing specific issues such as difficulties falling asleep and frequent night awakenings. This led to the development of two potential solutions: the Ambient Sound Visualizer and the Family Locator. The Ambient Sound Visualizer helps alleviate anxiety by displaying ambient sounds through light, while the Family Locator shows the locations of family members to provide reassurance and comfort.

The design process involved a co-design approach with the mother and her child, ensuring the solutions were tailored to user needs. Despite some unmet safety requirements, the prototypes provide a solid foundation for future development. Recommendations for future research include conducting more extensive studies with a larger and more diverse participant pool, exploring alternative sensory stimuli, and ensuring safety compliance. This thesis contributes valuable insights into the unique sleep challenges of deaf and hard-of-hearing children and proposes innovative solutions to enhance their sleep quality.

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1 INTRODUCTION

This chapter gives an introduction on the context, relevance and structure of this graduation project, developing a solution for deaf and hard of hearing children with sleeping difficulties.

1.1 Context

Ability Tech is a student-run citizen science hub in the DesignLab at the University of Twente [4]. In Autumn 2023, Ability Tech was approached by a mother of a child with a hearing disability who sought to make a difference for her daughter and the deaf and hard-of-hearing community. Following this request, several meetings were held with the mother, during which the idea to address the sleep problems experienced by deaf and hard-of-hearing children emerged. The mother's initial experiences with her child's sleep issues, combined with the numerous questions she encountered in various Facebook groups, highlighted the importance of this topic. This thesis aims to address these significant sleep challenges faced by deaf and hard-of-hearing children.

1.2 Problem Statement

Sleep is a fundamental necessity for humans [5]. Research has shown that poor quality of sleep has negative impact on many different areas related to both physical and mental health [6]. Individuals who are deaf or hard of hearing often experience difficulties with sleeping, with approximately two-thirds of this demographic experiencing insomnia [7].

For young children with a hearing impairment, this poses a significant challenge as they are expected to undergo substantial development during their sleep [8]. Moreover, adequate rest during the night is crucial for refueling their energy, enabling them to actively engage in daytime activities and further their development. In the Netherlands, the prevalence of deafness or hearing impairment among newborns is estimated to be 1 to 2 per 1000, equating to between 180 and 215 babies a year [9]. Hearing loss may also arise during later stages of life, thereby contributing to an augmented total count of children affected by hearing impairment and deafness.

Hence, addressing the sleeping difficulties experienced by children with hearing impairment is essential. Utilizing a specifically designed product that caters to the diverse needs of deaf and hard of hearing children should effectively improve their sleep quality.

Therefore, the objective of this bachelor thesis is to design a product that improves the sleep of deaf and hard of hearing children that encounter sleeping problems.

1.3 Research Questions

The problem statement results in the following main research question:

- **RQ**: How to design a solution that aims to improve the sleep quality of deaf and hard of hearing children that encounter sleeping difficulties?

This leads to the following sub-questions:

- **Sub RQ 1**: How is quality of sleep defined?
- **Sub RQ 2**: What factors influence the sleep of deaf and hard of hearing children in particular, and what factors impact the sleep of children in general?
- **Sub RQ 3**: What are the exact sleeping problems that they encounter?
- **Sub RQ 4**: Which solutions that might relate to this problem already exist?
- **Sub RQ 5**: What are the requirements that the product must meet?

1.4 Structure of Thesis

This thesis is structured into chapters, starting with chapter 2: Background Research, to deepen the understanding of the research area and problem domain. All sub-questions are addressed in this chapter. Sub-questions 1, 2, and 3 will be answered in section 2.1, the literature review of the background research. Sub-question 3 will be elaborated further, in addition to the literature research, in subsection 2.2.1, using answers from online questionnaires completed by parents of children with hearing impairment. Sub-question 4 will be addressed in the state-of-the-art research, section 2.3. Sub-question 5 will be addressed in section 2.4 and in chapter 5: Specification and chapter 7: Evaluation since the number of design requirements increases during the design process. The background research will be followed by chapter 3: Methods and Techniques, where approaches to find a solution for the posed problem are explained and justified. chapter 4: Ideation, presents the generated concepts and the process of filtering them down to a limited number of concepts. In chapter 5: Specification, several prototypes are explored and evaluated. Following chapter 6: Realisation which elaborates on the chosen prototypes, explaining the integration of all its components. These prototypes are subsequently evaluated in chapter 7: Evaluation. The conclusion of the main research question, along with the discussion and future work, will be detailed in chapter 8: Discussion & Future Work, and chapter 9: Conclusion.

2 BACKGROUND RESEARCH

This chapter provides an exploration of the research area and problem domain for this graduation project, addressing sub-questions 1, 2, 3, 4, and 5. It begins with a literature review aimed at understanding the sleeping difficulties experienced by children with hearing impairments and potential solutions to these challenges. To address gaps in the existing literature, a questionnaire was conducted and analyzed to gather insights from parents of children with hearing impairments. Additionally, interviews were conducted with various experts, including an assistive technology specialist and an interaction and product designer, to gain deeper insights into designing supportive solutions.

The background research also includes other methods of gathering information. Multiple meetings were held with the client using a co-design approach, as discussed further in Chapter 3 . Furthermore, state-of-the-art research was conducted to investigate products, concepts, and theories related to this problem domain, potentially yielding new ideas for solutions and design requirements.

Each section concludes with key findings and identifies further research needs to address specific information necessary for answering the research questions. Section 2.4 of this chapter will list all the design requirements identified, providing a clear overview of critical considerations for designing assistive technology, particularly tailored for the client's child.

2.1 A Literature Review: Understanding and Addressing Sleep Difficulties in Children with Hearing Impairment

The primary objective of this literature review is to explore potential interventions aimed at improving sleep quality for deaf and hard of hearing children by understanding the underlying factors influencing their sleep. This includes defining and assessing the concepts of sleep quality and sleep quantity (sub RQ 1), as outlined in subsection 2.1.1. Additionally, it involves identifying the main factors (sub RQ 2) contributing to sleep difficulties (sub RQ 3) to inform targeted interventions (part of sub RQ 4) tailored to the unique needs of this demographic. This literature review has been conducted as the final assignment for the Academic Writing course in the Creative Technology bachelor's program [10].

This literature review will begin with an evaluation of sleep processes, focusing on the definitions and assessments of sleep quality and sleep quantity. It will then explore the factors contributing to sleep problems specifically in deaf and hard of hearing children, followed by a discussion on related factors affecting children in general. Finally, the review will present a range of strategies and interventions aimed at addressing these sleep problems. It will finish with a conclusion and discussion that comments on the valuable insights gained during this literature review.

2.1.1 Defining and assessing sleep quality and sleep quantity

In this section, the concept of sleep quality will be initially defined, followed by an exploration of methods for its assessment. Subsequently, sleep quantity will be defined, and its assessment methods will be discussed. The section will conclude with a short comparative analysis of the correlation between the two terms.

Sleep quality does not have a medically defined definition, however, various factors describing sleep quality emerge in published literature. The factors described in literature involve both objective and subjective measures. These measures appear to be combined or used separately in various evaluations methods to assess sleep quality.

The National Sleep Foundation of the United Kingdom [11] claims that sleep quality can be assessed by the following four objective factors: sleep efficiency (the amount of time actually asleep compared to the time laying in bed), sleep latency (the time it takes to fall asleep), sleep continuity (the amount of times woken up during the night) and wakefulness (the time it takes to fall asleep after waking up during the night). Additionally, the National Sleep Foundation [11] defines poor sleep quality as taking longer than 30 minutes to fall asleep, spending more than 15% of the time awake while in bed, awakening more than once per night, and being awake for more than 20 minutes after waking during the night before falling asleep again.

Another method found to describe sleep quality is polysomnography [12]. This is a test that can diagnose sleep disorders by monitoring brain waves, blood oxygen levels, as well as heart rate and breathing. This method also entails the same objective measures as the sleep quality method of the National Sleep Foundation [11], together with additional objective measures. Such as parameters that describe sleep onset (the transition process from wakefulness to sleep), total sleep time and wake time after sleep onset, but can also examine sleep architecture, including the percentage of stage 1 sleep, stage 2 sleep, slow wave sleep, and rapid eye movement (REM) sleep. This method does not take any subjective measures into account.

The Pittsburgh Sleep Quality Index (PSQI) [13] is also a method to assess sleep quality. It incorporates objective measures similar to those of the National Sleep Foundation [11], including certain additional measures as sleeping medicine and sleep disturbances. Additionally, the PSQI includes subjective measures such as perceived sleep quality and daytime dysfunction, which are self-rated by participants through questionnaires and diary evaluations. However, other researchers, such as Fabbri et al. [14], argue differently. They see the Pittsburgh Sleep Quality Index (PSQI) primarily as a tool for subjective assessment. According to them, the PSQI is widely used in research as a way to subjectively measure sleep quality. They even go as far as to call it the most commonly employed tool for self-reported sleep quality and suggest it serves as a standard for such assessments.

Furthermore, Gomes et al. [15] showed that children may have difficulty evaluating the perceived quality of their sleep. This is indicated by the notable discrepancy observed between children's self-assessment and parental evaluation of sleep quality. While children tend to positively rate their own sleep quality, parents consistently perceive their children's sleep as poor.

In conclusion, the assessment of sleep quality lacks a universally accepted medical definition, yet literature commonly relies on objective measures for its evaluation. Parameters such as sleep efficiency, latency, continuity, and wakefulness are frequently cited in this regard. Despite the acknowledgment of subjective measures, their assessment may present challenges, especially when considering children. Gomes et al. [15] emphasize the difficulties children face in accurately assessing their sleep quality, evident in the discordance between their self-assessment and parental evaluation. The Pittsburgh Sleep Quality Index (PSQI) is a notable tool in this domain, with Buysse et al. [13] suggesting it encompasses both objective and subjective measures, while Fabbri et al. [14] claim it focuses solely on subjective aspects. Thus, while objective measures continue to dominate sleep quality assessments, the challenges posed by subjective measures, particularly in the context of children, highlight the complexity inherent in comprehensively understanding and evaluating sleep quality.

In addition to qualitative aspects of sleep, it is important to consider established guidelines regarding sleep quantity, specifically the duration of sleep, for children. However, Pilcher et al. [16] discovered that average sleep quality exhibited a stronger correlation with health, well-being, and sleepiness compared to sleep quantity. These findings underscore the greater significance of prioritizing sleep quality, although the importance of not overlooking sleep quantity remains crucial.

The amount of sleep that a child needs depends on the age of the child. Hirshkowitz et al.[17] and Carter et al. [18] concur that the younger the child, the more sleep they require. However, specific values for sleep duration differ in the literature due to difference in age grouping. The National Sleep Foundation [17] recommends 14 to 17 hours of sleep per day for children with the age between 0 and 3 months, with a minimum of 11 hours of sleep. Whilst Carter et al. [18] recommend 16 to 18 hours of sleep a day for children between 0 and 2 months old, including a nap with a minimum of 3.5 hours of sleep, without mentioning a recommended minimum of the total sleep time. The National Sleep Foundation [17] recommends 12 to 15 hours of sleep a day for children between the age of 4 and 11 months and Carter et al. [18] recommend 12 to 16 hours of sleep per day for children between 2 to 12 months old. For toddlers, 1 to 2 years old, The National Sleep Foundation [17] recommends 11 to 14 hours of sleep a day and Carter et al. [18] recommend 10 to 16 hours of sleep a day for children with the age of 1 to 3 years old. Preschoolers, 3 to 5 years old, should sleep between 10 to 13 hours of sleep per day according to The National Sleep Foundation [17], whilst Carter et al. claims [18] that preschoolers should sleep between 11 to 15 hours a day.

In conclusion, while recommendations for sleep duration vary among studies, there is a consensus among researchers regarding the sleep needs of children at different ages. Generally, younger children require more sleep. Specifically, infants aged 0 to 2 months are advised to sleep for 17 hours per day, while those aged 2 to 12 months should aim for 12 to 15 hours. Toddlers aged 1 to 2 years old are recommended to sleep between 11 and 14 hours, and preschoolers aged 3 to 5 years old should aim for 11 to 13 hours of sleep daily. However, it's important to acknowledge discrepancies in recommended sleep duration, which may arise due to variations in age grouping and methodologies. Moreover, Pilcher et al. [16] underscores the significance of sleep quality over quantity in influencing sleepiness, well-being, and overall health. Nonetheless, sleep quantity and quality are closely intertwined. Furthermore, understanding these findings is crucial, particularly in the context of testing a product designed specifically for deaf and hard of hearing children.

2.1.2 Understanding the causes of sleeplessness

Anxiety emerges as a predominant factor causing sleep problems among deaf and hard of hearing children, while bad sleep hygiene influenced by parental factors emerges as a prominent contributor to sleeping problems in general for both hearing impaired and hearing children.

Sleeplessness in general is common for children, according to Sheldon [19], as they are still developing their sleep-wake pattern. Willcocks [20] adds that children who have sensory disabilities, such as a hearing impairment, encounter comparable sleeping problems caused by comparable factors as most hearing children. However, the elevated frequency of sleep-related problems in this group typically arises from a greater prevalence of various factors that impede quality sleep.

Anxiety emerges as such a significant contributing factor to sleep difficulties in deaf and hard of hearing children according to Willcocks [20], Clarke et al. [21], and the National Deaf Children's Society [22]. The National Deaf Children's Society [22] specifically claims that the experience of lying in a dark room in combination with the removal of hearing aids during the night, lead to a significant decrease in sensory stimuli causing anxiety which subsequently negatively influences sleep quality.

According to Clarke et al. [21] and the National Deaf Children's Society [22], tinnitus, characterized by experiencing sound without an external source, can negatively impact sleep quality and lead to sleeping problems in children. However, as tinnitus represents a distinct subtype of hearing impairment, with limited relevance to the focus of the current study, it will not be further explored in this literature review. Instead, the National Deaf Children's Society [22] recommends individuals to seek for assistance from their doctor for help in managing these issues.

Another prominent factor contributing to sleeping problems to children overall, including deaf and hard of hearing children, is bad sleep hygiene caused by parental influence according to Willcocks [20], Clarke et al. [21], the National Deaf Children's Society [22]. Sleep hygiene encompasses several key practices according to Moore [23], namely establishing consistent and suitable sleep schedules tailored to one's age, cultivating healthy bedtime routines such as avoiding electronic devices before sleep, creating a sleep-conducive environment characterized by cool, dark, and quiet surroundings, and adopting physiological habits that promote sleep, such as timing exercise appropriately. Specific examples of poor sleep hygiene include deviations from a regular bedtime, failure to signal bedtime to the child, or allowing the child to sleep in locations other than their designated bed. Additionally, prompt responses to a child's cries by parents can contribute to childhood behavioral insomnia, as suggested by Sheldon [19]. This type of sleep disorder, characterized by sleeplessness that causes distress for either the child or the parents/caretakers, poses a significant challenge to children's overall well-being. It warrants timely attention and intervention, surpassing the common sleeplessness observed in children generally according to Sheldon [19]. Liu et al. [24] further elaborate that childhood behavioral insomnia often presents as difficulties or reluctance on the part of the child to initiate or resume sleep under specific conditions, such as needing parental rocking or when appropriate boundaries have not been established by the parents. These manifestations represent behavioral symptoms of insomnia.

Further influencing factors are the use of electronic devices exposing light just before going to bed as mentioned before by Moore [23]. The National Deaf Children's Society [22], Clarke et al. [21], and Liu et al [24] also argue that this has a negative influence on the sleeping process for children in general.

Additionally, Sheldon [19] argues that sleep quality, sleep quantity and possible problem causing factors differ per person. Liu et al. [24] add that there are many different things that can cause sleeping problems, examples of such factors are dietary choices or obesity. Other causes of sleeping problems that Liu et al. [24] mention are even unchangeable, they cannot be solved anymore, such as prenatal factors like alcohol usage during pregnancy or postnatal factors like preterm birth, which all have an influence on the child's sleep. This implies that while addressing the factors mentioned above may impact children's sleep, resolving them does not guarantee improvement due to the immense number of variables influencing children's sleep patterns.

In conclusion, anxiety and poor sleep hygiene are significant factors impacting sleep quality in deaf and hard of hearing children. It's crucial to acknowledge the broader range of factors contributing to sleep difficulties in children, including pre-sleep exposure to electronic devices, darkness, and tinnitus. Due to individual differences and the multitude of potential factors involved, improvement or resolution is not guaranteed. However, when developing a tailored product to address the sleeping difficulties of deaf and hard of hearing children, the most significant factors such as sleep hygiene and anxiety will be prioritized.

Furthermore, specific connections between factors and problems have not yet been fully clarified. Therefore, it remains unclear which factors cause specific problems. Further research is necessary to identify the specific issues encountered by deaf and hard of hearing children, allowing for more targeted interventions and solutions.

2.1.3 Approaches to address sleeplessness

To address sleeping difficulties among deaf and hard of hearing children, essential solutions include encouraging sensory stimuli to alleviate anxiety-related sleep issues and educating parents to prevent bad sleep hygiene. This approach is particularly important as bad sleep hygiene can contribute to behavioral childhood insomnia. Additionally, the most effective solution for addressing this type of insomnia is the method ”unmodified extinction”.

One of the most the most significant contributing factors to sleeping problems in deaf and hard of hearing children is anxiety, caused by the lack of sensory stimuli during the night as described in the previous section. The National Deaf Children’s Society [22] suggests that leaving a light at night on might help decreasing the anxious feeling. Furthermore, providing an additional light source attached to the child’s hearing aid can foster a sense of autonomy, as the child can independently choose to wear the device, which subsequently leads to a potential decrease in anxiety. However, not all children are capable of doing that themselves (yet). Additionally, adding a piece of clothing that smells like one of the family members to the bed might help according to the National Deaf Children’s Society [22]. Willcocks [20] and the National Deaf Children’s Society [22] both advice to give the child a weighted blanked to increase sensory stimuli and to make the child feel more secure.

Poor sleep hygiene is identified as another significant contributor to sleep difficulties among children in general, not just among children who are deaf or hard of hearing. According to Clarke et al. [21], it is crucial to educate parents about the importance of fostering good sleep hygiene practices. Consistent schedules are emphasized by Clarke et al. [21], the National Deaf Children’s Society [22], and Willcocks [20]. Willcocks [20] recommends using visual schedules to prepare and clarify the sleep routine for the child, while the National Deaf Children’s Society [22] goes along with this but adds that the visuals should consist of pictures. Furthermore, Willcocks [20] emphasizes the importance of not rushing the bedtime routine and advises allocating 30 minutes for the sleep routine to prepare the child for going to sleep. Next to that, The National Deaf Children’s Society [22] stresses the significance of ensuring that the child settles in their own bed. Moving the child to another location after they have fallen asleep may cause fear if they wake up in a different place. All these guidelines help to prevent behavioral childhood insomnia, but what if it is already too late?

The method ”unmodified extinction” is one of the most effective approach to solve behavioral childhood insomnia according to Carter et al. [18] and Barkoukis et al. [25]. This method entails parents refraining from attending to their child when they cry out while in bed, except in cases where the child is ill or in imminent danger [25]. Parents are instructed not to intervene until the following morning to avoid inadvertently reinforcing crying behavior and teaching the child undesirable habits. However, this practice can be challenging for parents and may induce stress according to Carter et al. [18]. As an alternative suggests Carter et al. [18] ”graduated extinction”, albeit slightly less effective, yet still considered a viable solution. This alternative method is the same as ”unmodified extinction” but incorporated with check-ins that are scheduled.

Another advice to combat sleep problems, for children in general, is to avoid electronic devices exposing light just before going to bed according to Moore [23], the National Deaf Children's Society [22], Clarke et al. [21], and Liu et al. [24].

In summary, effective solutions for addressing the most significant factors potentially causing sleeping difficulties among deaf and hard of hearing children include implementing sensory stimuli interventions to alleviate anxiety and educating parents about sleep hygiene practices. Encouraging sensory stimuli, such as extra light sources or weighted blankets, should potentially reduce anxiety. Educating parents about consistent sleep schedules and routines prevents bad sleep hygiene, a factor that can cause behavioral childhood insomnia. Additionally, the 'unmodified extinction' method has been identified as effective in addressing behavioral childhood insomnia. By refraining from attending to the child's cries during bedtime and maintaining consistent bedtime routines, parents can help their children establish healthy sleep habits. However, it's important to recognize that not all factors contributing to sleeping difficulties are easily addressable or applicable to children who are deaf or hard of hearing. Nonetheless, these targeted interventions represent important steps towards improving the overall sleep health and well-being of this population and can be used in the design of a product that addresses this problem. Further research is necessary to uncover specific relationships between certain problems and the factors that cause them in deaf and hard of hearing children, thus enabling more tailored interventions in the future.

2.1.4 Conclusion and Discussion

The primary objective of this literature review was to explore potential interventions aimed at improving sleep quality for deaf and hard of hearing children by understanding the underlying factors influencing their sleep. By comprehensively examining sleep evaluation methods and identifying prominent factors contributing to sleep difficulties, insights were gained to inform targeted interventions tailored to the unique needs of this demographic.

From the research, anxiety emerges as a significant factor affecting sleep in deaf and hard of hearing children, while poor sleep hygiene, influenced by parental behavior, significantly contributes to sleep difficulties in both hearing impaired and hearing children. Interventions such as sensory stimulation to reduce anxiety and parental education to promote good sleep hygiene are recommended.

In addition, this review underscores the significance of both subjective and objective measures in evaluating sleep quality. While subjective measures can provide valuable insights, especially in adults, their application in children may be challenging due to their limited capability for accurate self-assessment. Therefore, the focus on objective measures such as sleep efficiency, latency, continuity, and wakefulness remains paramount. Furthermore, the review highlights the importance of recognizing the varying sleep needs of children across different developmental stages, thereby emphasizing the significance of adhering to age-appropriate sleep durations.

However, the research faces limitations, including a scarcity of studies specifically focused on particular sleep problems among deaf and hard of hearing children, as well as the specific factors that influence these problems, indicating a gap in understanding the relationship between the identified factors and the sleep difficulties experienced by this demographic. The lack of research highlights the need for further investigation, offering a chance to better understand and address the distinct sleep challenges faced by deaf and hard of hearing children. Furthermore, the complexity of sleep and its multifaceted nature encompasses the intricate interplay of various factors influencing sleep, presenting challenges in addressing all relevant aspects within the confines of a single study. These limitations underscore the need for further research to deepen the understanding and inform tailored interventions for addressing sleep issues among children. Individual differences among children add another layer of complexity, as each child may respond differently to interventions, potentially necessitating tailored approaches to address their specific needs and characteristics.

In summary, while this review provides valuable insights, further research is needed to address the identified limitations and gaps in the existing literature, ultimately advancing the understanding and enhancing interventions for better sleep health among deaf and hard of hearing children. Nonetheless, this literature review has enabled the generation of potential ideas for designing interventions aimed at effectively enhancing the sleep quality of deaf and hard of hearing children.

2.2 Data collection

2.2.1 Questionnaire for parents of deaf and hard of hearing children

A questionnaire was conducted to attempt to fill the gap discovered during the literature review in section 2.1. The missing information regards the specific sleeping problems that deaf and hard of hearing children specifically might encounter and the relation between specific problems and specific factors that cause those particular problems. The self-made questionnaire was conducted and shared in multiple Facebook groups for parents with deaf and hard of hearing children. The Facebook post can be found in figure 2.1 together with the logo from the website of Babyoortjes [26], the website of my client.

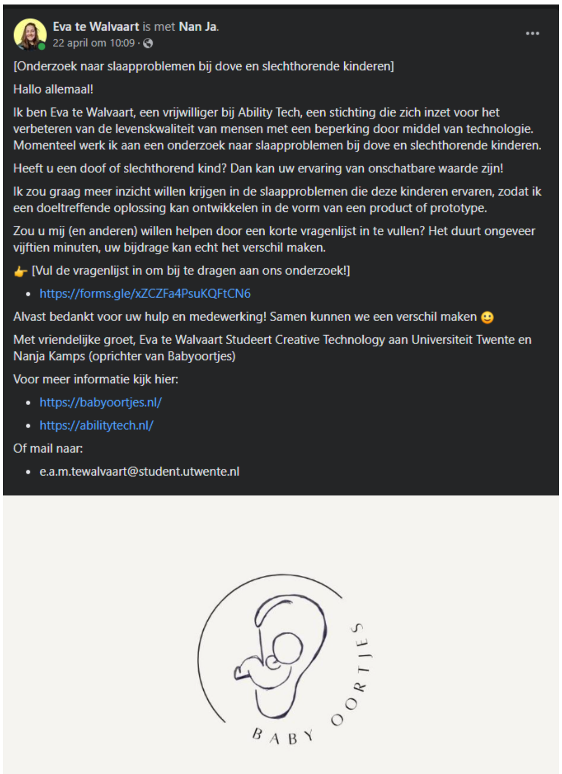

Figure 2.1: The Facebook post, placed in multiple Facebook groups, asking people to fill out the questionnaire.

The specific questions can be found in Appendix 10.1. The questionnaire covered various topics including the home situation, sleep rituals, specific sleep problems, and potential solutions that have been experimented with. Twenty-eight answered forms were collected. Noticeable findings were revealed. Multiple parents answered that their child has difficulties with falling asleep, wakes up multiple times at night, and experiences fear/anxiety. Additionally, several children show a desire to have people around them and to have sensory stimuli. Solutions that work for a lot of children include sleeping with their parents. Some parents lay their child in their own bed initially, but during the night, the child often migrates into the parents' bed. Adding sensory stimuli by turning on a night lamp, turning on a radio (particularly for children with tinnitus), parents hugging and stroking a child, or adding a weighted blanket is also mentioned by multiple people. While these measures provide some relief, they do not fully resolve the issue. Giving the child Melatonin is also mentioned multiple times. Sleep training and explaining sleep rituals with visuals, as well as letting the child know that it is nighttime and everyone is asleep, are also strategies suggested by respondents.

One parent mentioned specifically that she notices that her child needs more sleep than other children of her sons age. There were also 4 parents of the 28 participants that mentioned that their hearing impaired child does not have any sleeping problems at all.

In summary, the particular problems that deaf and hard of hearing generally encounter are: having difficulties falling asleep, waking up multiple times at night and experiencing fear/anxiety. This is probably caused by the lack of sensory stimuli and the absence of trusted people during the sleeping process. This conclusion is very valuable for the process of developing a solution for the sleeping problems that multiple deaf and hard of hearing children encounter.

2.2.2 Interviews with Client

Multiple interviews were conducted with the client to gather detailed information about the specific problem domain, the child's disability, and their home situation. These interviews also played a crucial role in establishing clear design requirements for the project.

The introduction interview aimed to clarify the client's initial request and understand the circumstances surrounding their needs. It highlighted the challenges faced by the client's 2.5-year-old daughter with moderate hearing loss and identified gaps in available solutions, particularly in toys and sensory aids.

The second interview focused on refining the project's design focus. It provided deeper insights into the daughter's daily experiences and sleep patterns, emphasizing the need for tailored solutions that could benefit deaf and hard-of-hearing children more broadly.

The third interview centered on brainstorming practical solutions to sleep disturbances among deaf and hard-of-hearing children. It also laid the groundwork for developing a comprehensive online questionnaire to gather insights from the community.

The fourth interview finalized plans for distributing the questionnaire and ensuring its effectiveness in gathering relevant feedback from parents in the deaf and hard-of-hearing community.

These interviews were pivotal in capturing the client's perspectives and her daughters needs, ensuring that the project's direction and proposed solutions were firmly grounded in a thorough understanding of the challenges faced by children with hearing impairments.

1. **Introduction Interview - January 12th, 2024**

The primary objectives of the initial meeting, which took place in the DesignLab at the University of Twente on January 12th at 13:00 in the open space ”Ideate,” were to identify and clarify the issues to be addressed and to understand the specific circumstances and design requirements for the project. Before this meeting, the client had contacted Ability Tech with a request that needed further clarification. It was not yet clear that this request would turn into a graduation project; we only knew it involved research questions and product ideas for deaf and hard of hearing children. This meeting was very helpful in clarifying the client's request and setting the stage for the project's direction. The meeting included the founder of Ability Tech, who acted as the process supervisor, and an expert in communications and custom technology.

The client, a mother of a 2.5-year-old girl with a hearing disability, had several inquiries regarding the development of deaf and hard-of-hearing children. During the meeting, it became clear what she was questioning:

- Does the attachment process between parents and child differ for children with hearing impairments?
- Is there a difference in raising children with auditory impairments?
- How does play development occur in young children with hearing impairments?
- Can toys be developed where vibrations replace sound, considering that many regular toys produce sounds that her daughter, cannot always hear? For instance, could a play mat serve this purpose?

The mother's primary concern was to find solutions that would support the development of the child and other children in similar situations. Specifically, she was interested in exploring the development of a play mat where the role of sound is replaced by vibrations.

During the discussion, the client noted that many parents resort to using V-Tech toys due to their bright lights, despite these toys not being tailored to the sensory needs of children with hearing impairments.

Regarding the child, it was established that she hears quite well with hearing aids. However, she faces challenges understanding her parents when they are in another room. This observation prompted consideration of compensating for her auditory limitations by enhancing her other senses—visual, tactile, olfactory, and sensory integration. These senses might strengthen due to her brain's adaptation to her reduced hearing ability according to the client.

The primary objectives of the initial meeting were to identify and clarify the issues to be addressed, understand the specific circumstances, and define the possible design question for the (graduation) project. This introductory session also provided an opportunity for all parties involved to become acquainted with each other.

At the end of the meeting I was very intrigued about these research and design questions and posed this to the program coordinator of the graduation program of Creative Technology. I wrote a proposal and asked a supervisor that is part of Ability Tech to become my supervisor. Both proposals got accepted.

2. **Second interview - February 17th, 2024**

   On February 17th, 2024, a follow-up meeting was held online via Teams with my client and me to clarify the design focus for the graduation project. The meeting lasted about one hour. The primary objective was to identify a specific problem faced by deaf and hard-of-hearing children that the project could address through a technological prototype. Additionally, more information about the child was gathered to create a clearer picture of the problem background and the child's situation and needs.

   Both my client and I conducted research beforehand to explore various issues faced by deaf and hard-of-hearing children. During the meeting, we discussed several key problems to find the most impact full area for the project. The main issues we discussed are placed in the following list:

   (a) **Emotional Development**: These children often struggle with recognizing and regulating emotions, particularly complex social emotions like guilt and shame. They may also face social isolation, which affects their overall emotional well-being.

   (b) **Communication Challenges**: Communication difficulties can result in frustration and impede the ability to follow instructions, leading to additional stress. Effective communication is crucial for their development, and current aids are not always sufficient.

   (c) **Educational Development**: Limited incidental learning and difficulties in understanding context impact their educational progress, particularly in areas such as language and math development. Children with hearing impairments often need to attend special schools to receive the necessary support.

   (d) **Sleep Problems**: Many deaf and hard-of-hearing children, including my client's daughter, experience sleeping difficulties. In the case of the client's daughter, these sleep issues manifest as trouble falling asleep, singing to self-soothe, and frequent night wakings. The lack of auditory input can lead to insecurity in the dark. My client found that this issue is frequently discussed among parents in various Facebook groups.

   Detailed information about the client's 2.5-year-old daughter, who experiences moderate hearing loss, was gathered during the meeting. It was noted that while she can hear adequately with her hearing aids, without them, she primarily perceives low frequencies. Her sleep patterns were highlighted, revealing difficulties in falling asleep and frequent night wakings, often accompanied by self-soothing behaviors like singing. These insights underscored the significant impact of auditory deprivation on her sense of security, particularly in low-light environments. The client expressed concerns commonly shared among parents in various online communities, emphasizing the critical need for effective solutions to improve her daughter's sleep quality and overall well-being. We discussed this posed problem and decided that this was going to be the topic to address in the graduation project as it possibly helps the daughter of the client but possibly also a lot of other people in the deaf and hard of hearing community.

During the first interview, the client expressed concerns about whether the attachment of deaf and hard of hearing children to their parents differs from that of hearing children. This issue was researched, and it was determined that there is no difference in the quality of attachment between the two groups, according to Uilenburg researcher at NSDSK [27]. Vaccari et al. [28] also support this finding, showing that effective communication and supportive environments are key determinants of attachment quality, rather than the child's hearing status.

Based on the comprehensive discussion, the project's primary focus was refined to address sleep problems due to their significant impact on the well-being and development of deaf and hard-of-hearing children, including the client's child. Additionally, the client and me discussed possible design requirements posed in the following list.

Design Requirements inspired by the client:

- The product could be modular, allowing users to add only the necessary components.
- The product could be sold as a package containing various parts, enabling users to personalize it according to their specific home environment.
- The product might have an intuitive on/off button that the child can easily understand and operate consciously.

The last design requirement is debatable, as hearing children cannot turn their hearing off.

Regarding the next steps that needed to be investigated, conducting further research on sleep patterns and preferences among deaf and hard-of-hearing children was essential. This research is outlined in section 2.1. An agreement was made to schedule regular follow-up meetings to monitor progress and gather additional insights.

This second meeting was crucial in refining the project's direction to address a critical area where technology has the potential to significantly enhance the lives of deaf and hard-of-hearing children. By prioritizing improvements in sleep quality through innovative design, this project aims to contribute meaningfully to their overall well-being and developmental outcomes.

3. **Third Interview - March 9th, 2024** On March 9th, 2024, at 12:00, an online interview was conducted via Teams that lasted approximately one hour, focused on exploring various, more specific, challenges faced by children with hearing impairments. The primary aim was to refine the project's focus and brainstorm potential solutions for sleeping problems that deaf and hard of hearing children often encounter.

   The interview highlighted the child's difficulty falling asleep and her tendency to wake up frequently at night, often singing and exhibiting signs of anxiety. This prompted us to explore potential solutions tailored to her sensory needs, such as integrating familiar scents into her bedding and using gentle vibrations to provide comforting sensations, reflecting her mother's insights during the brainstorming session.

   We discussed specific challenges and potential solutions related to improving the child's sleep:

   Challenges:

   - Difficulty in sleep initiation and frequent nighttime awakenings.
   - Challenges related to managing anxiety during sleep.
   - Preferences for comforting stimuli, such as the moon.
   - Issues with independently managing hearing aids.

   For the brainstorming session, we followed a structured approach. Initially, I invited the client to propose several ideas. Afterward, I supplemented these with additional solutions to enrich our discussion.

   Possible solutions:

   - Integrating familiar scents into the child's bedding.
   - Exploring the use of gentle vibrations for soothing sensations.
   - Considering visual cues like moonlight or soft lighting.
   - Developing methods for managing anxiety during nighttime awakenings.
   - Enhancing the child's autonomy in managing hearing aids.

   Furthermore, we identified a need for further research. Consequently, I conducted a literature review, see section 2.1, that underscores the lack of information regardfing specific sleep issues faced by deaf and hard-of-hearing children, as well as the efficacy of current sleep aids for this population. Recognizing this gap, we deemed it crucial to initiate our own investigation. Our initial step involved formulating questions for a questionnaire targeted at parents of deaf and hard-of-hearing children. This questionnaire aims to gather firsthand insights into their children's sleep patterns and the effectiveness of current sleep interventions.

In the following part of the interview, I presented a Facebook message and Google Forms to get feedback on the questionnaire that was made to be shared online (Facebook groups) and aimed at parents who are connected to my client in some way via deaf and hard of hearing intervention services, like Kentalis. More information about the questionnaire can be found in Section 2.2.1.

4. **Fourth Interview - April 6th, 2024**

   On April 6, 2024, my client and I held a brief 20-minute online meeting via Teams to finalize the content and distribution plan for an online message and questionnaire. We made minor adjustments to both during our discussion. Initially, I planned for my client to handle the Facebook posting, but she requested that I join various Facebook groups related to parents of deaf and hard of hearing children in the Netherlands and handle the posting myself.

   Following our meeting, I sought ethical approval from the Ethical Review Committee of the EEMCS department at the University of Twente [29] to proceed with distributing the questionnaire as discussed. After receiving approval, I posted the message and questionnaire not only on in the Facebook groups but also on LinkedIn. Additionally, my client also distributed the forms with the parents of other children of the 'early intervention group" of Kentalis .

   We successfully finalized our distribution plan during the meeting. If you would like too read the full questionnaire, please look at Section 10.1.

   The next step was to complete the background literature research and draw conclusions from the questionnaire for parents of deaf and hard-of-hearing children, see the result in section 2.2.1.

Following these four client interviews and the review of the questionnaire, several co-design sessions were conducted to find more solutions for the posed problem and to evaluate and iterate on posed prototypes. Details of this approach and its outcomes can be found in Chapter 3 Methods and Techniques.

2.2.3 Interview with assistive technology specialist

An interview [30] was conducted,on Wednesday April 3th 2024 from 14:30 until 16:30, with Eric van Heuvelen, an assistive technology specialist at Bartiméus Doorn. Bartiméus supports individuals who are partially sighted or blind in their efforts to function as independently as possible within society [31]. At the Bartiméus location in Doorn, there is a Fablab, an inspiring and accessible environment where clients, staff, and visitors collaborate to explore, experience, and develop technology for people with visual and intellectual disabilities. After the interview in the inspiration lab a tour through the Fablab took place where the brain-lab, speach-lab and maker-lab where shown.

During the interview, questions were posed regarding van Heuvelen's design process, his career journey, Bartiméus's Fablab, ideation and feedback on the graduation project, and technology-related topics.

Assistive technology specialist Eric van Heuvelen has a diverse educational background, having studied nursing and "ICT and micro electronics." With seven years of experience working in supervised groups, he has developed strong empathy and a deep understanding of workplace dynamics. This experience enables him to navigate the practical challenges of collaborative projects effectively. Van Heuvelen's current focus lies in developing technology for individuals who are blind, visually impaired, deaf-blind, and those with severe multiple disabilities

Additionally, van Heuvelen actively participates in various conferences to network with peers, share his visions, and gather new inspiration for his work. Next to that, he is deeply involved in educational initiatives related to assistive technology, contributing significantly to the field's advancement through his expertise and dedication. This combination of academic training, practical experience, and professional engagement underscores his commitment to enhancing the lives of individuals with disabilities through innovative technology solutions.

Van Heuvelen's design process is primarily driven by design questions. When a client comes into the Fab Lab with a specific question, the designers often take a step back to evaluate the situation. They consider whether there is an existing solution that meets the client's needs or if a better alternative can be developed. This approach frequently involves multidisciplinary collaboration with experts from various fields, such as behavioral experts. In this context, waiting for a solution can be challenging, so swift action is taken. The design process focuses on individual needs and is executed as efficiently as possible. A solution is conceptualized and then developed, emphasizing ease of application. Van Heuvelen experienced during his work as a supervisor on groups that if supervisors cannot easily use a solution, they are unlikely to adopt it. This important note resulted in a new design requirement for the new assistive technology product coming out of this project "Applying the designed solution should be easy to understand for the target audience who need to apply the solution". Furthermore, Most clients who present questions or challenges live nearby the Fablab, facilitating rapid adjustments to prototypes as needed. This immediate responsiveness is a key advantage of the local client base.

The Fablab comprises different rooms close to each other designed for specific purpose, the inspiration lab (place to generate ideas), brain lab (office), speech lab (control devices by voice and try out many smart gadgets), maker lab (workshop). The Fablab team consists of 11 members, including four individuals focused on innovation, several team members dedicated to marketing, and others specializing in business product design. Van Heuvelen is the sole individual responsible for physically creating new technology within the team.

Regarding the problem domain of this thesis and the possible solutions for the posed problem, multiple questions were asked about senses, technology, autonomy, sensory stimulation and perceptions. Van heuvelen mentions that heat is difficult to use in technology as it is mostly delayed, it is not possible to turn it on or off directly, it needs to warm up and cool down. Smell is also difficult to add to technology as people react differently on it. Additionally, it is difficult to take it away after a certain smell has been outputted. He emphasized the value of haptic feedback, highlighting the importance of researching the specific application context and duration for optimal implementation. This important note resulted in a new design requirement for the new assistive technology product coming out of this project "The product might use haptic feedback to provide the user with new information". An intriguing application he mentioned was memory metal, currently being researched at Delft University of Technology, which can dynamically bend and exert power along two-dimensional strips. Visual and auditory stimuli were notably absent from our discussion.

During our discussion about autonomy, important questions were raised regarding sensory stimulation. We considered whether adding sensory stimulation, even if the child does not prefer it, necessitates providing them with the option to turn it off. Additionally, we pondered whether children are capable of consciously making the decision to deactivate such stimulation. No definitive conclusion was reached beyond engaging in an ethical dilemma discussion. During the debate, an example was mentioned to illustrate the complexity of this issue, just as hearing children cannot turn off their hearing, the question arises whether similar considerations should apply to sensory technologies. This resulted in a new design requirement "The product does not necessarily need an intuitive on/off button that the child can easily understand and operate consciously".

Finally, a potential research direction was proposed: exploring how babies perceive sensations inside the belly. We questioned whether babies feel secure due to the vibrations of sounds rather than the actual audio itself. The inquiry raised whether it's feasible to replicate this sensation externally after the baby is born. In considering this research direction, it's crucial to prioritize the well-being of the child, since a possible solution should contribute to reducing the child's stress and promoting a sense of security. Resulting in the following design requirements "The product should contribute to reduction of the child's stress" and "The product should promote a sense of security". More on ethical reflection regarding this thesis can be found in the appendix in section 10.2.

Additionally, multiple inspiring technologies were talked about during the interview, further elaboration on this can be found in section 2.3, State of the art.

In summary, the interview with Eric van Heuvelen, an assistive technology specialist at Bartiméus Doorn, underscored critical considerations for developing technology for vulnerable populations. Firstly, it is vital that any technology developed is easy to apply, ensuring usability and adoption by users. Challenges discussed include integrating heat and smell into technology effectively, given delays and user variability. The importance of offering options for sensory stimulation, particularly through haptic feedback, was emphasized. On the other hand, an ethical dilemma arose regarding autonomy and the consciousness of a child, whether they can decide to activate or deactivate sensory stimulation, like hearing children cannot turn off their hearing. Additionally, in pursuing technology solutions, a multidisciplinary approach is essential, considering the diverse needs and abilities of the target group. This inquiry highlights the importance of prioritizing the child's well-being and reducing stress through innovative technology solutions. Further details on related technologies can be found in section 2.3, State of the Art, and further information regarding the posed design requirements can be found in the list below.

Design Requirements inspired by assistive technology expert:

- Applying the designed solution should be easy to understand for the target audience who need to apply the solution
- The product might use haptic feedback to provide the user with new information
- The product does not necessarily need an intuitive on/off button that the child can easily understand and operate consciously.
- The product should contribute to reduction of the child's stress.
- The product should promote a sense of security.

2.3 State of the art

Technologies and products that already exist can be inspiring for new ideas, requirements and insights. In this section, the state of the art related to the posed problem is evaluated looking at different categories:

1. Things used to encourage sensory stimuli to alleviate anxiety related sleep issues. (see section 2.3.1
2. Theories to prevent bad sleep hygiene (see section 2.3.2)
3. Methods aiming to solve behavioral childhood insomnia. (see section 2.3.3)
4. Theories and specifically crafted toys to aid children in falling asleep, guiding them through their sleep, or supporting their sleep routines. (see section 2.3.4)
5. Products designed specifically to facilitate sound communication with deaf and hard of hearing individuals. (see section 2.3.5)

In each category, technologies, products, or concepts will be explained and evaluated for their relevance to the problem domain in this graduation project. Useful insights will be extracted, highlighting aspects that may serve as inspiration or potential solutions. At the end of this chapter, a summary will be provided to clarify the useful findings from the state-of-the-art evaluation

2.3.1 Things used to encourage sensory stimuli to alleviate anxiety related sleep issues

Several strategies and products are recommended to alleviate anxiety-related sleep issues in deaf and hard-of-hearing children. These strategies focus on enhancing sensory experiences to promote feelings of security and comfort which subsequesntly should reduce anxiety.

1. **Clothing with Familiar Scent**
   Placing a piece of clothing in the child's bed that smells like a family member can reduce anxiety by stimulating the sense of smell and providing a comforting sense of closeness, according to the National Deaf Children's Society [22]. (this is also mentioned in the literature review)

2. **Weighted blanket**
   Both Willcocks [20] and the National Deaf Children's Society [22] recommend using weighted blankets. These blankets provide sensory stimulation that can help the child feel more secure and calm. (this is also mentioned in the literature review)

3. **Co-sleeping**
   Many parents reported in questionnaire responses (Section 10.1) that their children experience fewer sleep problems when co-sleeping with family members. However, it's crucial not to disturb the child by moving them to their own bed after they have fallen asleep [22]. The National Deaf Children's Society [22] emphasizes the importance of ensuring that children settle in their own beds from the beginning. Relocating a sleeping child can cause fear and confusion if they wake up in a different place.
   (this is also mentioned in the literature review)

4. **Melatonin**
   In the responses to the questionnaire from section 10.1, a few parents mentioned that they give their children melatonin to help them fall asleep. Melatonin is a hormone naturally produced by the brain in response to darkness, aiding in the regulation of the sleep-wake cycle and the internal clock. According to The National Center for Complementary and Integrative Health [32], melatonin can also help reduce anxiety. However, the effects of taking melatonin are not fully understood.

5. **Stimulating touch**
   Hugging and stroking the child provide tactile sensory stimulation, which is particularly beneficial when other senses, such as hearing, may be less effective during bedtime. This approach is recommended by Willcocks [20] and the National Deaf Children's Society [22]. In responses to the questionnaire from section 10.1, several parents noted practicing this technique, reporting that their children find it comforting and enjoyable. (this is also mentioned in the literature review)

6. **Night Lamp**
   In responses to the questionnaire from section 10.1, parents noted using night lamps to provide comforting sensory stimulation for their children at bedtime. This practice aligns with recommendations from the National Deaf Children's Society [22] to reduce bedtime anxiety by leaving a light on at night.

   An example of such a night lamp is the ZAZU wall light [33]. The ZAZU wall light exemplifies this approach with its user-friendly design operated by hand gestures like waving or tapping. It offers adjustable brightness and features a variety of soothing colors including white, orange, red, pink, blue, turquoise, green, or a multi-color option. This flexibility allows parents to create a calming environment tailored to the child's preferences, which is conducive to reducing anxiety in children.

   The ZAZU wall light's ability to adapt to individual preferences inspired the creation of a new design requirement: "The product must be adjustable to personal preferences and needs to make the user as comfortable as possible."

   Additionally, the Zazu wall light comes with three magnetic soft toys that can be attached to the light, providing a comforting presence for children as they fall asleep.

Figure 2.2: Zazu wall light with magnetic soft toys

Figure 2.3: Zazu wall light in use

7. **Adding light to the hearing aid** Providing a light source attached to the child's hearing aid can foster a sense of autonomy, as the child can independently choose to wear the device, which can potentially lead to a decrease in anxiety [22]. However, not all children are capable of doing so independently yet.

   This concept has led to the new design requirement: "The product should include a designated place for storing hearing aids that is visible in the room and illuminated by lights."

8. **Visual sleep routine**
   Consistent schedules are emphasized by Clarke et al. [21], the National Deaf Children's Society [22], and Willcocks [20]. Willcocks [20] recommends using visual schedules to prepare and clarify the sleep routine for the child, while the National Deaf Children's Society [22] goes along with this but adds that the visuals should consist of pictures. Furthermore, Willcocks [20] emphasizes the importance of not rushing the bedtime routine and advises allocating 30 minutes for the sleep routine to prepare the child for going to sleep.

9. **Lisa DS-1/RF**
   This is an alarm clock [34], see figure 2.4, that can be connected to a vibrating mat that one can add to their bed. Additionally, this alarm clock can be connected to the smoke alarm, doorbell and additional sensors. An external wireless vibration device is also part of this system that can be used when one wants to walk around, this wireless device will also notify the user of possible danger/alarm like the vibrating mat of the bed. This can be used by everyone, adults but also children.

Figure 2.4: The Lisa SD-1/RF

This system can also be used as an inspiration for a possible solution. This system can help children with feeling less stressed about possible audible signals (smoke alarm) that they might miss when they are asleep. It might possible reduce their anxiety.

2.3.2 Theories to prevent bad sleep hygiene

In the previous section, we discussed the use of visual sleep routines, maintaining a consistent sleep schedule, and avoiding disturbing the child after they have fallen asleep. However, there are additional crucial considerations for children's sleep. This section pertains to children in general, including those who are deaf or hard of hearing. Furthermore, there is a diversity of theories regarding optimal sleep practices for children, reflecting significant variations in opinions and research findings among scholars. The theories mentioned below are particularly notable in this context. Future research focusing on exploring additional theories aimed at preventing poor sleep hygiene could further enhance our understanding of sleep issues in children

10. **Clear Bedtime Routine**: Taking the time to guide the child to bed and consistently signaling bedtime are essential. Utilizing visuals, such as visual schedules or bedtime storybooks with pictures, can significantly enhance understanding and predictability. This approach is particularly beneficial for children who are deaf or hard of hearing, providing clear, accessible cues.

    Furthermore, Willcocks [20] emphasizes the importance of not rushing the bedtime routine and advises allocating 30 minutes for the sleep routine to prepare the child for going to sleep.

11. **Avoidance of Electronic Devices**: It is crucial to avoid electronic devices before bedtime, especially those emitting blue light. Blue light suppresses melatonin production, making it harder for children to fall asleep. Therefore, a new design requirement emerges: "The product should not emit blue light when a light source is used."

2.3.3 Methods aiming to solve behavioral childhood insomnia

This section explores effective methods proposed to mitigate behavioral insomnia in children, as discussed in the literature review in Section 2.1. These methods aim to establish structured approaches that foster self-regulated sleep patterns, which are crucial for promoting the overall well-being and development of children. Addressing significant sleep challenges is essential, as persistent sleep disturbances can have profound impacts on children's physical health, cognitive function, and emotional stability.

12. **Unmodified Extinction**: This method involves refraining from attending to a child's cries during the night, except in cases of illness or imminent danger. By allowing the child to self-soothe and learn to fall asleep independently, unmodified extinction aims to promote self-regulated sleep patterns [18, 25]. This approach encourages the development of skills necessary for maintaining consistent and rest-

ful sleep throughout the night, which is crucial for overall well-being and daytime functioning.

13. **Graduated Extinction**: Similar to unmodified extinction, graduated extinction includes scheduled check-ins to reassure the child without fully attending to their cries. This approach introduces a gradual reduction in parental intervention during nighttime awakenings, helping the child to learn self-soothing techniques gradually [18]. While somewhat less strict than unmodified extinction, graduated extinction remains effective in addressing behavioral childhood insomnia by encouraging the development of independent sleep habits over time.

    These methods represent important steps forward in understanding and addressing behavioral childhood insomnia. Further research is needed to explore additional effective strategies and refine existing approaches to better support children's sleep health.

2.3.4 Theories and specifically crafted toys to aid children in falling asleep, guiding them through their sleep, or supporting their sleep routines

14. **Visual sleep routine**
    Consistent schedules are emphasized by Clarke et al. [21], the National Deaf Children's Society [22], and Willcocks [20]. Willcocks [20] recommends using visual schedules to prepare and clarify the sleep routine for the child, while the National Deaf Children's Society [22] goes along with this but adds that the visuals should consist of pictures. Furthermore, Willcocks [20] emphasizes the importance of not rushing the bedtime routine and advises allocating 30 minutes for the sleep routine to prepare the child for going to sleep.
    (this is also mentioned in the literature review)

15. **Mobile in Crib**
    Using a mobile in the crib is a common option parents use to create a soothing environment for their child to fall asleep. It provides the child with visual and sometimes audio stimulation. Mobiles often feature gentle music, rotating toys, or soft lights to calm infants and encourage them to drift off to sleep peacefully. However, it's important to note that each child responds differently. The client shared that while she initially introduced a mobile in her child's crib as a soothing aid, her child became frightened and started crying when it was turned on. The child found the movements and sounds of the mobile unsettling and perceived them as scary. This experience highlights the importance of understanding and respecting each child's comfort and preferences when introducing sleep aids.

Figure 2.5: Example of a mobile that can hang above a crib.

16. **Sleep trainer**

ZAZU [35] offers multiple sleep trainers, one of which is Brody the bear. Brody's stomach lights up in different colors to indicate the time, see figure 2.6: red during the night to signal that the child should sleep, orange in the morning, and green when it is time to get up. Brody can also play a variety of calming music, including lullabies, white noise, and African sunset sounds. The music automatically switches off after 10 minutes.

Additionally, Brody features a cry sensor. When the child wakes up at night and starts crying, Brody lights up his belly and plays music. This responsiveness to the surroundings is particularly beneficial for deaf and hard-of-hearing children. While they may not always hear the calming music, they can see Brody's belly light up, providing them with a sense of control and understanding of the situation. This is especially helpful since not all young children know how to read a clock.

Another interesting sleep trainer that ZAZU offers is Pam the Penguin, see figure 2.7, which works similarly to Brody.

Figure 2.6: ZAZU sleep trainer Brody the bear

Figure 2.7: ZAZU sleep trainer Pam the Penguin

2.3.5 Products Designed Specifically to Facilitate Communication with Deaf and Hard of Hearing Individuals

This section explores various innovative products tailored to enhance communication and safety for individuals who are deaf or hard of hearing. These products not only address specific sensory needs but also aim to improve overall quality of life through enhanced communication and environmental awareness.

17. **HomeSound**

    HomeSound [36] is an in-home sound awareness system that utilizes microphones to detect and classify ambient sounds. These detections are then visualized on a home floor plan (Figure 2.8), providing users with a clear representation of sounds such as doorbells, alarms, or voices. This system enhances situational awareness in everyday environments, which is particularly beneficial for deaf and hard of hearing children during sleep. By visualizing sound sources, HomeSound fosters a sense of connection and control over their surroundings, potentially reducing anxiety. However, the complexity of the user interface may pose a challenge for younger users in fully comprehending the displayed information.

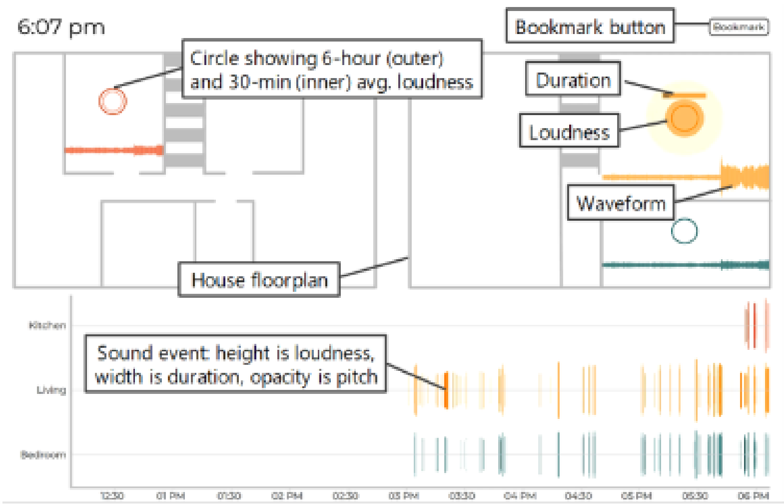

Figure 2.8: Screenshot of HomeSound prototype display

This paper and working system was an inspiration for two potential solutions for the posed problem, concept 1b and 2a that can be found in the ideation phase 4. These two concepts have been very important for the realisation of the final prototypes.

18. **Smart Nocturnal Environment Monitoring System**

    The Smart Nocturnal Environment Monitoring System for the Hearing Impaired [37] utilizes machine learning to detect ambient sounds during sleep, identifying indicative or dangerous situations and triggering vibrations to awaken the user (Figure 2.9). This innovative prototype exemplifies the integration of machine learning in personalized environmental monitoring, crucial for ensuring safety and peace of mind for deaf and hard of hearing individuals during sleep. Such advancements aim to alleviate anxiety by alerting users to potential dangers they might otherwise miss due to their hearing impairment.

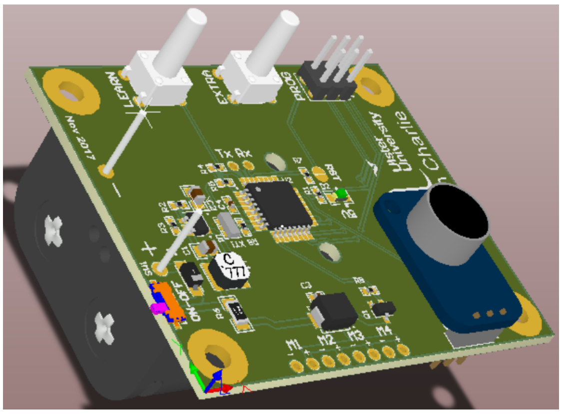

Figure 2.9: Prototype of the Smart Nocturnal Environment Monitoring System

19. **ProxaCare**

    ProxaCare, designed by Eric van Heuvelen, resembles a flower and serves as an alert system for deaf-blind individuals (Figure 2.10). It features a vibrating component that increases as a person or object approaches, providing clear proximity indications.

    During an interview detailed in Section 2.2.3, van Heuvelen underscored the significance of providing visual feedback to users when someone enters the room. To address this need, a practical LED indicator was seamlessly integrated into the flower design. This LED visually alerts individuals whenever the sensor detects their presence, enhancing their awareness of surrounding activities.

    This innovative feature has prompted a new design requirement: "The product should provide users with clear feedback upon detecting and receiving information during communication."

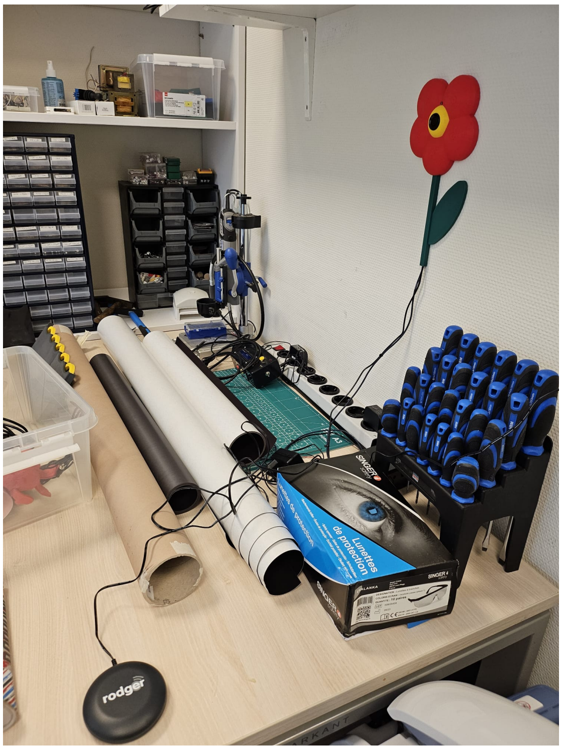

Figure 2.10: ProxaCare alert system

20. **Heartbeat**
    Heartbeat, utilized at Bartiméus [38], is a vital communication tool designed for the deaf-blind community (Figure 2.11). It functions by alerting caregivers when assistance is required, employing tactile feedback through vibrations and signaling proximity through its intuitive design.

Figure 2.11: Heartbeat communication tool

This innovative product has been a source of inspiration for developing solutions within this thesis. It empowers deafblind individuals to independently request assistance, thereby fostering their autonomy in an environment where traditional auditory and visual cues are not accessible.

Autonomy is a central theme in this thesis, particularly as it pertains to enabling children to use a possible solution independently in their bedrooms without reliance on caregivers. This requirement has guided the design principle that "The product should be easy and intuitive for the user to use autonomously."

2.3.6 Summary of useful findings

The state-of-the-art research explored various strategies and products aimed at alleviating anxiety-related sleep issues and addressing poor sleep hygiene in deaf and hard-of-hearing children. Solutions such as weighted blankets, familiar scents, and adjustable night lamps provide targeted approaches to enhance sensory comfort and promote a secure sleep environment. However, these individual solutions do not comprehensively resolve the challenges faced.

Combining these approaches shows promise in offering a more effective solution. Poor sleep hygiene, often worsened by a lack of parental education, presents a significant challenge. The decision to prioritize anxiety reduction over directly addressing poor sleep hygiene stems from its potential to indirectly improve sleep quality. Parental education can be facilitated through resources such as books and workshops, empowering parents with the knowledge to effectively support their children. Given the complexities of parenting theories and practices, focusing on anxiety as a manageable and targeted approach was considered more feasible.

These insights underscore the importance of integrated solutions that consider both anxiety reduction and parental education to foster better sleep hygiene and overall well-being in deaf and hard-of-hearing children. This approach acknowledges the primary role of anxiety reduction in improving sleep outcomes since it seems more manageable.

From the state-of-the-art analysis, several new design requirements emerged to guide the development of effective solutions:

1. Ensuring products are adjustable to personal preferences and needs to maximize user comfort.
2. Including a designated place for storing hearing aids that is visible in the room and illuminated by lights.
3. Avoiding the emission of blue light when a light source is used.
4. Providing users with clear feedback upon detecting and receiving information during communication.
5. Ensuring the product is easy and intuitive for the user to use autonomously.

These design requirements aim to create holistic solutions that address the complex interplay between anxiety, sleep hygiene, and parental support in improving the sleep experiences of deaf and hard-of-hearing children.

2.4 Design requirements found in Background Research

This section summarizes all the design requirements identified in the background research chapter. These requirements are derived from conversations with the client (see subsection 2.2.2), discussions with the assistive technology specialist (see subsection 2.2.3), and evaluations of existing products in the state of the art (see section 2.3). Each requirement is listed and visualized with a prefix indicating its origin, color-coded according to the following legend:

legend (color = __origin__):

- purple = Client
- blue = Assistive technology expert
- orange = self formulated

Design Requirements:

1. (Client - Second interview) The product could be modular, allowing users to add only the necessary components.
2. (Client - Second interview) The product could be sold as a package containing various parts, enabling users to personalize it according to their specific home environment.
3. (Client - second interview) The product might have an intuitive on/off button that the child can easily understand and operate consciously.
4. (Assistive technology expert - Interview) Applying the designed solution should be easy to understand for the target audience who need to apply the solution
5. (Assistive technology expert - Interview) The product might use haptic feedback to provide the user with new information.
6. (Assistive technology expert - Interview) The product does not necessarily need an intuitive on/off button that the child can easily understand and operate consciously.
7. (Assistive technology expert - Interview) The product should contribute to reduction of the child's stress.
8. (Assistive technology expert - Interview) The product should promote a sense of security
9. (Self formulated - State of the art) The product must be adjustable to personal preferences and needs to make the user as comfortable as possible.
10. (Self formulated - State of the art) The product should include a designated place for storing hearing aids that is visible in the room and illuminated by lights.
11. (Self formulated - State of the art) The product should not emit blue light when a light source is used.

12. (Self formulated - State of the art) The product should provide users with clear feedback upon detecting and receiving information during communication.
13. (Self formulated - State of the art) The product should be easy and intuitive for the user to use autonomously.

These design requirements serve as the foundational elements guiding the development of concepts in the ideation phase (see chapter 4) and subsequent stages (chapter 5,6, and 7) . By integrating insights from clients, assistive technology specialists, and evaluations of existing state-of-the-art products, the aim is to ensure that the final product is user-centric, innovative, and effective. This collaboration and thorough research underscore the commitment to creating a solution that is modular, intuitive, and tailored to reduce anxiety and stress while promoting security. As the project progresses, these requirements will be pivotal in shaping a product that meets the diverse needs of its users, reflecting both practical and visionary objectives.

3 METHODS AND TECHNIQUES

The main objective of this graduation project is to design a solution that improves the sleep quality of deaf and hard of hearing children. This is achieved by utilizing various methods and techniques, which are elaborated on in this chapter.

A key approach used intensively throughout this project is the co-design approach, detailed in section 3.1. Additionally, the Creative Technology design process was chosen to follow an iterative and structured approach, as discussed in section 3.2. An ethical reflection was also conducted to address the posed problem and possible solutions ethically, generate new user requirements, and resolve ethical dilemmas. This reflection is partly detailed in section 3.3 and partially in chapter 5: Specification.

Additionally, an explanation of the differences between the ethical cycle, from van der poel et al [39], elaborated on in the ethical reflection and the creative technology design cycle, from Mader et al. [1], will be explained at the end of this chapter in section section 3.4.

3.1 Co-design

At the beginning of 2024, the mother of a child with a hearing disability contacted Ability Tech with a request to develop a product tailored to the needs of deaf and hard-of-hearing children, as outlined in section 2.2.2. Despite her deep understanding of the problem domain, she lacked the technical expertise to bring her ideas to life. During the initial intake session, the Ability Tech team engaged in thorough discussions with the mother, asking detailed questions. It became evident that I could assist her and potentially integrate this project into my graduation work. Given her wealth of ideas and my background as a designer with technical skills, we opted for a collaborative approach, utilizing co-design principles. With the definition of co-design being a collaborative design method where designers collaborate closely with non-designers [40].

Following the intake session, the specifics of the request remained unclear, prompting us to conduct four interviews as documented in section 2.2.2 from the background research. These interviews clarified the design question and several related design requirements. Subsequently, the ideation phase of the creative technology design process commenced (see section 3.2.1 for an explanation), generating numerous concepts. This was followed by the specification phase (see subsection 3.2.2 for an explanation of the phase), where two concepts were developed and tested in an iterative process.

Three rounds of iterative refinement ensued, each involving co-design sessions where the client provided feedback, proposed new ideas and design requirements, and evaluated and tested the prototypes again. Further details about these specific co-design sessions can be found in the specification phase in chapter 5.

Throughout these co-design sessions, we utilized the Design Your Life toolkit [41], originally designed by a team from the University of Twente and HAN University of Applied Sciences. Originally intended for young autistic adults to create and adapt their own supportive technological environments, promoting independence and autonomy in daily life. However, the toolkit proved highly adaptable and beneficial in our context as well.

After three iterations of improving the prototypes, the realization phase emerged, where the final two prototypes were refined. Subsequently, an evaluation (see subsection 3.2.4 for an explanation of this phase) took place where all the design requirements throughout the process, including those from experts, ethical cycle, etc., were assessed. A midday nap test was conducted to further test these design requirements, as detailed in the evaluation phase (look at section 3.2.4 for an explanation of this phase).

This marked the conclusion of our design process, where a happy, proud, and satisfied client was pleasantly surprised with the outcome of this co-design process.

3.2 A Creative Technology Design Process

The Creative Technology Design Process, as described by Mader et al. [1], guided this project. This process consists of four phases: Ideation, Specification, Realisation, and Evaluation shown in Figure 10.2. Subsequently, a conclusion, discussion, & future work chapter will elaborate on the overall reflection on the research questions posed in the introduction of this thesis through the evaluation of these four phases.

In the following subsection, the Creative Technology Design Process will be explained in detail for each phase. This will include the approaches used and actions taken to provide a clear overview of the methodology employed and its implementation.

3.2.1 Ideation Phase

The main goal of this thesis is to find solutions that aim to improve the sleep of deaf and hard of hearing children. The ideation phase is crucial for this task, focusing on generating many ideas and then selecting the best ones that are realistic, affordable, effective, easy to use, safe, and ethically acceptable.

Based on insights from a thorough literature review, which highlighted issues such as anxiety due to lack of sensory stimuli during the night and problems with sleep hygiene influenced by inadequate parental guidance, the ideation process aims to develop innovative solutions tailored to these specific challenges.

The Ideation approach that was chosen starts with divergent brainstorming, where a variety of ideas is explored without restrictions, encouraging creativity and considering unconventional approaches. This is followed by convergent brainstorming, where ideas are evaluated carefully against criteria such as feasibility, effectiveness in solving identified problems, cost-effectiveness, ease of use, safety, and ethical considerations.

Through several rounds of brainstorming, ideas were refined to improve their practicality and suitability within the project's resources. This iterative approach ensures that the proposed solutions not only address the identified challenges but also meet ethical standards and are feasible to implement.

At the end of the ideation phase (chapter 4), two promising concepts are chosen for further development in the specifiction phase (chapter 5).

3.2.2 Specification Phase

Building on the ideation phase, where numerous innovative ideas were generated and refined, the specification phase focuses on further developing the two most promising concepts into working prototypes. This phase is critical for detailing design requirements and ensuring the feasibility of the designs through the testing of different technologies.

In the specification phase, the selected concepts are developed into working prototypes. This involves defining technical specifications, user requirements, and other critical details to ensure the feasibility of the design. As described in the co-design section 3.1, multiple iterations of the chosen concepts took place. Initially, it was intended for the client to choose the most promising idea in the first round, but she liked both concepts, so rounds 2 and 3 continued with both.

Each iteration involved creating a prototype, testing it with users and stakeholders, and gathering feedback. Based on this feedback, the prototype was modified and improved. The iterative process was crucial for identifying and resolving issues early, ensuring that the final design was both practical and effective. The specification phase involved three rounds of prototyping:

- The first round focused on rapid low-fidelity prototyping. The goal was to quickly develop simple models to explore fundamental concepts, test the functionality of technological components, and gather initial feedback.
- The second round involved semi-rapid and mid-fidelity prototyping. This round built on the initial models, adding more detail and functionality to the prototypes. Feedback from this round helped refine the design further and identify any remaining issues.
- The final round centered on high-fidelity prototyping with designs nearing the final product stage. These prototypes were highly detailed and functional, closely resembling the envisioned final product. This round ensured that all design requirements were met and that the prototypes were ready for real-world testing.

Furthermore, an interview with an interaction and product designer specializing in interactive systems, content, and adaptations for individuals with communicative, motor, and/or intellectual disabilities [42] significantly enhanced the understanding of regulatory requirements. This input played a crucial role in shaping the development and refinement of the prototypes. Ethical considerations were rigorously addressed during the specification phase, integrating insights from various ethical theories to derive design requirements aligned with ethical values. An ethical cycle was implemented to ensure the ethical integrity of both product solutions.

At the conclusion of the specification phase, a comprehensive list of design requirements was compiled and categorized using the MOSCOW method to ensure that the prototypes met the most important needs of all stakeholders, complied with official regulations, were ethically acceptable and addressed practical considerations. The iterative process not only refined the design but also deepened the understanding of the design requirements, ensuring alignment with the project's goals and constraints. This systematic approach facilitated the development of solutions aimed at enhancing the sleep quality of deaf and hard of hearing children.

3.2.3 Realisation Phase

The realization phase encompassed the detailed documentation of the construction and functionality of the two prototypes. This included thorough explanations of the code, wiring schemes, and other technical details to enable replication by others. A comprehensive list of necessary components was compiled, accompanied by a step-by-step assembly guide.

3.2.4 Evaluation Phase

After three iterations of improving the prototypes, an evaluation was conducted. This evaluation assessed all design requirements formed in the whole design process. A midday nap test was also performed to further validate these design requirements, as detailed in the evaluation phase (refer to section 3.2.4 for details on this phase).

3.2.5 Conclusion and Discussion & Future work

Although not part of the creative technology design cycle, the conclusion and discussion sections are essential for reflecting on the main research question in relation to the four phases explored in this thesis. These sections provide an opportunity to analyze the findings comprehensively and offer insights for future research.

3.3 Ethical reflection

In the specification phase of this thesis, a comprehensive ethical reflection was conducted to critically assess the two proposed concepts as explained in the previous section. This reflection report is titled "Developing an Ethical Solution for Sleeping Problems Encountered by Deaf and Hard of Hearing Children," submitted as part of the Reflection II course within the creative technology graduation curriculum.

The ethical reflection integrates insights from various ethical theories to establish design requirements that align with ethical values regarding my graduation project. An ethical cycle was systematically applied to ensure the ethical integrity of both product solutions. This phase is crucial in the design process, especially since the focus is on developing solutions for vulnerable children, placing high importance on the perspectives of users and stakeholders.

In this section, I will elaborate on a part of this reflection report namely my personal code of ethics, which guides my professional practice in designing technologies for children with disabilities and their caregivers. I will explain how these ethical principles are implemented in the design of the prototypes and discuss their relevance to the overall design process.

The full report, including detailed insights and methodologies applied during the ethical reflection, can be found in the appendix in Section 10.2.

3.3.1 My Own Code of Ethics

In this subsection, I elaborate on my self-written code of ethics based upon to the ”code of conduct” posed in chapter 2 of the book ”Ethics, Technology, and Engineering” written by van der Poel et al. [39], which consists of professional ethical principles that I believe are important as a professional designing technologies for children with disabilities and their caregivers. I will explain how I adhere to these principles and why they are relevant to the design process of the prototypes. A big part of this entire subsection is taken from the reflection report 10.2 that I wrote for Reflection II that is part of the creative technology graduation curriculum.

1. **Legal compliance**: As a designer, I will comply with all legal obligations in the Netherlands related to the development of safe toys for children. All toys produced for children in the Netherlands must meet specific obligations and directives set forth in the Official Journal of the European Union [43], according to The Dutch Food and Commodities Authority [44]. (These EU directives will be elaborated on in the specification phase, chapter 5)Additionally, adequate product testing will be reviewed by the Ethics Committee of Computer & Information Science at the University of Twente [29] before testing the prototypes.

   This principle, based on the code of conduct outlined by The International Council of Design in ”The Professional Code of Conduct for Designers” [45], is essential to producing an ethically sound product. Products must be produced ethically and must be safe, especially for a vulnerable target group like children, who may not always be aware of the consequences of their actions. For instance, if they decide to put the product in their mouth, it should not expose them to toxic substances or electrical hazards.

2. **Client Confidentiality**: As a designer I will respect the confidentiality of my client, ensuring that any private information is protected. I will never expose private information without explicit consent of the client. As a bachelor student doing research at the University of Twente it is an obligation to act responsible and to protect the personal data that is collected [46]. The way information, data and consent

will be collected and protected according to the General Data Protection Regulation, the European privacy law [47]. This will reviewed by the Ethics Committee of Computer & Information Science from the University of Twente [29] before collecting any information, data or permissions. Information letters and consent forms will be used to inform the client and to collect informed consent. This principle, Client Confidentiality, is based on the code of conduct outlined by The International Council of Design's in "The Professional Code of Conduct for designers" [45] and important since the information collected involves very confidential information such as the child's medical diagnoses.

3. **Fair and respectful treatment**: As an engineer, I will treat the participants in my research fairly and with respect, avoiding harassment, discrimination, and injury. This principle is based on the code of conduct outlined in [48].

   A part of the target audience consists of disabled children, and it is important to respect and protect them. They are vulnerable. This should be explicitly taken into account in all aspects of the design and testing processes, ensuring their safety, dignity, and well-being are prioritized at all times.

4. **Transparency and Accountability**: Transparency is crucial throughout my design process as I communicate openly with my client, ensuring they are fully informed. This principle of openness is outlined in the handbook of Ethics, Values, and Technological Design by Hulstijn et al. [49]. Accountability complements transparency by ensuring I take full responsibility for my decisions and actions.

   In my co-design process with the mother of a child with hearing disabilities, transparency is especially important to maintain trust and ensure the well-being of the child. According to the guidelines from the Central Committee on Research Involving Human Subjects [50], the child's mother serves as the legal representative, underscoring the need for clear communication and respect for their decisions.

   Adhering to the Ethics Committee's guidelines at the University of Twente [51], I maintain transparency to prevent any actions against the wishes of the parent or child, fostering a secure and ethical environment.

   These principles shape my design approach by facilitating ongoing dialogue with the client, providing regular updates, and documenting decisions meticulously. By upholding transparency and accountability, I ensure the project aligns with ethical standards and meets the user's needs effectively.

5. **Attribution and Acknowledgement**: As an engineer, I will credit the creators and designers of technologies or parts that I use, and I will avoid plagiarism. This principle is based on the code of Ethics for Engineers written by the National Society of Professional Engineers [52].

   Attribution means giving proper credit to the original creators of any work or ideas that I use in my project. Acknowledgement involves recognizing the contributions of others to my work.

I will ensure that all sources, inspirations, and contributions are properly attributed and acknowledged, reflecting the collaborative nature of engineering work and the respect for intellectual property and effort. Proper citation and acknowledgment of the work of others not only show respect for their contributions but also maintain the integrity of the profession and the advancement of knowledge.

For example, if I utilize a specific design framework or tool developed by another engineer or researcher, I will explicitly mention their contribution in my documentation and presentations. Additionally, if I create something myself and use it for purposes other than my graduation project, I will also mention my own contributions. This practice not only gives credit where it is due but also allows others to trace the origins of certain methodologies and potentially collaborate further.

These principles are relevant to my project as they ensure that all contributions are properly recognized, which is essential for maintaining ethical standards and fostering a collaborative environment. They influenced my design by ensuring that all borrowed ideas and tools are properly credited, and that the contributions of all team members and collaborators are acknowledged.

3.4 Differences of The Creative Technology Design process, of Mader et al. [1], compared to the Ethical Cycle, of Van de Poel et al. [2]

There is a difference between the Ethical Cycle of Van de Poel et al. [2] and the Creative Technology Design process, displayed in figure 10.1 and figure 10.2 in the appendix.

The approach of the 'Ethical Cycle', created by Van de Poel et al. [2], starts with describing the moral problem by asking a moral question that meets three conditions.

1. It must clearly state what the problem is.
2. It must state who has to act.
3. The moral nature of the problem needs to be articulated.

Following that comes the problem analysis, where the relevant elements of the moral problem are described by three important elements.

1. The stakeholders and their interests
2. The moral values that are relevant in the situation.
3. The relevant facts.

(This full ethical cycle is completely worked out in the specification phase)

This is different from the CreaTe design process, which starts with a problem analysis and background research before the actual Creative Technology design process, as displayed in figure 10.2, comes to light. Before the CreaTe design process begins, one must first research the reason for the design question that will be handled in the design process, what exactly is the problem for which something needs to be designed. During the design process one often finds out that moral problems play a role. These were not known at the beginning, at least not in my project. Therefore, it is not possible to describe an ethical problem before it arises.

The approach that I took was to first start following the Create problem analysis steps, where I investigated the design request and the problem that needed to be addressed. During the design process I realised that there are moral problems involved. I then started with taking a look at the Ethical Cycle and conducted a problem analysis again, but this time the 'ethical cycle' problem analysis that is addressing an ethical problem instead of a design question. Then I adjusted my design process to solve the moral problems as much as possible so that the most ethical product is designed in the most ethical way possible.

A big part of this section is taken from the reflection report, full version can be found in section 10.2, this report was an assignment for Reflection II that is part of the creative technology graduation curriculum.

4 IDEATION

This chapter focuses on the ideation phase of the project, aiming to generate innovative concepts and ideas that effectively address the sleep challenges faced by deaf and hard of hearing children. Drawing on insights from the literature review, which identified key factors such as anxiety (resulting from sensory stimulation deficits) and poor sleep hygiene (affected by inadequate parental education). These insights play a crucial role in guiding the development of effective solutions.

In the concept generation phase, various brainstorming methods are employed to transform insights from the background research into practical solutions. The outcomes of this research consistently guide the process, with categories created to prioritize factors contributing to the sleeping difficulties of deaf and hard of hearing children. Addressing anxiety is chosen as a primary focus because the issue of poor sleep hygiene could potentially be mitigated through parental education. Given the extensive and often conflicting theories on parenting, addressing anxiety was selected as a more focused and manageable approach.

Initially, the ideation phase begins with divergent brainstorming, which encourages the exploration of ideas without constraints, including unconventional approaches. Subsequently, concepts for the divergent brainstorming phase are filtered in the convergent brainstorming phase, where they are evaluated against criteria such as feasibility, effectiveness, affordability, usability, safety and ethical considerations. Following this, another round of divergent brainstorming focuses on refining selected concepts, culminating in convergent brainstorming to identify two concepts for further investigation in the specification phase, chapter 5, as final solutions.

4.1 Divergent brainstorming on possible solutions

The ideation phase started with divergent brainstorming, generating a wide array of concepts inspired by the client, research, expert insights, and personal creativity. Various sensory stimuli like taste, smell, and tactile sensations (vibration, texture, pressure, temperature) and light were explored, while audio was not considered. Divergent brainstorming encourages exploring ideas without limits, welcoming unconventional concepts. During this phase, design requirements from background research weren't applied yet. This is done in the specification phase, see chapter 5. However, concepts were categorized based on their goals to ensure they could potentially solve the problem addressed in this thesis.

Addressing anxiety:

Parent detector:

- **Concept 1a**: Connecting a wire to the bed of the child and to one of the parents so that the child always knows where one of their parents is.
- **Concept 1b**: A visualization of the location of the parents and possibly other family members inside the house. This visualization can take various forms, such as a painting, a large ball, text, ”Find My iPhone,” or a ”parentofoon.” The parentofoon is designed for children instead of parents, similar to a baby monitor/babyfoon, allowing the child to see what family members are doing through security cameras in the house.
  This idea was inspired by the analysis of concepts in the state-of-the-art phase, specifically the Home Sound system discussed in section 17.
- **Concept 1c**: Vibrating mat in bed. This consist of a kind of grid of multiple vibration motors. One possibility is that the edge of the mat indicates the direction of a parent. The motor vibrates more intensely when the parent is closer. Another option is that the mat functions as a map of the house, with the motors vibrating in a pattern that mirrors the parents' movements.
  This idea was mostly inspired by the client who's initial idea was to make play mat with vibration motors in it.
- **Concept 1d**: A physical 3D artwork/painting placed on the bedside table. The artwork is composed of numerous rods, each adjustable in height. When mounted on walls, the rods extend to their maximum height. As people move around the house, the rods rise and they lower when no one is present.
- **Concept 1e**: A stuffed animal that can answer questions of the child by communicating via sign language or speech.
- **Concept 1f**: Bracelet that vibrates. Works as a detector. If one of the parents walks towards the child it will vibrate louder. There is a button that the child can press if they want to know where the parent is. If they do not press it there is no vibration, if they press it the vibration is activated.
  This concept was inspired by Heartbeat, see section 20, elaborated on in the state-of-the-art section in the background research.

Ambient sound converter:

- **Concept 2a**: A ball placed next to the bed that shows (through colored LEDs) activities going on outside of the bedroom of the child. Colors are connected to certain activities and the location of the color on the ball to the direction where the sound is coming from. (brightness can be connected to the loudness of the sound)

- **Concept 2b**: Mat in bed that convert ambient sound through vibration and possibly light.
  This idea was mostly inspired by the client who's initial idea was to make play mat with vibration motors in it.
- **Concept 2c**: A stuffed animal that signs what ambient sounds are present. And a little light added to the room otherwise the stuffed animal will not be visible.

Night routine:

- **Concept 3a**: A visualisation of the night routine trough visuals.
  (This already exists nut could be improved.)
- **Concept 3b**: Snoezel room in which sensory stimuli are activated by touch, passage, vibration and the warmth of someones body. The use of hearing and vision is slowly reduced in the process.
  (This already exists but to my knowledge not yet made specifically for deaf and hard-of-hearing children.)
- **Concept 3c**: Mat that child helps to dream away. This will be done trough physicalizing a story by a grid of vibration motors that will be vibrating in a certain pattern.
- **Concept 3d**: A warm weighted blanket.
- **Concept 3e**: Augmented reality / holograms that helps the child to fall asleep/-dream away

Prevent lonelyness;

- **Concept 4a**: A stuffed animal that feels like a friend. Has the warmth of a body and wakes up the child in situations of danger. This stuffed animal is able to communicate with the child through understanding sign and also through speech.
- **Concept 4b**: A stuffed animal mimicking the feeling that the baby felt in the belly when the mother was pregnant

Other:

- **Concept 5a**: Adding light to the hearing aid so that the child feels the autonomy to put it back up again.
- **Concept 5b**: A bracelet with a button that can always page the parents in case of an emergency.
  This concept was inspired by Heartbeat, see section 20, elaborated on in the state-of-the-art section in the background research.

4.2 Convergent brainstorming on possible solutions

In this phase, the concepts generated during the divergent brainstorming session are evaluated and filtered based on criteria such as potential, feasibility, effectiveness, innovation, and affordability. Initially, pros and cons are listed in a table (see Table 4.1). to justify the decisions made during the filtering process (see Subsection 4.2.2). This filtering involves using the table of arguments (pros and cons) and plotting the various concepts on x-y graphs, each with different criteria on the axes. At the end of this section, a conclusion is drawn from these graphs and tables to identify the most appropriate solution to proceed with.

4.2.1 pros and cons per generated concept

All the concepts generated during the divergent brainstorming session are evaluated by examining their pros and cons, as shown in Table 4.1. This evaluation forms the basis for the creation of the graphs in Section 4.2.2. The most appropriate solutions for the posed problem of this thesis are then selected based on these graphs and shown in the conclusion in subsection 4.2.3

Concept	pros	cons	Notes
1a	Provides constant awareness of a parent's location	May be intrusive or uncomfortable for both child and parent	
1b	Allows visual tracking of family members	Privacy concerns: potential technical difficulties	Inspired by Home Sound system in 17
1c	Interactive and engaging for children; can provide comfort	May be complicated to implement; could be overwhelming for some children	Inspired by client's initial play mat idea
1d	Aesthetic and functional: Provides real-time location feedback	Complex to design, potentially unappealing to some children and mechanical components may need regular maintenance to avoid breakdowns.	
1e	Interactive and comforting: uses familiar toy form	Technical challenges in implementing sign language/speech	
1f	Simple and direct feedback: easy for children to use	Limited functionality: could cause constant vibration discomfort	Inspired by Heartbeat, see 20
2a	Provides visual feedback on ambient activities: helps orient the child	May cause distraction and technical implementation challenges	
2b	Converts sound into vibrations/-light, engages multiple senses	May be too stimulating: technical implementation challenges	Inspired by client's initial play mat idea
2c	Combines comfort with functionality: integrates signing and light	Complexity in integrating multiple functions and potential for sensory overload	
3a	Visualizes routine, making it easier for children to follow	Limited innovation, improvements may be marginal	Exists but can be improved
3b	Sensory-rich environment tailored for deaf children	Existing concept, may need significant customization	Exists but not specifically for deaf children
3c	Engages imagination through tactile feedback, helps children relax	Potentially complex to implement	
3d	Provides warmth and comfort, proven to help with anxiety	Weighted blankets may not be suitable for all children	
3e	Innovative use of AR/holograms to aid sleep	High-tech solutions may be expensive, potential exposure to screen light	Ensure no blue light is used
4a	Combines warmth, communication, and safety features	High complexity, may be technically challenging. Using heath should be safe	
4b	Mimics comforting prenatal sensations	Concept may be abstract and challenging to implement	
5a	Enhances autonomy, encourages use of hearing aids when the child wants to	Limited scope	
5b	Provides a simple emergency communication method	Limited functionality, may cause unnecessary alarms	Inspired by Heartbeat, see 20

Table 4.1: Overview of pros and cons of the generated concepts

4.2.2 Filtering using graphs

All the concepts generated during the divergent brainstorming session are evaluated by examining their pros and cons, as shown in Table 4.1. The pros and cons will be evaluated in this section and will be placed on a graph looking at different important factors such as feasibility, effectiveness, affordability, usability, safety and ethical considerations. The most appropriate solutions for the posed problem of this thesis are then selected based on these graphs and supported in the conclusion in subsection 4.2.3.

The created graphs can be interpreted as follows: each axis represents a variable. The concepts are plotted on this x-y plane, where the bottom left indicates a very low (poor) value, and the bottom right indicates a very high (good) value for the different concepts. In the conslusion, see subsection 4.2.3, an overall answer on the analysis of the three graphs will be provided.

The first graph, shown in Figure 4.1, compares **feasibility** and **effectiveness** for every concept mentioned in section 4.1. Feasibility is considered both in terms of technical difficulty relative to my skills and in general, based on available technology. Effectiveness measures the solution's impact on solving the problem. These factors are of great importance in the filtering process.

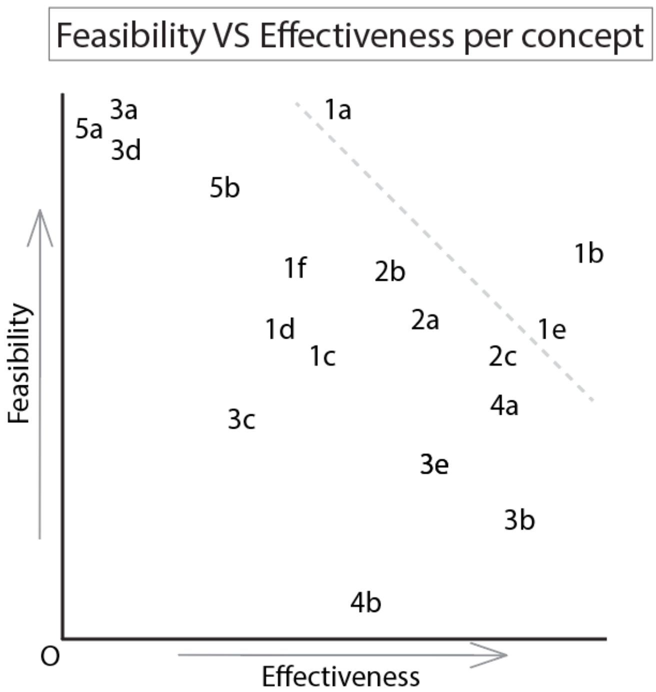

Figure 4.1: Concepts plotted on the feasibility versus effectiveness plot

Looking at figure 4.1, it is noticeable that there are almost no concepts positioned in the top right corner, indicating high feasibility and high effectiveness. However, concepts 1a, 1b, and 1e stand out as the most feasible and effective solutions among all the concepts. The separation of these concepts is indicated by a grey dashed line.

The second graph, shown in Figure 4.2, compares **affordability** and **usability** for every concept mentioned in section 4.1. Affordability refers to the cost of the product, while usability assesses the ease of use for the child. These factors are of great importance in the filtering process.

Looking at figure 4.2, it is noticeable that there are a lot concepts positioned in the top right corner, indicating high a affordability and high usability.

However, concepts 1a, 1b, 1f, 2a, 2b, 3a, 3c, 5a, and 5c are notably the most affordable and usable solutions among all concepts. The separation of these concepts is indicated by a grey dashed line.

The third graph, shown in Figure 4.3, compares **safety** and **ethical considerations** for every concept mentioned in section 4.1. Safety refers to the level of possible risk or harm, while ethical considerations pertain to privacy and what is morally acceptable. These factors are of great importance in the filtering process.

Looking at figure 4.3, it is noticeable that there are a lot concepts positioned in the top right corner, indicating high a quite high safety and high ethical consideration, and no concept in the rest of the graph accept for concept 1a.

However, concepts 1b, 1f, 2a, 3a, 3e, 4b,5a and 5b. are notably the most safe and ethical solutions among all concepts. The separation of these concepts is indicated by a grey dashed line.

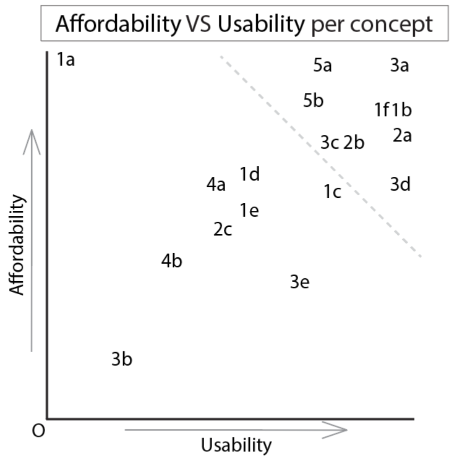

Figure 4.2: Concepts plotted on the affordability versus usability plot

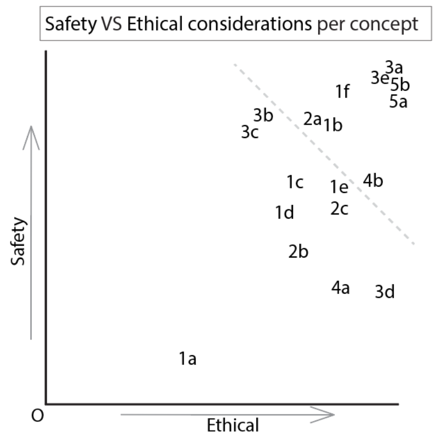

Figure 4.3: Concepts plotted on the safety and ethical consideration plot

4.2.3 Conclusion

Looking at all three graphs, the four concepts that stand out the most are concepts 1b, 1e, 2a, and 2c. Concept 1b, which visualizes the location of family members in the house, is consistently placed above the grey dashed line in all three graphs. Concept 2a, a ball placed next to the bed that shows activities outside the child's bedroom through colored LEDs, appears above the grey line twice and once close to it. Concept 2c, a stuffed animal that indicates ambient sounds and includes a small light to ensure visibility, is positioned once in the middle of the plot, once very close to the grey line, and once above the grey line. Concept 1e, a stuffed animal that can answer the child's questions via sign language or speech, is found once above the grey line, once very close to it, and once in the middle of the plot (when considering usability and affordability). None of these concepts are extreme outliers near the origin of the plot. Therefore, these concepts are chosen as the four most potential solutions for the problem posed in this thesis.

Concept 3a is also ranked quite high but is not considered a special approach, as it focuses on improving parent education on sleep hygiene. Thus, it was not chosen as a potential solution. Similarly, concept 1f ranked high, but since a product similar to it already exists, it was not selected to continue. Finally, concept 5a also ranked high, but its effectiveness is very low, leading to its exclusion.

4.3 Divergent brainstorming on chosen concepts

The concepts identified in the conclusion of subsection 4.2.3 are potential solutions for the problem posed in this thesis. In this subsection, these potential concepts will be elaborated on in more detail to clarify their components and functionalities.

Concept 1b: Visualization of the location of family members in the house.

Visualizing the location of family members inside the house can provide a child with a sense of control, allowing them to ”hear” and now see who is near them and who is not. This visualization can take various forms, which will be explored through a divergent brainstorming session to generate creative ideas for functionalities, layout, technical approaches, and more.

The primary goal is to address the sleeping difficulties faced by deaf and hard-of-hearing children. By placing this product inside the bedroom, the child can feel less scared when they want to sleep. Research conducted in the background study showed that most children seek closeness to other family members, and visualizing their presence can offer reassurance and comfort. This brainstorming aims to develop a comprehensive solution that not only addresses the technical aspects but also meets the emotional needs of the child.
A concept drawing is shown in figure 4.4.

Possible functions of the ”Family Locator”:

- The Family Locator should visualize the activity/location of family members.
- The device should not disturb the child when they want to sleep, so it needs an on/off switch and a dimmer knob.
- The device might include a feature to show the last known location of a family member if they are not currently detected.
- The device that family members carry with them should operate passively, allowing users to be tracked in the background.

Tracking system of the ”Family Locator”:

- The system tracks the location of family members via their phones. Phones are usually near the user and thus a simple background method to use.
- Family members carry a remote that tracks their movement through the house using IR signals. Each room has an IR transmitter that sends a signal indicating its location. The remote receives this signal from the transmitter in the current room and sends the location data to the child’s user interface.
- An AirTag could be used to track each family member. They can carry it in their pocket or attach it to their keychain.
- Each family member has a remote in their pocket. When they move out of a room, they press a button to notify the system that they are leaving and entering another room.
- The system could utilize a combination of Wi-Fi and Bluetooth signals to triangulate the position of family members within the house.

Possible layout of the ”Family Locator”:

- Locations could be visualized on a painting with a map of the house.
- Locations could be displayed in text on a digital screen.
- Locations could be visualized on a large TV screen.
- Locations could be displayed using LED lights to indicate the presence of family members in different rooms.
- A 3D model of the house could be used to show the real-time positions of family members.

Possible locations to Place the ”Family Locator”:

- Hang it on the wall.
- Place it on a bedside table.
- Lay it inside the bed.
- Hang it on the bed frame.
- Attach it to the door of the room.
- Place it in an open closet.
- Mount it on the ceiling for a better overview of the room.

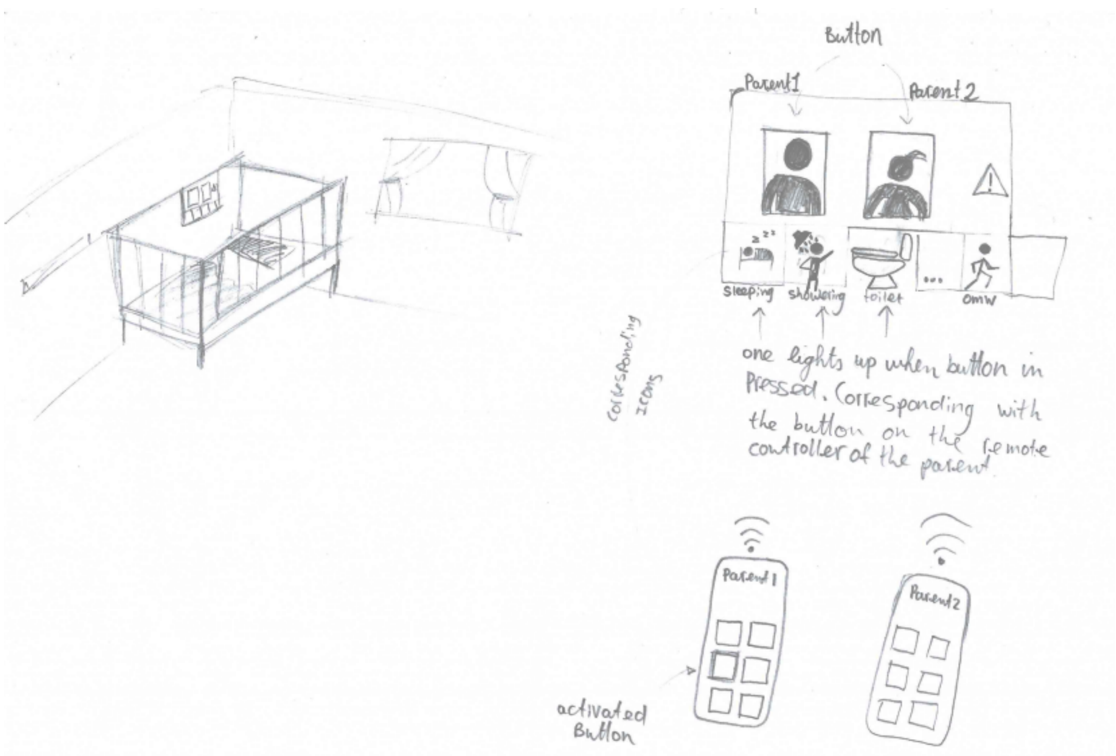

Figure 4.4: Concept drawing of concept 1b - ”The Family Locator”

Concept 1e: Stuffed animal that can answer questions of the child by communicating via sign language or speech

A stuffed animal that can answer questions of the child by communicating via sign language or speech can provide comfort and a sense of companionship. This concept uses the favorite stuffed animal of the client to create an interactive experience that can address the child's need for communication and reassurance, especially before or during bedtime. This realisation will be explored through a divergent brainstorming session to generate creative ideas for functionalities, layout, technical approaches, and more.

The primary goal is to address the sleeping difficulties faced by deaf and hard-of-hearing children. By integrating communication capabilities into a familiar and beloved stuffed animal, the child can feel more secure and understood. Research conducted in the background study showed that most children seek closeness to family members to feel safe. They often feel isolated in their bedroom, but having a companion, a stuffed animal, that can communicate—can help alleviate this loneliness. This interactive toy can provide a sense of connection to the world beyond their room, offering reassurance and comfort. A concept drawing is shown in figure 4.5.

Possible functions of the "Interactive Communicating Stuffed Animal":

- The stuffed animal should communicate using both sign language and speech.
- It should be able to answer simple questions and provide comforting messages.
- The toy should have an on/off switch to prevent disturbances during sleep.
- It might include a feature to help the child with their sleep routine.

Technical components of the "Interactive Communicating Stuffed Animal":

- The stuffed animal will have a display in the stomach area to show sign language gestures, similar to a Teletubby.
- It will be equipped with a speaker for verbal communication.
- A microphone will allow the child to ask questions or give commands.
- A camera will help the toy recognize the child's gestures and facial expressions.
- The system could utilize AI to understand and respond to the child's queries.

Possible layout of the "Interactive Communicating Stuffed Animal":

- The display could be seamlessly integrated into the stuffed animal's stomach area.
- The speaker and microphone can be discreetly placed to maintain the toy's aesthetic appeal.
- The camera can be integrated into the eyes or forehead of the stuffed animal.
- The stuffed animal could sign using their hands.
- The stuffed animal could show sign sign language or pictograms on their display.

Possible locations to place the ”Interactive Communicating Stuffed Animal”:

- The stuffed animal can be placed on the child’s bed.
- It can be positioned on a bedside table.
- The stuffed animal can be held by the child during bedtime.
- It can also be placed in a crib or on a shelf within the child’s reach.

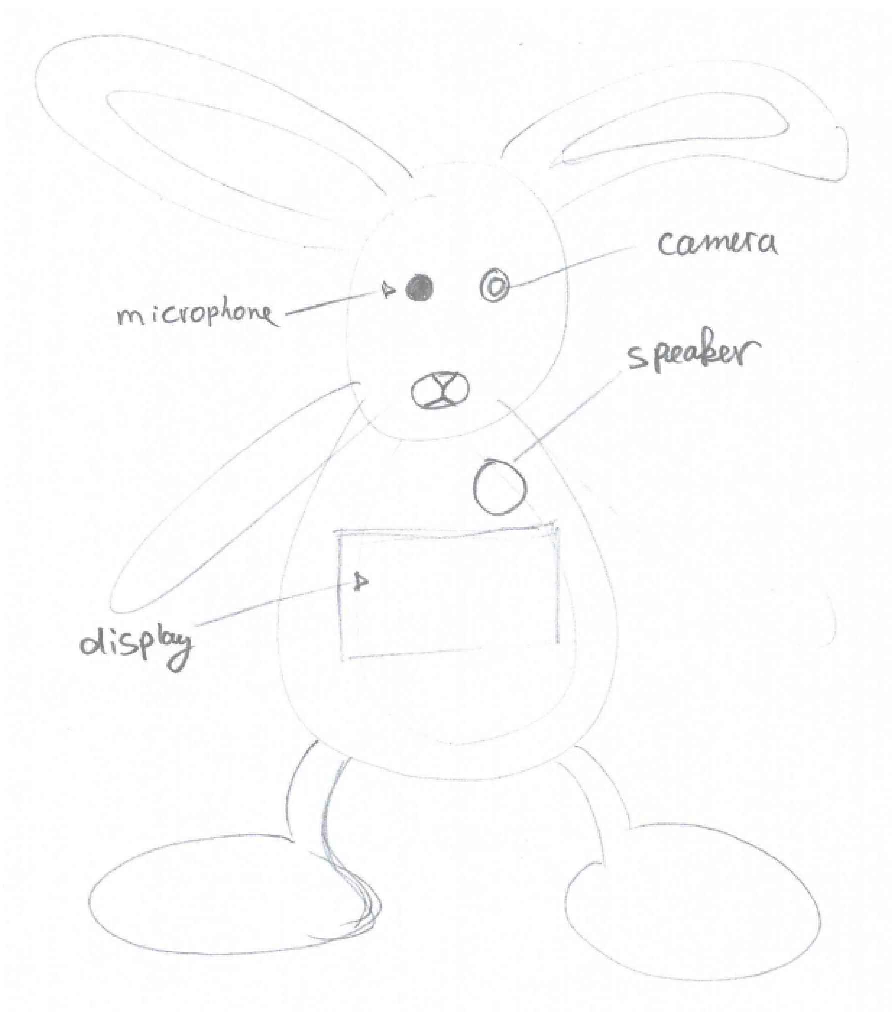

Figure 4.5: Concept drawing of concept 1e - ”Interactive Communicating Stuffed Animal”

Concept 2a: Ball placed next to the bed that shows (through colored LEDs) activities going on outside of the bedroom of the child

A ball placed next to the bed that shows, through colored LEDs, activities going on outside of the child's bedroom can provide a sense of awareness and security. This concept uses visual indicators to represent ambient sounds, helping the child understand what is happening around them without needing to hear. This visualization will be explored through a divergent brainstorming session to generate creative ideas for functionalities, layout, technical approaches, and more.

The primary goal is to address the sleeping difficulties faced by deaf and hard-of-hearing children. By integrating an ambient sound visualizer into the child's room, the child can feel more connected to their surroundings and feel less isolated. This device can offer reassurance and comfort by visually representing sounds from outside the bedroom. A concept drawing is shown in figure 4.6.

Possible functions of the ”Ambient Sound Visualizer”:

- Microphones could be used to capture ambient sounds from various directions.
- The visualizer may consist out of many LEDs that are individually addressable.
- The brightness of the LEDs will correspond to the volume of the sound.
- The color of the LEDs could be connected to the frequency of a certain sound.
- The location where LEDs light up shows the direction and location from which the sound is coming.
- AI could be used to identify sounds and visualize them accurately.

Technical components of the ”Ambient Sound Visualizer”:

- High-sensitivity directional microphones to capture ambient sounds accurately.
- Individually addressable LEDs for detailed visual representation.
- Volume-sensitive brightness control for the LEDs.
- Frequency-sensitive color control for the LEDs.
- Direction controlled LED lighting to indicate the source of the sound.
- AI algorithms to process and identify different sounds.

Possible layout of the ”Ambient Sound Visualizer”:

- The visualizer could be designed as a ball that can be placed next to the bed.
- The LEDs can be arranged in a clear pattern, a square grid, that allows for clear visualization of sound direction and frequency.
- It could be visualized as a pentagon or hexagon cylinder.
- It could be visualized on a Cube.
- it could be visualized on a painting with a map of the house or the child's bedroom.

Possible locations to place the ”Ambient Sound Visualizer”:

- On a bedside table.
- On the bed near the child’s pillow.
- Attached to the bed frame.
- On a shelf within the child’s view.
- Mounted on the ceiling.
- On the door of the room.
- In the center of the room.
- Mounted on the wall.
- On the floor, visible from above.

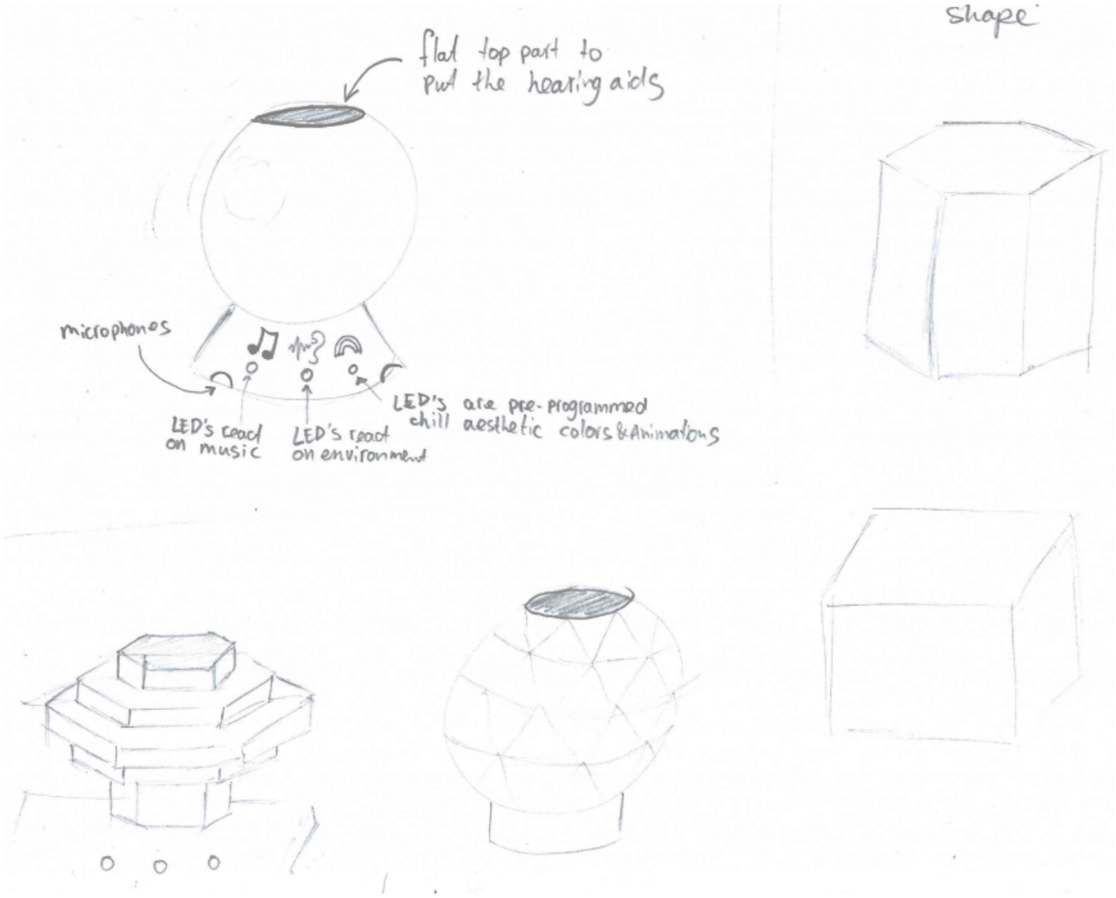

Figure 4.6: Concept drawing of concept 2a - The Ambient Sound Visualizer

Concept 2c: Stuffed animal that signs what ambient sounds are present. And a little light added to the room otherwise the stuffed animal will not be visible

A stuffed animal that signs what ambient sounds that are present, with an added light to ensure visibility, can provide a comforting and interactive way for deaf and hard-of-hearing children to understand their environment. This concept uses a familiar stuffed animal, the stuffed animal of the child of the client, to convey information about surrounding sounds through sign language, offering both companionship and situational awareness. This approach will be explored through a divergent brainstorming session to generate creative ideas for functionalities, layout, technical approaches, and more.

The primary goal is to address the sleeping difficulties faced by deaf and hard-of-hearing children. By integrating a communication feature into a beloved stuffed animal, the child can feel more secure and less isolated. Research conducted in the background study showed that children often feel isolated. Having a stuffed animal that can communicate ambient sounds through sign language can alleviate feelings of loneliness and provide a sense of connection to the outside world. This brainstorming aims to develop a comprehensive solution that addresses both the technical and emotional needs of the child. A concept drawing is shown in figure 4.7

Possible functions of the "Communicating Ambient Sounds Converting Stuffed Animal":

- The stuffed animal should sign what ambient sounds are present using sign language.
- The stuffed animal should display visualizations of ambient sounds on its screen.
- The stuffed animal should have a light to ensure the signs are visible even in the dark.
- The toy could provide comforting messages or reactions to sounds.
- The stuffed animal should feel warm to mimic the sensation of a living creature.
- The stuffed animal should simulate breathing to enhance the feeling of a living companion.
- The stuffed animal should appear to use a remote to adjust the display, creating an interactive experience.
- An on/off switch to prevent disturbances during sleep.
- A feature to help the child with their sleep routine.

Technical components of the "Communicating Ambient Sounds Converting Stuffed Animal":

- High-sensitivity microphones to capture ambient sounds.
- Servo to mimic breathing and to do sign language.
- Something that outputs warmth/heat.

- Fake remote.
- LED lights to ensure visibility of the signs in low light conditions.
- A display screen, and encasing, for visual cues or additional information.
- Mechanisms for the stuffed animal to perform sign language gestures.
- AI algorithms to process and identify different sounds.
- A speaker for audio feedback if needed.
- A rechargeable battery to power the components.

Possible layout of the ”Communicating Ambient Sounds Converting Stuffed Animal”:

- The LED lights could be integrated around the stuffed animal’s hands and face for clear visibility of signs.
- A small screen could be embedded in the stomach area or next to the bunny (as real television) for additional visual cues.
- The microphones and speakers can be discreetly placed to maintain the stuffed animal’s aesthetic appeal.
- The mechanisms for sign language gestures could be built into the arms and hands.
- The design should ensure that all components are safely enclosed within the stuffed animal.

Possible locations to place the ”Communicating Ambient Sounds Converting Stuffed Animal”:

- On the child’s bed.
- On a bedside table.
- In the child’s arms during bedtime.
- On a shelf within the child’s view.
- In the bed of the child.
- On a chair or other furniture near the bed.

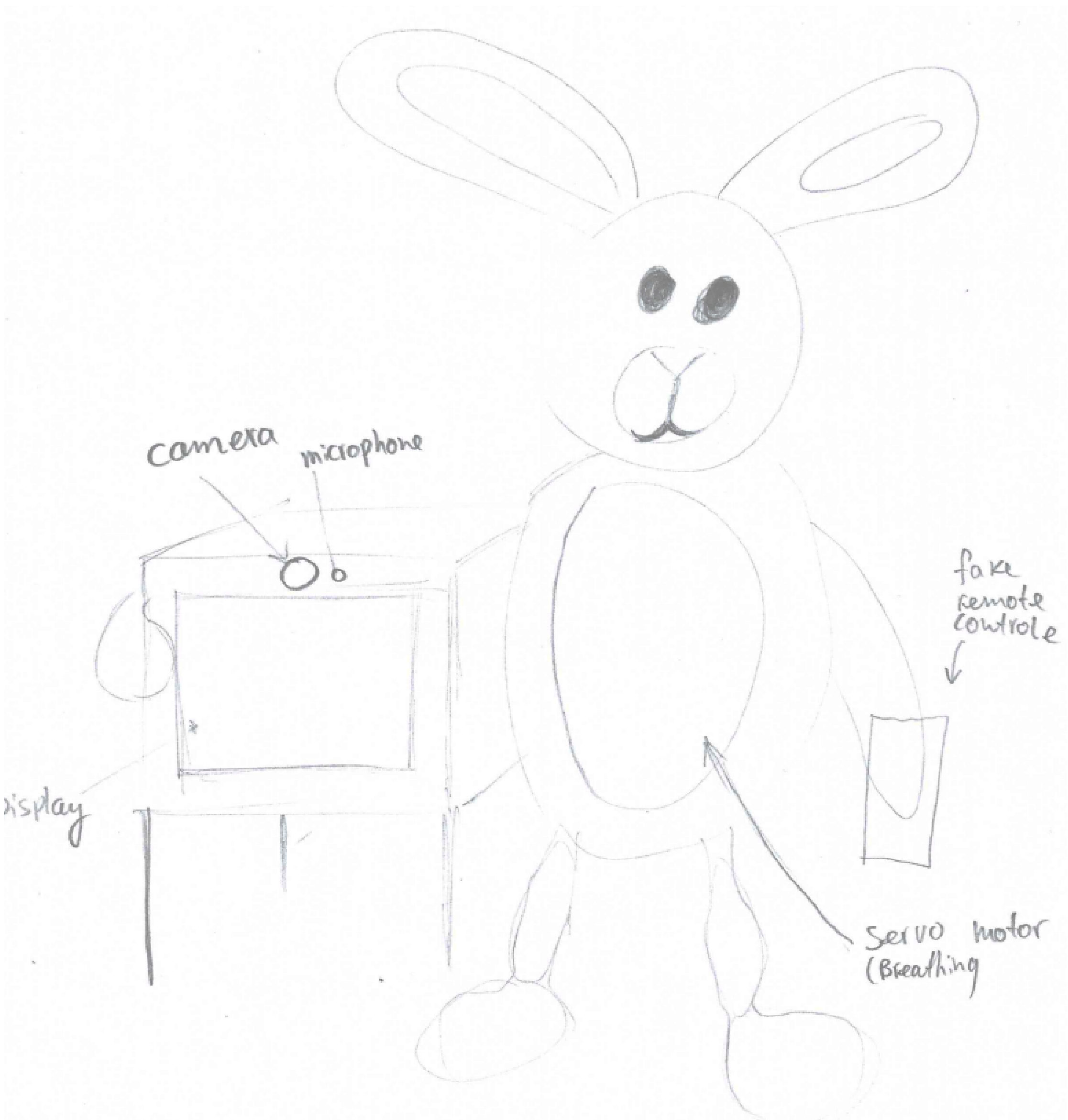

Figure 4.7: Concept drawing of concept 2c - Communicating Ambient Sounds Converting Stuffed Animal

4.4 Convergent brainstorming on chosen concepts

In this section, a choice will be made among the four proposed concepts to determine the most suitable options for further development. After careful evaluation, Concept 1b: Family Locator and Concept 2a: Ambient Sound Visualizer emerge as the strongest candidates. Both concepts effectively address the sleeping difficulties faced by deaf and hard-of-hearing children by promoting a sense of security and connection within their home environment. The Family Locator provides visual reassurance of family members' presence, alleviating feelings of isolation during nighttime. Meanwhile, the Ambient Sound Visualizer fosters awareness of surrounding activities through visual cues, helping children feel more engaged with their environment.

Concept 2c: Communicating Ambient Sounds Converting Stuffed Animal presents an innovative idea. However, it faces significant challenges in effectively implementing sign language recognition and the necessary mechanical functionalities. The integration of heating elements and moving parts raises potential safety concerns, which complicates its practical application.

Similarly, Concept 1e: Interactive Communicating Stuffed Animal also shows promise, but the complexities involved in achieving reliable communication through both sign language and speech, combined with the technical demands, render it less suitable for further development at this stage.

Ultimately, the Family Locator and Ambient Sound Visualizer not only align with the project's goals but also represent achievable solutions that directly respond to the emotional and practical needs of the target audience. By fostering connection and enhancing security, these concepts hold the potential to significantly improve the bedtime experience for deaf and hard-of-hearing children.

5 SPECIFICATION

This graduation project focuses on designing a solution to enhance the sleep quality of deaf and hard of hearing children. The specification phase marks a pivotal transition from ideation to developing two promising concepts into functional prototypes.

The ideation phase, informed by insights from a thorough literature review, identified key issues such as anxiety from sensory deficits and poor sleep hygiene exacerbated by limited parental education. The specification phase aims to translate these insights into viable solutions.

Initially, the specification phase aimed to select one concept after the initial prototyping phase based on client feedback. However, both concepts received positive reception, prompting continued development through rounds two and three. This iterative process allowed for comprehensive user testing, refinement, and integration of feedback from users and stakeholders.

This specification phase consists of two initial phases of technical prototyping conducted and three rounds of prototyping, each evaluated by the client. Throughout these iterative phases, ongoing discussions between the client and designer are crucial for generating ideas and collaboratively refining design requirements. The first round focuses on rapid low-fidelity prototypes to explore core concepts, test technological functionalities, and gather initial feedback. Progressing from there, the second round advances to semi-rapid and mid-fidelity prototypes, aimed at enhancing detail and functionality based on initial testing feedback. Finally, the third round concentrates on high-fidelity prototypes approaching the final product stage, ensuring thorough clarification of all design requirements and preparing for field testing.

Additionally, insights from an interview with an interaction and product designer specializing in adaptive technologies have informed regulatory requirements and guided prototype refinement. Ethical considerations have been rigorously addressed, integrating insights from ethical theories to ensure alignment with ethical values.

At the conclusion of the specification phase, a comprehensive set of design requirements will be established and prioritized using the MOSCOW method. These requirements aim to meet stakeholder needs, comply with regulatory standards, uphold ethical principles, and address practical considerations. The iterative nature of the specification process not only refines prototypes but also deepens the understanding of design requirements, ensuring alignment with project goals and constraints.

5.0.1 First phase of initial technical testing for Prototyping

Before beginning the prototyping phase, it was essential to research the various technologies available and assess their feasibility. Initially, two separate, very low-fidelity prototypes were created to explore potential solutions.

Ambient Sound Visualizer

The first prototype, an ambient sound visualizer, consisted of a glass ball, an individually addressable LED strip, cushion stuffing, and an Arduino Uno connected to a potentiometer. Figure 5.1 illustrates this prototype, showing different states with varying colors on different locations on the ball. Figure 5.2 shows the potentiometer knob that allowed the settings of the LEDs to change after rotating, demonstrating multiple states. This prototype served as a demonstration tool for the ”Storytelling through Oral Presentation” course, part of the graduation curriculum in Creative Technology.

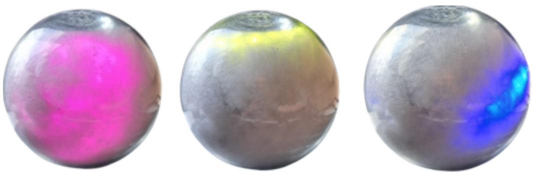

Figure 5.1: Very first demo version of the Ambient Sound Visualizer with different states showing different colors on different locations on the ball.

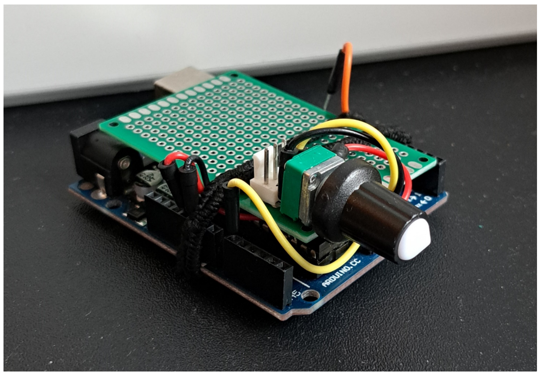

Figure 5.2: Soldered prototype board with a potentiometer and LED strip attachment point connected to an Arduino Uno, part of the first version of the ambient sound visualizer.

The individually addressable LEDs were easy to use and the demonstration for the ”Storytelling through Oral Presentation” course was clear to the audience. A microphone in the Ambinet Sound Visualizer was not incorporated at this stage. Instead, the potentiometer simulated different situations using the Wizard of Oz method.

Family Locator

The second prototype developed during the initial technical testing phase was the Family Locator. Multiple tests were conducted using ESP-NOW (a library that handles local WiFi connections between two ESP32 modules) and infrared (IR) transmitters and receivers.

The first test for IR communication was performed using an Arduino Uno connected to a breadboard with a receiver and transmitter placed directly next to each other (see Figure 5.3). This setup worked very well, only correct hex codes were received. The next step involved testing on an ESP32, but issues were encountered with the transmitter. Although a suitable library was found for the receiver, the transmitter did not function correctly. Consequently, a switch to Arduino Nano was made for the transmitter (see Figure 5.5), which functioned correctly. However, the processing of the signal was really slow and the received signals were not very reliable, incorrect hex codes were occasionally received, and the transmitter had to be in a stable position, precisely pointed at the receiver, to ensure it received a value. These transmitter and receiver components were very cheap, which might explain their unreliability.

Despite these challenges, a decision was made to continue with IR technology because its signals can pass through fabrics but not walls, making it suitable for the intended application.

Additionally, ESP-NOW was tested to facilitate communication between a remote device carried by family members and the user interface in the child's room. A relay device was also considered to ensure signal transmission to the user interface from all locations. The setup was tested successfully, providing stable communication even over a long distance of 10 meters, despite the presence of a tiled concrete wall. A potentiometer was used to send multiple values from one ESP32 to another via local WiFi, demonstrating reliable performance.

The final version of the receiver is shown in Figure 5.6, with a red LED that lights up when the correct signal is received. Figure 5.5 shows the final version of the transmitter.

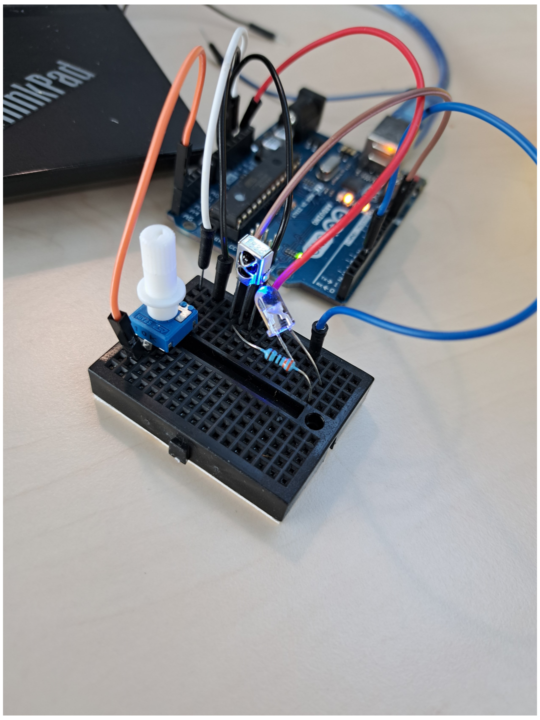

Figure 5.3: Arduino Uno setup with potentiometer IR receiver and transmitter to send and receive multiple IR hex codes.

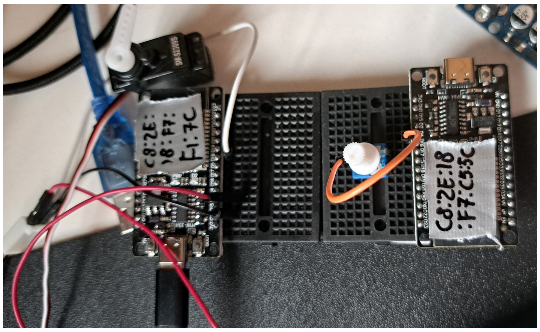

Figure 5.4: ESP now testing setup with potentiometer and two ESP's and their mac adresses. The potentiometer could be turned around to send different hex codes.

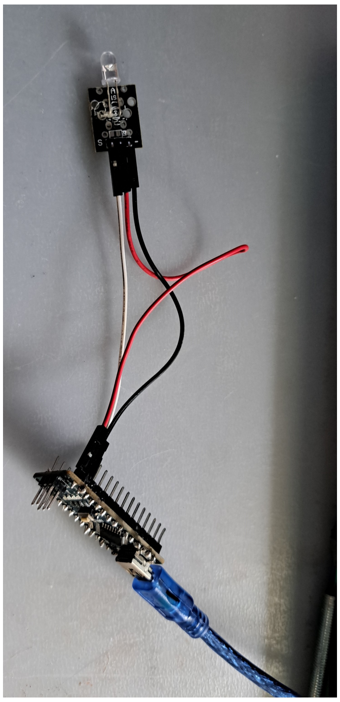

Figure 5.5: IR transmitter connected to a arduino Nano

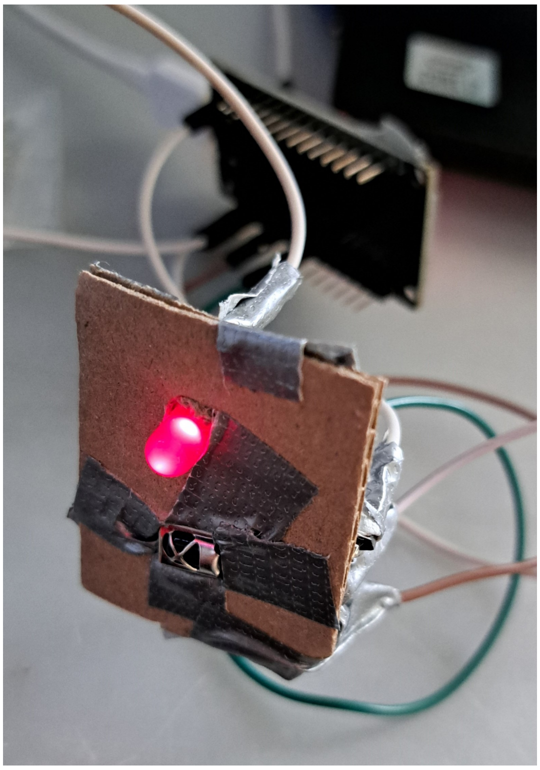

Figure 5.6: Semi final esp 32 receiver with led that lights up when correct signal is received

5.0.2 Following second phase of initial Technical Testing for Prototyping

Before beginning the prototyping phase, it was essential to research the various technologies available and assess their feasibility and to incorporate them. Initially, two separate, low-fidelity prototypes were created to explore potential designs for the posed solutions.

Family Locator

The concept for the Family Locator consists of a tracking device that family members will carry and a user interface that will display the status of all the tracking devices.

In the first phase of initial technical testing, the prototypes were described as follows: The tracking device features an Arduino Nano connected to an IR transmitter. The user interface, in this simplified version, consists of a red 5mm LED and an IR receiver connected to an ESP32. The red LED lights up when the correct hex code is received. To enhance usability during testing, an enclosure was constructed using duct tape and cardboard (see Figure 5.7).

Figure 5.7: Cardboard and duct tape version of the IR transmitter and receiver. The transmitter is on the right and the receiver is on the left.

Several tests were conducted, and while the IR transmitter and receiver functioned correctly, their response time was somewhat slow. However, signals were received, and the LED lit up. Further research indicated that this delay was likely due to the limited processing speed of the Arduino Nano.

Since the duct tape versions were not very sturdy, new designs for a more robust enclosure for the tracking device were developed. The first concept featured an enclosure with a sliding drawer. Both the enclosure and the drawer had openings for the IR receiver, while only the drawer included a hole for the USB power connection. See Figure 5.9 for the initial design drawing of the IR tracking device.

This design was printed, as shown in figures 5.9 and 5.10. Although it fit properly, it was not functional due to the sliding part frequently slipping out of the encasing. To address this issue, an enclosed design was created, as illustrated in figures 5.11 and 5.12.

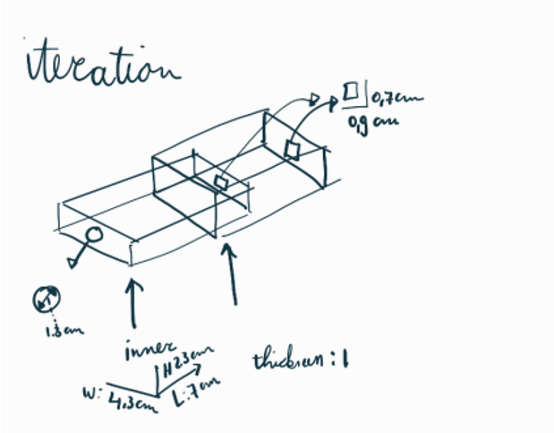

Figure 5.8: Encasing design drawing 1 of the IR tracking device

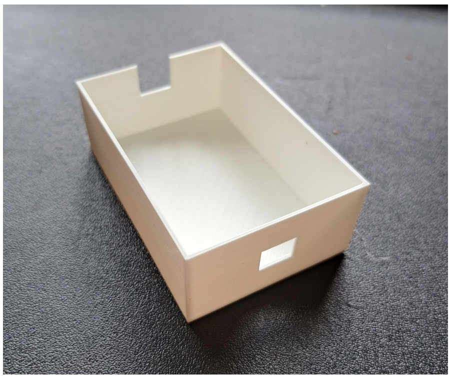

Figure 5.9: Printed version of encasing design 1 of IR tracking device

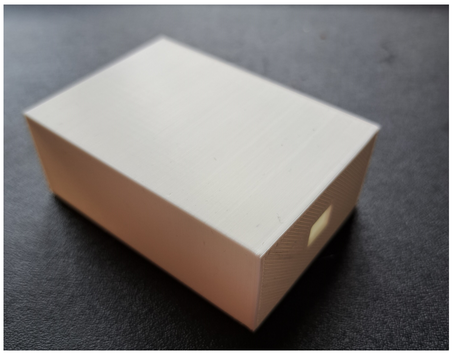

Figure 5.10: Printed version of encasing design 2 of IR tracking device

The second design of the IR tracking device encasing, as shown in figure 5.11 and figure 5.12, was printed successfully, see figure 5.13. While it fit properly, the lid attachment was ineffective, leading to the decision to glue the lid in place instead of making the lid detachable as originally planned.

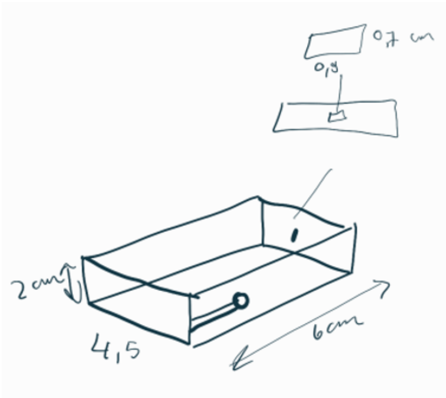

Figure 5.11: Encasing design 2 of IR tracking device

Figure 5.12: Lid of encasing design of IR tracking device

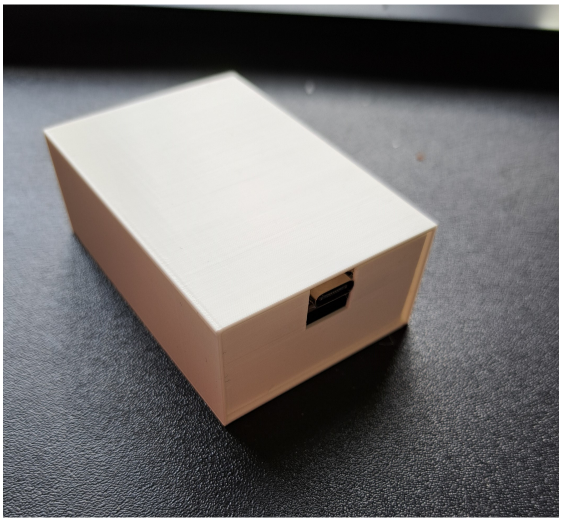

Figure 5.13: Printed version of encasing design 2 of IR tracking device

Additionally, a rapid prototype of the user interface for the receiver was created consisting of four red 5mm LEDs and an ESP32 microcontroller (see Figure 5.15 and figure 5.14). The concept behind this user interface was that the LEDs would illuminate according to the hex code transmitted by the transmitter. The transmitter was programmed to output one of the four hex code IR signals in a structured sequence every five seconds, with the expectation that the corresponding LEDs would light up accordingly.

However, during testing, the expected behavior was not observed. Various tests were conducted, including adjusting baud rates, changing distances between the receiver and transmitter, and testing both stationary and moving positions of the IR transmitter. Despite these efforts, the signals were often missed, and at times, incorrect hex codes were received. This indicated that another approach for this prototype might be better and that the inexpensive sensors might not be suitable for this project.

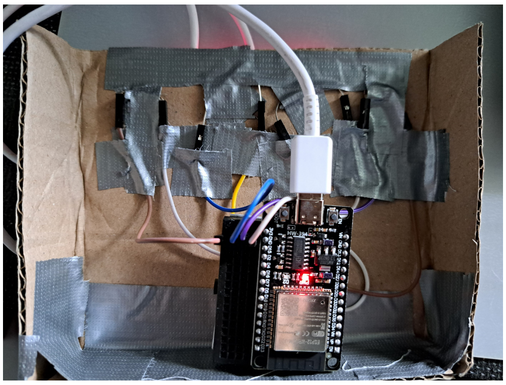

Figure 5.14: Inside of the duct tape and cardboard version 1 of the user interface.

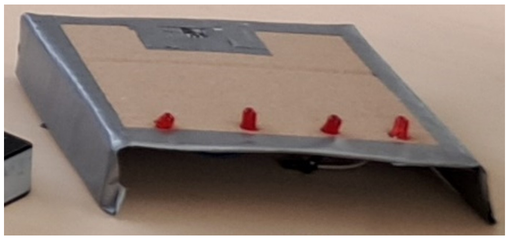

Figure 5.15: Duct tape and cardboard version of the first user interface.

In conclusion, the IR-based tracking device did not perform as expected, and this approach will be excluded from further development. For the initial demonstration to the client, a remote with buttons could be developed as an alternative using the Wizard of Oz technique, with each button representing a different room. Additionally, the user interface can be improved, as the current version is somewhat abstract. Moving forward, exploring different sensors or switching to WiFi communication may provide better performance and reliability compared to the IR transmitter and receiver.

The Ambient Sound Visualizer

The concept for the ambient sound visualizer was to display ambient sounds at specific locations on a spherical object. This required a ball capable of holding individually addressable LEDs. An existing design for such a ball was found on printables.com, created by Whity [3]. This ball, shown in Figure 5.16, features multiple small triangles, each capable of changing color independently, as individual addressable LEDs are connected to each triangle. For this project, the ”small” ball, consisting of 80 triangles, was deemed sufficient to precisely indicate the direction of sound.

The design of the ”small” LED ball is divided into multiple rings, with the first ring being the top layer and the sixth ring the bottom layer. However, based on background research, a flat surface was desired to facilitate autonomy for the child by allowing hearing aids to be placed on top of the ball. This ensures that the child always knows where their hearing aids are since they will be lighted during the night. Since the top part of the ball was not flat, an adjusted design was created for the first ring, as shown in Figure 5.17, maintaining the same ring size but with a flat top.

During printing, a mistake occurred: the infill was not turned off when generating the G-code (see Figure 5.18 to see the printed parts). While this was not a major issue, it adversely affected the aesthetics, as the light diffusion was uneven. After gluing the two rings together and adding an LED strip to the inside of the ball, Figure 5.19 illustrates the first two rings assembled with the LEDs turned on. This experience provided valuable insights for future improvements. The prints shown in Figure 5.18 were part of the trial phase and can be enhanced in subsequent iterations.

In conclusion, the design created by Whity [3] seemed suitable. However, there were issues with infill during printing. For the final improved prototype, a version of the LED ball without infill is desired. Additionally, adjusting each individual LED was feasible, making this a viable approach. Furthermore, no microphone was used yet to make the LEDs react to sound. This will be implemented in the next phase.

5.1 Co-design process with client

The initial prototyping phase has been conducted. To ensure that the developed concepts meet the client’s expectations, a co-design session was held to further refine and specify the design requirements for both prototypes. During this co-design process, three rounds of iterative refinement were performed. Each round involved co-design sessions where the client provided feedback, proposed new ideas and design requirements, and evaluated and tested the prototypes again.

5.1.1 Round one of co-design iterations

The first round of co-design iterations focused on rapid low-fidelity prototyping. The aim was to explore fundamental concepts, test technological functionalities, and gather feedback from the client. First, an explanation of the improved prototypes for the co-design session is elaborated on, followed by a detailed co-design session.

Figure 5.16: 3D printable LED ball designed by Whity. This picture is also made by Whity.[3]

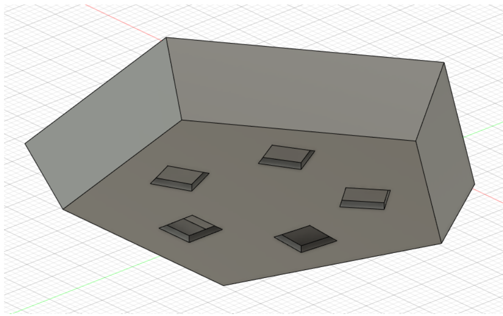

Figure 5.17: Flat top ring of the ball

Prototype improvements for Co-Design session one

To prepare the prototypes for demonstration during the co-design session, improvements were made following the initial technical testing phase. These enhancements are detailed in this subsubsection.

Family Locator

During the initial phases of the technical prototype testing, it became apparent that the implementation of IR communication was not feasible. In response, a backup plan was devised that involved using a remote control instead of a background tracking system. In this new setup, each button on the remote corresponds to a different room in the house, employing the Wizard of Oz technique to simulate the location changes of family members. This approach not only enables demonstration scenarios but also facilitates user testing in real situations. However, a notable drawback is that family members must actively indicate their location, which requires more effort compared to a passive background tracking solution.

Subsequently, a remote control, see figure 5.20, was designed with five buttons, each representing a distinct room. The remote also features a red 5 mm LED that lights up when a button is pressed, confirming that the remote has registered the action. These components are connected to an ESP-32 microcontroller, which communicates over a

Figure 5.18: The printed LED ball components with infill. The top part consists of 5 triangles, followed by Ring 2, which contains 15 triangles surrounding the top part. The two components underneath make up Ring 3. Together, these parts represent half of the ball.

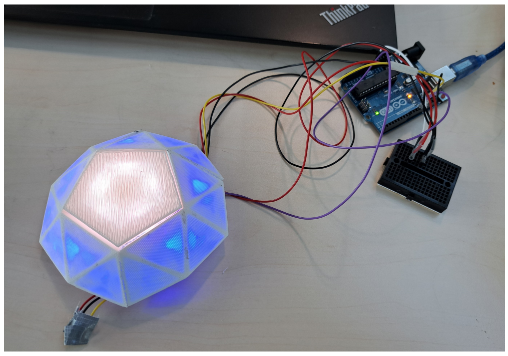

Figure 5.19: First two rings of the LED ball assembled.

Wi-Fi network with another ESP-32 using the ESP-NOW library. This second ESP-32 is linked to the user interface, allowing signals sent from the remote to be received seamlessly.

The user interface features two profile pictures representing the parents, along with five pictograms that correspond to the rooms in the house. These pictogram designs were developed during the ideation phase, as detailed in Chapter refchap:Ideation. Each pictogram includes two individually addressable LEDs, with one LED's color matching that of the LEDs in the profile pictures (see Figure 5.20).

When a button on the remote is pressed, the red LED on the remote illuminates, and the corresponding LED on the user interface lights up based on which button is pressed. For instance, if the bathroom is designated as room four, that corresponding LED will light up in the color assigned to Parent 1, who is programmed as the remote's user (see Figure 5.20). Currently, there is no remote designated for Parent 2.

Ambient Sound Visualizer

During the initial phases of the technical prototype testing, multiple parts of the LED ball were assembled. In this phase, an additional ring was added to the first version of the ”ball”. The LEDs of rings 1 and 2 were soldered and placed inside the ball using duct tape, see figure 5.22. Two microphones were installed, one on each side of the box (see figure 5.21). However, only one microphone seemed to be functioning at a time. The

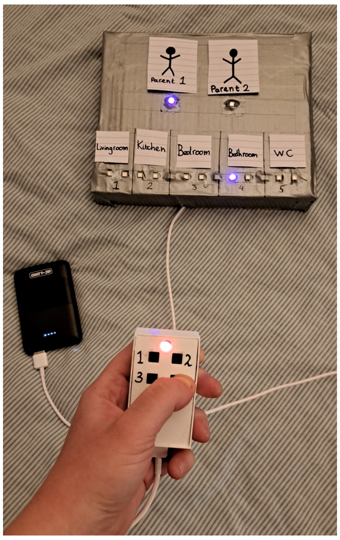

Figure 5.20: User interface and remote control for the Family Locator, round 1 of iterations

signal from the working microphone, received by the ESP-32, was filtered, and a factor derived from the volume of the sound was connected to the brightness of the LEDs on one side of the second ring. When no sound is detected, the LEDs remain off. However, when ambient sounds are present, the LEDs on one side illuminate in proportion to the loudness (see Figure 5.23): the louder the sound, the brighter the LEDs light up. While blowing into the microphone or clapping produces a clear response, normal sounds are not accurately captured, likely due to the low quality of the sensors. Extensive analysis and filtering was performed by printing the microphone values and plotting filtered values in Arduino IDE's serial plotter, but these efforts did not yield any improvements.

This indicates that one part of the Ambient Sound Visualizer can visualize some ambient sounds. Although the functionality is not yet of high quality, this represents a significant step in the right direction. The next step is to ensure it works with multiple reliable microphones.

Co-design sessions one

On Monday, June 10th, 2024, a co-design session was conducted with my client in their home. The session took place in a real-life setting with the child playing around and the father present nearby, providing a realistic context for observing the prototypes in use.

The session began with sharing information and obtaining signed consent forms from the participants. Following this, I presented prototypes of the Ambient Sound Visualizer and the Family Locator. The Family Locator prototype featured a 3D-printed, sturdy remote casing with buttons that sent signals to a user interface, which would light up an LED to indicate reception. Although the prototype was very low-fidelity and made using cardboard and duct tape, it was functional and safe. We discussed the potential

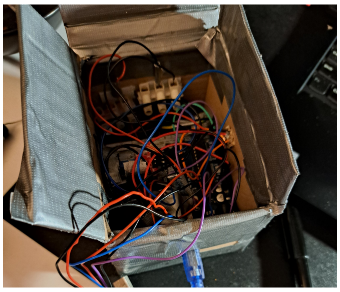

Figure 5.21: *Box containing electronics for the Ambient Sound Visualizer, Round 1 of iterations*

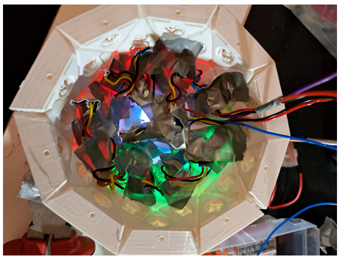

Figure 5.22: LEDs attached with duct tape on the inside of the LED ball of the Ambient Sound Visualizer, Round 1 of iterations

Figure 5.23: The fully assembled Ambient Sound Visualizer from the first round of iterations, featuring the half sphere and the enclosed electronics box. The red/pink side reacts to sound.

applications of these devices, drawing inspiration from the Design Your Life toolkit [41], and I explained the reasoning behind the current designs. The flat top of the sphere was highlighted for its potential to enhance user autonomy. Additionally, I demonstrated a vibration motor to stimulate creativity and generate ideas, although it had not yet been incorporated into the prototypes.

Feedback on the Family Locator was insightful. The client noted the need for confirmation that signals sent from the remote were received by the user interface, suggesting a feature similar to the double check marks used in messaging apps like WhatsApp. They proposed that an app-based solution might eventually be more convenient than a physical device. For now, however, the current device was acceptable, though the client suggested that it should vibrate if the signal was not received, making it more user-friendly. They also noted that the current device was somewhat large and proposed adding a ”we are going to sleep” button with a light indicator to help their daughter understand when to sleep and how long until she would be woken up.

Regarding the user interface of the Family Locator, I mentioned to the client that the duct tape version needed improvement and asked what kind of layout she preferred. I explained that I had created several drawings of possible layouts and wanted to know her preference. I gave her the option to either start drawing her own concept or first look at mine. My drawings can be found in figures 5.24, 5.25 and 5.26. She responded, ”I am not good at drawing, can I first see your drawings?” I then showed her my designs.

Regarding the first concept design (Figure 5.24), she mentioned that she really liked the layered floors but noted it could be challenging to adapt to different house layouts.

For the second drawing (Figure 5.25), she said it was nice but not quite the design she envisioned. For the last one (Figure 5.26, she appreciated the idea of LEDs around the profile pictures but found the shape a bit boring. After reviewing my designs, she created her own concept (Figure 5.27). She described a shape of the user interface resembling a cloud or flower, with the LEDs placed around the pictograms instead of the profile pictures.

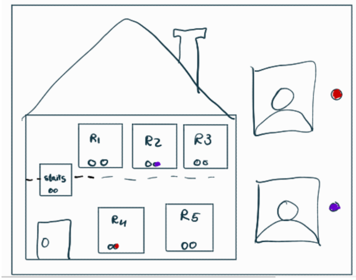

Figure 5.24: First concept drawing of the user interface of the Family Locator, designed in the shape of a house with different floors. The letter "R" represents a room number, and the two dots inside each room are individually addressable LEDs.

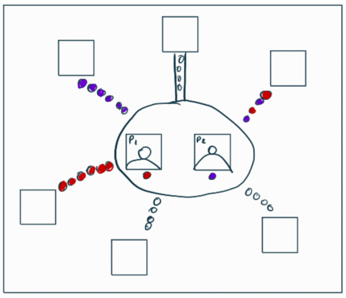

Figure 5.25: Second concept drawing of the user interface of the Family Locator, designed in the shape of a web. The dots represent individually addressable LEDs.

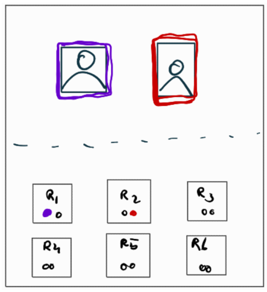

Figure 5.26: Third concept drawing of the user interface of the Family Locator in a basic shape. The letter "R" represents a room number, and the two dots inside each room are individually addressable LEDs. The purple and red squares around the profile pictures also represent individually addressable LEDs.

Additionally, I told the client that the designs of both prototypes will definitely be improved to make them more engaging. The client also proposed sending the pictograms they use in their home for communication, which could replace the drawings on the duct-tape and cardboard version of the user interface.

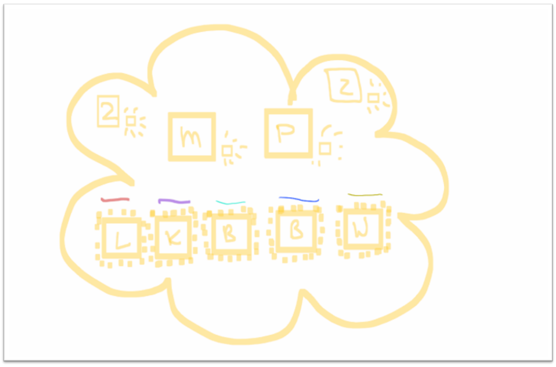

Figure 5.27: The final concept design of the user interface of the Family Locator drawn by the client

Regarding the Ambient Sound Visualizer, the client suggested adding a dimmer switch for the LEDs to adjust brightness during the night. We discussed that researching which light colors are most soothing for children. The client noted that she had heard that red light could help children to sleep. The client also proposed incorporating a cry sensor to calm the child when needed. Additionally, she suggested that the activities detected by the Ambient Sound Visualizer could be visually represented on the Family Locator's interface using consistent colors.

When discussing age-appropriate pictograms, the client, who is a supervisor and communication support worker for children with special needs, emphasized the importance of these pictograms evolving as the child grows. Different categories of pictograms could be developed to cater to the varying communication needs of children at different ages, from 1 to 5 years old. This insight is crucial for ensuring effective communication tools are integrated into the design.

When asked which idea they preferred, the client expressed enthusiasm for both prototypes and showed a strong interest in continuing to develop both designs. During the session, the daughter also joined the meeting. She walked towards the LED ball, and her mother began explaining how it works. The child started clapping, and she smiled, clapping for a few seconds before stopping and clapping again (see Figure 5.28).

Additional suggestions included creating a portable wristband version of the device and designing a version with vibration motors for deaf-blind individuals, allowing them to feel sounds. They also mentioned the possibility of incorporating ground vibrations into the feedback system. We discussed the importance of determining whether the lamp wakes the child and considered adding an intuitive on/off switch. The client emphasized the importance of offering reliable service if the product were brought to market, suggesting quick replacement services or having a spare product available to avoid prolonged disruptions. They also suggested a potential emergency button for the child to call for help, though acknowledged the risk of overuse.

In conclusion, this co-design session provided essential insights and feedback, guiding the next steps in the development process. The collaborative approach helped identify user needs and preferences, ensuring the products' designs align with real-world use cases and enhancing their overall feasibility and appeal.

Figure 5.28: The client's daughter testing the Ambient Sound Visualizer while clapping

New Design Requirements from Co-Design Session One

During the first co-design session, several new design requirements were identified. See the list below for details.

- (Client – First co-design session) The remote of the family locator should confirm whether a signal is received by the user interface or not.
- (Client – First co-design session) The remote of the family locator could be an application, allowing family members to be tracked by their phone in the background instead of using a bulky remote.
- (Client – First co-design session) The remote of the family locator could have a ”we are going to sleep” button to inform the child that the parents are going to sleep in a moment.
- (Client – First co-design session) The user interface should use the pictograms that the client uses in their house for communication.
- (Client – First co-design session) The user interface should use pictograms that are age-appropriate.
- (Client – First co-design session) The ambient sound visualizer should have a dimmer to adjust the LED brightness.
- (Client – First co-design session) The ambient sound visualizer should emit light that helps the child sleep rather than wake them up.
- (Client – First co-design session) The ambient sound visualizer and the family locator could use the same color coding to maintain consistency with activities in different rooms.
- (Client – First co-design session) The ambient sound visualizer might have a cry sensor to calm the child when needed.
- (Client – First co-design session) The type of light and brightness of the LEDs in the ambient sound visualizer should not wake or keep the child awake.

After the meeting, the plan was to continue working on incorporating IR sensors to detect presence in different rooms and to improve the user interface design of the Family Locator. The Ambient Sound Visualizer was particularly well-received, and the focus would be on enhancing its functionality and integration with the Family Locator.

The first round focused on rapid low-fidelity prototyping. The goal was to quickly develop simple models to explore fundamental concepts, test the functionality of technological components, and gather initial feedback.

5.1.2 Round two of prototype iterations

After the first co-design session, several improvements were made based on the new design requirements identified. These improvements are detailed in the following subsubsection. Subsequently, an evaluation and ideation co-design session will be conducted to further refine the prototypes. This second round of prototyping involved semi-rapid and mid-fidelity prototyping, building on the initial prototypes and adding more detail and functionality. Feedback from the previous round helped refine the design and identify any remaining issues.

Prototype improvements for Co-Design session two

To enhance the previous prototypes, feedback and design requirements from the initial co-design session were used to inspire new versions. These improvements address the client's suggestions and integrate additional features for a more effective demonstration. This round focuses primarily on the Family Locator, as it has seen the most significant improvements.

Family Locator

The second round of the iterative design process of the Family Locator began with incorporating the User interface layout drawing of the client gathered during the initial co-design session. A laser cut design was made (Figure 5.29) incorporating spaces for six room pictograms, placeholders for two family members, a red circle for a potentiometer (to adjust LED brightness), and a small rectangle designated for the on/off button.

Following the laser cutting process, the room pictograms provided by the client (see Figure 5.31) were specifically placed on certain locations on the user interface of the Family Locator. Ground floor rooms were strategically placed lower on the interface, with first-floor rooms positioned above them and connected by stair symbols. This layout aimed to provide an intuitive representation of the client's living space within the Family Locator's interface. Alongside this integration, strategically placed LEDs were incorporated to simulate the presence of family members across different rooms, as depicted in Figure 5.30. Despite our careful planning, a technical oversight during laser cutting resulted in the incomplete incorporation of the potentiometer into the wooden substrate.

Ambient Sound Visualizer

In round two of this iterative process, the LED ball, designed by Whity [3], was 3D printed again, this time without infill so that the LEDs on the inside of the ball would be diffused equally. A whole new version of the Ambient Sound Visualizer was assem-

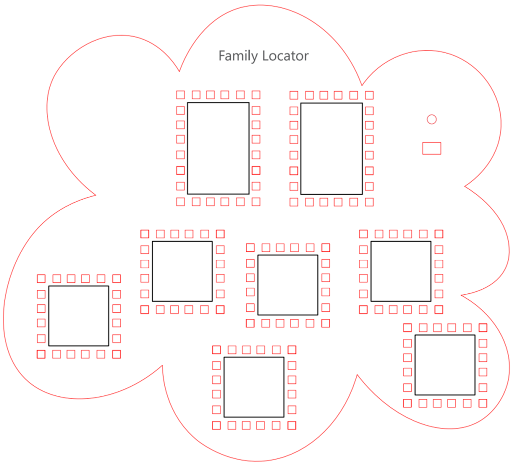

Figure 5.29: Design of the Family Locator's user interface inspired by the client's drawing.

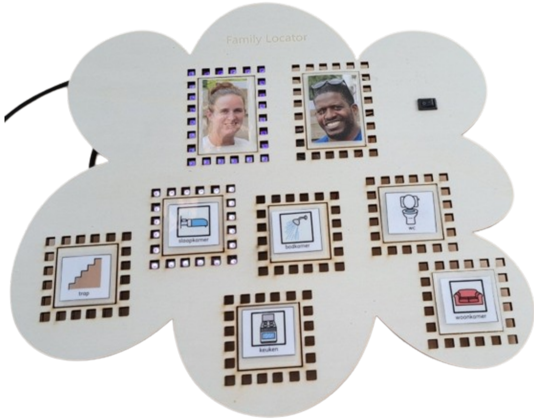

Figure 5.30: Layout of the user interface with integrated LEDs to simulate family member presence.

Figure 5.31: Pictograms utilized in the final user interface, sourced from the client.

bled, while the first version remained unchanged. Additionally, a self-made base was designed for the newly printed ball, as shown in Figure 5.32. The base includes various holes for buttons serving multiple functions: a square hole for an on/off button, a round hole for a potentiometer (used to adjust the overall brightness of all the LEDs), and a hole for the USB cable. Additionally, multiple holes for the microphones were strategically added, positioned on each side of the pentagon-shaped base. The fully assembled LED ball with its base can be seen in Figure 5.33.

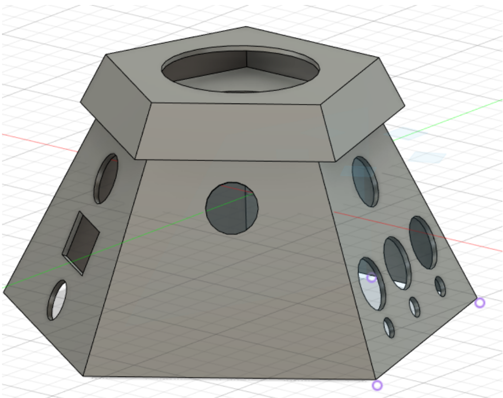

Figure 5.32: First design of base for the Ambient Sound Visualizer

Figure 5.33: The Ambient Sound Visualizer after iteration round 2

Co-design session two

On Wednesday, June 19th, 2024, I conducted a co-design session with my client at a McDonald's in Utrecht. The meeting, held from 11:00 to 11:45, provided a relaxed environment conducive to collaboration and discussion. During this session, I presented updates of the prototypes, showcasing the Family Locator and the Ambient Sound Visualizer. The Family Locator featured a completely new look (compared to the previous co-design session) and a redesigned remote control, now equipped with an additional feature that indicates whether a signal has been successfully received by the user interface in the child's room. The Ambient Sound Visualizer had also undergone a visual update, with a second version created that, while not yet functional, included new buttons for adjusting brightness, toggling on and off, and switching between different modes such as sleep routine (with relaxing LED effects), ambient sound, and disco.

We reviewed existing products on the market and considered potential areas for improvement. I asked the client if there were any aspects they felt were lacking in the designs. They emphasized the importance of maintaining a minimalist aesthetic and cautioned against over-engineering the devices. We also discussed the shape of the Ambient Sound Visualizer. The Ambient Sound Visualizer is currently designed in a spherical shape, but we discussed whether this was the best choice. Since there hasn't been research done on the optimal design, I presented several alternative shapes for consideration (see Figure 5.34).

The client expressed a clear preference for the spherical shape, finding it the most visually appealing. I inquired about preferences if the device were to be mounted or placed in different locations. She suggested that a flat design could also be suitable if mounted on a wall or ceiling. Another option discussed was a semi-spherical design for wall or ceiling placement, but the client favored the full spherical shape.

After reviewing designs for the Ambient Sound Visualizer, an interesting idea emerged regarding the development of a comprehensive system where each room in the house could be assigned a specific color. These assigned colors could correspond to the same colors displayed on the Ambient Sound Visualizer, creating a cohesive visual language throughout the home. This approach could involve using stickers or NFC tags, allowing for a modular setup that enables visual cues reflecting the presence of family members.

The use of NFC tags could enhance the user interface of the Family Locator, making it more adaptable to individual home situations. For instance, the pictograms representing different rooms could be easily switched out, enabling customization based on the specific layout of a household. This modular design would cater to varying needs—some families may have a garage, while others may not. Furthermore, the client's bonus daughters could have their own profile pictures linked to NFC tags, which could be placed on the Family Locator when they are at home. This feature would allow the system to dynamically reflect who is present in the house and could easily accommodate changes when family members are not at home.

The client expressed enthusiasm for both prototypes and showed a strong interest in continuing to develop both designs. This co-design session provided essential insights and feedback, guiding the next steps in the development process.

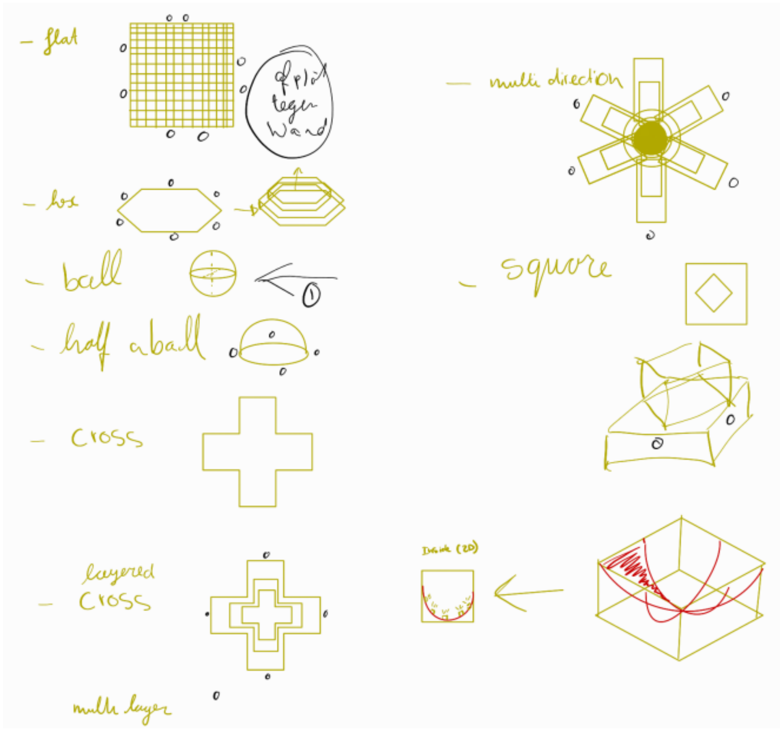

Figure 5.34: Concept drawings of possible shapes of the Ambient sound Visualizor

After the meeting, the next steps involved further development of both prototypes. For the Family Locator, the focus will be on creating a casing for the remote and potentially designing a modular user interface. Meanwhile, for the Ambient Sound Visualizer, efforts will concentrate on enhancing the ball's functionality by integrating multiple microphones.

New Design Requirements from Co-Design Session Two

During the first co-design session, several new design requirements were identified. See the list below for details.

- (Client – Second co-design session) The Ambient Sound Visualizer should have a minimalist aesthetic and not be over-engineered.
- (Client – Second co-design session) The LED part of the Ambient Sound Visualizer should have a spherical shape.
- (Client – Second co-design session) The Family Locator should have a minimalist aesthetic and not be over-engineered.
- (Client – Second co-design session) The pictograms and profile pictures on the Family Locator could have NFC tags on the back of them, allowing the user interface layout to be personalized to one's household and family situation.

5.2 Ethical reflection

Following the second round of co-design sessions, an ethical reflection was conducted for Reflection II, a component of the Creative Technology graduation curriculum. This reflection addresses several significant ethical dilemmas and examines relevant design requirements in accordance with European Council Directives. Additionally, the ethical cycle developed by Van de Poel et al. [2] was followed throughout the design process, ensuring that ethical considerations were integrated into the development of both prototypes. The complete ethical reflection can be found in the appendix, specifically in section 10.2.

5.2.1 Ethical landscape

Throughout the design process of the two prototypes, several ethical dilemmas emerged. With an ethical dilemma being defined by Turvey et al. [53] as an ethical issue that is impossible to solve, since it is not possible to satisfy two ethical principles at the same time. In this section, one ethical dilemma unique to each prototype and one shared ethical dilemma will be elaborated on.

One ethical dilemma that emerged during the design process of the Ambient Sound Visualizer is balancing over-stimulation with autonomy. During the sleep process, children are not yet familiar with the information and light the prototype provides, which could lead to over-stimulation. However, hearing children cannot simply turn off their hearing either. Should the child have the ability to turn the prototype off? If so, how? If there were an option to turn it off, how would it work, and would the child understand how to use it?

One ethical dilemma that emerged during the design process of the Family Locator is ensuring the balance between security and dependence. Additionally, there's the concern that a child's trust could be impacted if the product provides inaccurate information. The goal of the product is to help children feel the proximity of their parents and subsequently become more relaxed, which aids in improving their sleep. However, if the product were to malfunction and not work for a couple of days, it raises the question of whether the child might become more anxious compared to the level of anxiety before the use of the product. Hearing children can sense the proximity of their parents and other household members through sound. However, deaf and hard of hearing children may not have this ability. While the product aims to provide security for children with hearing impairments, there's a concern that over reliance on the Family Locator could potentially worsen a child's fear of separation if the device malfunctions. Additionally, there's a risk of dependency, where the child may struggle to sleep without the reassurance of the locator, highlighting the delicate balance between support and independence in children.

An ethical dilemma that emerged during the design process of both prototypes is safety. Children are very vulnerable and often do not know the possible consequences of their actions. While the prototype is in the room together with the child during sleep, no one else is present in the room. If the child decides to put the product in their mouth, lick it or throw it, it must be safe. No toxic substances should be released and no fire should occur. But there are electronics involved so it is very difficult to get this done, especially with a prototype that has to be made in a fairly short time.

5.2.2 Engaging the design process through moral values and ethical decision making

This section will elaborate on the assessment of this graduation project according to the ethical cycle of Van de Poel et al. described in Chapter 5 ”The Ethical Cycle” of the book ”Ethics, Technology, and Engineering”[2]. The comparison between this design cycle and the Creative Technology Design Cycle, both utilised in the design process, designed by mader et al. [1] are elaborated on in chapter 3.

The Ethical Cycle consists out of 5 phases: Moral problem statement, Problem analysis, Options for action, Ethical evaluation and Reflection. All these steps will be elaborated on in this section.

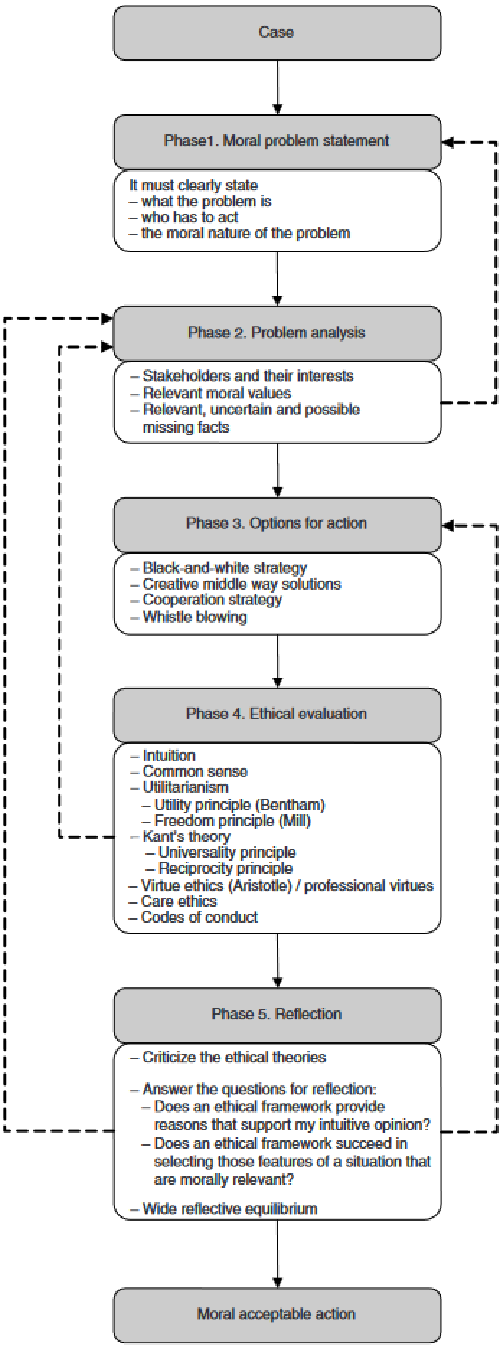

Figure 5.35: Detailed overview of the ethical cycle from Van de poel et al. [2] consisting out of 5 different phases.

Phase 1: Moral problem statement

This phase analyses the following questions to clarify the moral problem statement.

- **What is the problem?:**

  One of the ethical dilemmas in this project revolves around the trade-off between low-cost production and ensuring safety and quality. This problem is crucial because it impacts both the affordability and the well-being of the end users.

- **Who has to act?:**

  The key stakeholders in this scenario are the design and engineering team (comprising myself and the mother of the child, as we are collaborating in a co-design process), Ability Tech (the foundation where I work as a volunteer and the source of the project request), and potential production companies interested in manufacturing and marketing the product if it proves successful after testing.

- **What is the moral nature of this project?:**

  The moral problem centers on whether it is ethically justifiable to compromise on safety and quality to achieve lower production costs. This dilemma involves balancing utilitarian benefits (greater product accessibility) against deontological principles (duty to ensure safety and quality).

Phase 2: Problem analysis

To clarify the problem, an analysis will be done in this phase by first looking at all the stakeholders and their interests, then explicitly mention the relevant moral values and finish with mentioning the relevant, uncertain, and possible missing facts.

- **Stakeholders and their interests:**
  - **The design and Engineering Team (my client and me)**
    Interested in creating a reliable, high-quality, safe product that meets all technical and safety standards that helps deaf and hard of hearing to improve their sleep process.
  - **Ability Tech**
    Focused on fulfilling project requests aimed at enhancing the quality of life for people with disabilities while supporting the development process.
  - **End Users**
    Parents of the children for whom the product is designed prioritize safety, reliability, pedagogical soundness, and effectiveness in addressing their child's sleep problems. As for the children, they may not fully understand or articulate their motivations, but the product should ultimately make them feel safe.
  - **Potential Production Companies:** Interested in the feasibility of manufacturing and marketing the product if it proves successful after testing.

- **Relevant Moral Values:**

  - **Safety:**
    Ensuring the product does not pose any harm to the users.
  - **Quality:**
    Maintaining high standards in the product's performance and durability.
  - **Reliability:**
    Guaranteeing consistent performance and durability.
  - **Responsibility:**
    Upholding ethical duties towards users and society.
  - **Effectiveness:**
    Successfully addressing the intended problem of improving sleep for children.
  - **Inclusivity:**
    Considering the needs and well-being of people with disabilities.
  - **Affordability:** Making the product accessible to a larger audience by keeping costs low.

- **Relevant, uncertain, and possible missing facts:**

  - **Relevant facts:**
    The costs associated with different levels of safety and quality.
  - **Uncertain facts:**
    The actual impact of cost reduction on safety and quality.
  - **Possible missing facts:**
    Long-term consequences of compromised safety and quality on brand reputation and user trust.

Phase 3: Options for Action

This phase explores potential solutions to address the ethical dilemma. Various strategies are considered, ranging from straightforward choices to more nuanced, collaborative approaches, ensuring a thorough examination of possible actions.

- **Black-and-white strategy:**

  - **Option 1:** Prioritize safety and quality regardless of cost implications.
  - **Option 2:** Focus on minimizing costs, accepting potential reductions in safety and quality.

- **Creative middle way solutions:**

  - **Option 3:** Implement cost-effective safety measures that do not significantly compromise quality.

- **Option 4:** Develop a tiered product line with varying levels of safety and quality at different price points.

- **Cooperation strategy:**
  Engage with stakeholders to collaboratively find a balance between cost, safety, and quality. This might involve transparent discussions about the trade-offs and seeking consensus on acceptable compromises.
- **Whistle blowing:**
  If it becomes evident that cost-cutting measures significantly endanger user safety, whistle blowing might be considered to alert regulatory bodies or the public about the potential risks.

Phase 4: Ethical Evaluation

In this phase, the moral acceptability of the various options outlined in Phase 3 is systematically evaluated. This evaluation entails the application of a self-authored code of ethics, coupled with the utilization of diverse ethical theories. Through this analytical process, these options are evaluated from multiple ethical standpoints, fostering a comprehensive assessment aimed at upholding ethical integrity and moral accountability in decision-making.

1. Moral principles used to evaluate options of actions

   - **Legal Compliance:**
     - **Option 1:** Prioritizing safety and quality aligns with legal compliance by ensuring the product meets all safety regulations.
     - **Option 2:** Focusing on minimizing costs might risk non-compliance with safety standards, potentially leading to legal issues.
     - **Option 3:** Implementing cost-effective safety measures ensures compliance without significantly compromising quality.
     - **Option 4:** Developing a tiered product line must ensure all tiers meet basic safety regulations to comply with legal standards.
   - **Client Confidentiality:**
     - **All Options:** Ensure that any private information about the client or end users is protected throughout the design and evaluation process. This principle does not directly influence the choice between options but must be maintained regardless of the chosen action.
   - **Fair and Respectful Treatment:**
     - **Option 1:** Treating participants with respect is upheld by prioritizing their safety and quality of the product.
     - **Option 2:** Reducing safety and quality could potentially harm users, thus violating the principle of fair and respectful treatment.

- **Option 3:** Balancing cost-effective safety measures respects the well-being of users without unnecessary expense.
- **Option 4:** Offering different tiers allows for respect of user choice and financial capability, provided all tiers meet basic safety and quality standards.

- **Transparency and Accountability:**
  - **Option 1:** Maintaining high transparency about the prioritization of safety and quality builds trust.
  - **Option 2:** Transparency about cost-cutting measures and their impact on safety is crucial but may negatively affect accountability if safety is compromised.
  - **Option 3:** Clear communication about the implementation of cost-effective safety measures ensures accountability.
  - **Option 4:** Transparency about the different safety and quality levels in the tiered product line is essential for informed user choice.
- **Attribution and Acknowledgement:**
  - **All Options:** Properly crediting all sources and contributors is necessary throughout the design process. This principle supports ethical practices but does not directly impact the evaluation of the options for action.

After careful evaluation of the ethical implications of the options presented in phase 3, it is evident that prioritizing safety and quality (Option 1) aligns most closely with the professional ethical principles outlined in my code of ethics. While cost considerations are important, compromising on safety and quality could lead to potential harm to the end users, which conflicts with the principle of fair and respectful treatment. Additionally, maintaining transparency about the prioritization of safety and quality helps build trust with stakeholders and ensures accountability for the design decisions made.

Therefore, the recommended approach would be to prioritize safety and quality while exploring cost-effective measures (Option 3) to minimize production expenses without compromising on essential aspects of the product. This approach allows for the development of a reliable, high-quality product that meets the needs of the target users while also addressing budget constraints and ensuring legal compliance and ethical integrity throughout the design process.

2. Moral theories used to evaluate options of actions

The moral acceptability of the various options mentioned in Phase 3 can also be evaluated using ethical theories, namely utilitarianism, deontology, and virtue ethics. The definitions of these theories can be found in the section ”Ethical theories” .

- **Utilitarian Evaluation:**

- **Option 1:** Prioritizing safety and quality aligns with utilitarian principles by potentially maximizing overall well-being. This option ensures that the product meets safety regulations and provides a reliable solution for improving sleep in children with disabilities, hypothetically optimizing the overall well-being. Utilitarianism dictates doing whatever brings the most happiness or benefit to the largest number of people, making Option 1 ethically favorable in this context.
- **Option 2:** Focusing solely on minimizing costs might lead to negative consequences, such as compromising safety and quality, which could outweigh any potential benefits in terms of affordability. This approach may not align with utilitarian principles, as it could result in negative impacts on the well-being of children, making this option less favorable from a utilitarian perspective.
- **Option 3:** Implementing cost-effective safety measures balances the need for affordability with the goal of ensuring safety and quality, potentially maximizing overall happiness by providing a reasonably priced solution that meets essential standards. This approach aligns well with utilitarian principles, as it aims to optimize overall happiness by providing a solution that is both affordable and safe, thus making it the most favorable option from a utilitarian perspective.
- **Option 4:** Developing a product line with different levels offers flexibility and accessibility but must ensure that all levels meet basic safety and quality standards to prevent potential harm to users. This approach considers diverse needs and preferences, in line with utilitarian principles. However, it is important to acknowledge that offering different levels of products carries risks, especially if users may not be fully aware of the potential consequences of cheaper options. This is particularly relevant for products aimed at children, as they may not be able to fully comprehend the potential risks. Therefore, it is crucial to prioritize safety and quality across all levels of the product line to safeguard the well-being of users, especially children. However, due to the potential risks associated with varying levels of products and the possibility of users not fully understanding the consequences, this option may not be the most favorable.

• **Deontological Evaluation:**
  - **Option 1:** Prioritizing safety and quality reflects a deontological approach by adhering to universal moral rules that prioritize the well-being and safety of users, regardless of cost considerations. Making this option the most favorable option regarding deontological evaluation.
  - **Option 2:** Prioritizing cost reduction over safety and quality may violate deontological principles by neglecting the obligation to safeguard the safety and well-being of users. Therefore, this option is not in alignment with deontological principles, which emphasize the importance of

fulfilling moral duties and obligations.

- **Option 3:** Implementing cost-effective safety measures demonstrates a commitment to fulfilling ethical obligations while seeking practical solutions, balancing the duty to ensure safety with the need for affordability. This option, while pragmatic, may involve trade-offs in safety and quality to some extent, potentially deviating from strict deontological principles. Therefore, from a deontological perspective, while this option may be acceptable, it may not fully align with the uncompromising duty to prioritize safety and quality above all else.
- **Option 4:** Developing a tiered product line requires ensuring that each tier meets basic safety and quality standards, reflecting a deontological perspective by upholding ethical duties towards users and society. This underscores the notion that safety is paramount and should not be compromised, regardless of the product's tier or features.

- **Virtue Ethics Evaluation:**
  - **Option 1:** Prioritizing safety and quality exemplifies virtuous behavior by demonstrating integrity, responsibility, and a commitment to excellence in engineering design. This option reflects the virtues of integrity, responsibility, and excellence, making it a favorable choice from a virtue ethics perspective. Virtue ethics emphasizes the development of positive character traits, such as honesty and courage, which are evident in Option 1's focus on safety and quality. By prioritizing these virtues, engineers uphold moral autonomy and cultivate ethical decision-making aligned with their professional practice. Making this the most favorable option following virue ethics.
  - **Option 2:** Focusing solely on cost reduction may undermine virtuous qualities by neglecting the importance of safety and quality in product development. This option contradicts virtues such as integrity and responsibility, as it prioritizes cost over the well-being of users and the quality of the product, making it less favorable from a virtue ethics standpoint. Virtue ethics encourages engineers to cultivate positive character traits like integrity and responsibility, which are compromised in Option 2's cost-focused approach.
  - **Option 3:** Implementing cost-effective safety measures showcases virtuous behavior by finding a balance between economic considerations and ethical responsibilities, demonstrating caution and practical wisdom in decision-making. This option demonstrates virtues such as caution and practical wisdom by balancing economic concerns with ethical responsibilities, making it a favorable choice from a virtue ethics perspective, but not the most favorable option compared to option 1. Engineers exercise moral autonomy by prioritizing safety and quality while considering cost-effectiveness, aligning their actions with the virtues of integrity

and responsibility but sacrificing the absolute commitment to safety that option 1 provides. While option 3 embodies virtues such as prudence and practical wisdom, it may involve some degree of compromise in safety standards to achieve cost-effectiveness, which may not fully align with the uncompromising dedication to safety upheld by option 1. Therefore, while option 3 reflects virtuous behavior in decision-making, it may not be the most favorable choice when prioritizing safety and quality above all else.

  - **Option 4:** Developing a tiered product line, while aiming to accommodate diverse needs and provide affordable solutions, must ensure that all tiers meet the same rigorous safety and quality standards. However, there is a risk that safety may be compromised in the pursuit of cost-effectiveness, especially in the lower-priced versions. This potential trade-off between safety and affordability may not align with the virtues of responsibility and consideration for diverse needs advocated by virtue ethics, which emphasizes the cultivation of positive character traits such as integrity, empathy, and responsibility. While Option 4 demonstrates empathy and consideration for user needs, the potential sacrifice of safety in the cheaper versions raises ethical concerns, making it less favorable from a virtue ethics standpoint compared to Option 1.

3. Conclusion Based on the evaluation using various ethical theories and the self-authored code of ethics, Option 1 emerges as the most favorable overall, as it prioritizes safety and quality in line with multiple ethical perspectives. However, it's worth noting that Option 3 closely follows as a strong contender, particularly favored by utilitarianism. Option 3 strikes a balance between cost-effectiveness and ethical responsibilities, making it a compelling choice from a utilitarian standpoint. Despite this, Option 1 excels in meeting the criteria set forth by all ethical theories and the code of ethics. Therefore, while Option 1 may be the most comprehensive choice, Option 3 aligns more closely with utilitarian principles and presents a viable alternative solution.

Phase 5: Reflection

In this phase, a critical examination of the ethical evaluation conducted in Phase 4 is undertaken. The ethical theories employed and their alignment with intuitive judgments regarding the posed ethical dilemma are evaluated, aiming to assess whether they adequately capture the moral nuances of the situation.

The code of ethics formulated for Phase 4 provided a structured framework for evaluating various options. However, upon reflection, it becomes apparent that this code may not comprehensively address all ethical considerations. While it addresses elements such as legal compliance and fair client treatment, it may overlook other pertinent values or fail to prioritize certain ethical principles. Thus, a revision of the code may be necessary to ensure it effectively encompasses the ethical responsibilities incumbent upon engineers.

The ethical theories utilized, including utilitarianism, deontology, and virtue ethics, are evaluated for their efficacy. While utilitarianism facilitates a focus on maximizing overall well-being, it occasionally disregards individual rights. Deontology, with its emphasis on moral duties, may prove too inflexible in practical scenarios. Meanwhile, virtue ethics, centered on character traits, may lack clear directives for action.

Upon introspection of intuitive judgments, it becomes evident that ethical frameworks do not invariably align perfectly with personal instincts. While these frameworks furnish valuable tools for ethical decision-making, they may not fully encompass all factors deemed significant. Achieving equilibrium between personal judgments, ethical theories, and pragmatic considerations remains an ongoing effort.

In conclusion, while the ethical evaluation conducted in Phase 4 serves as a commendable starting point, a critical stance is imperative. Through continual refinement of ethical frameworks and eligibility to diverse viewpoints, engineers can strive toward enhanced ethical responsibility in their professional practice.

5.2.3 Applied Ethics

In this section, specific moral reasoning and ethical problem solving, regarding the graduation project, is conducted by the use of specific tools that were provided during the reflection course that took place in module 11 and 12 of the study program Creative Technology. First ethical theories are used to elaborate on a part of this.

Translating Values into design requirements

In this section, certain design choices and design requirements that are made regarding this graduation project will be argued. These choices are inspired by the method used in Chapter 20 ”Translating Values into Design Requirements” written by Van De Poel [54] from the book ”Philosophy and Engineering: Reflections on Practice, Principles and Process”. This section provides designers a method to create design requirements based upon moral values. Parts of this section are taken from the Take home assignment [55] from the course Reflection I and adjusted accordingly to the received feedback. The posed values, norms and requirements can bee seen in the detailed overview of the value hierarchy in figure 5.36, it shows how the value layers interrelate.

In this graduation project I am making a product for deaf and hard of hearing children that addresses their possible sleeping problems. As this is a vulnerable target group, because they are children and have a disability, it is especially important to live up to certain values and thus establish design requirements for this product. One of the values that I perceive as very important is safety, see the top layer of figure 5.36. This can be ensured through the establishment of design requirements by examining directives related to products and toys for children, such as those outlined by the European Parliament and Council [43]. These directives, formulated by the European Union, aim to guarantee that the produced toys for children in the European Union adhere to some of the most stringent safety standards globally, particularly with regard to the use of chemicals in toys.

The first step in the method of creating requirements by looking at moral norms and values is to write down the norms and values. This is shown in the following list, and in the second top layer in figure 5.36 consisting out of norms based upon the directives formulated by the European Parliament and Council[43].

The main norms are as follows:

1. The product may not physically hurt the user.
2. The product must not have any negative long-term effects on the mental and physical health of the users.
3. The product must not constitute a fire hazard.
4. The product must adhere to all relevant electrical safety standards and regulations.

The next step is drawing requirements from the proposed norms and values. They can be found in the following section and in figure 5.36 in the layers beneath the two top layers. The numbers in front of a particular norm of the above list corresponds to the number in front of the related requirement(s) in the list below.

Requirements:

1. (a) The accessible edges, protrusions, cords, wires, and fastenings of the product need to be made and constructed in a way that minimizes the possibility of physical harm occurring from contact with them.
   (b) The product, along with all its components must possess sufficient mechanical robustness and, when necessary, stability to endure the pressures experienced during usage without fracturing or warping, thereby minimizing the potential for physical harm.
   (c) The temperatures generated by the electronics must not hurt the users.
2. (a) The product should be made out of toxic-free materials.
   (b) The product should be made out of water-resistant and durable materials for electronic components to ensure reliability and longevity, even in adverse conditions.
3. (a) The product does not ignite when directly exposed to a flame, spark, or other potential source of fire.
   (b) The product is not readily flammable, meaning the flame extinguishes as soon as the fire source is removed.
   (c) If the product does ignite, it burns slowly and has a low rate of flame spread.
   (d) Regardless of the toy's chemical composition, it is engineered to mechanically delay the combustion process.
4. (a) The electronic system of the product may not use voltages higher than 24V.

(b) The electronic connections within the product must be adequately insulated and mechanically protected to minimize the risk of electrical shock.
(c) The product must remain operational and secure even in the event of system malfunctions, external factors, or failures.

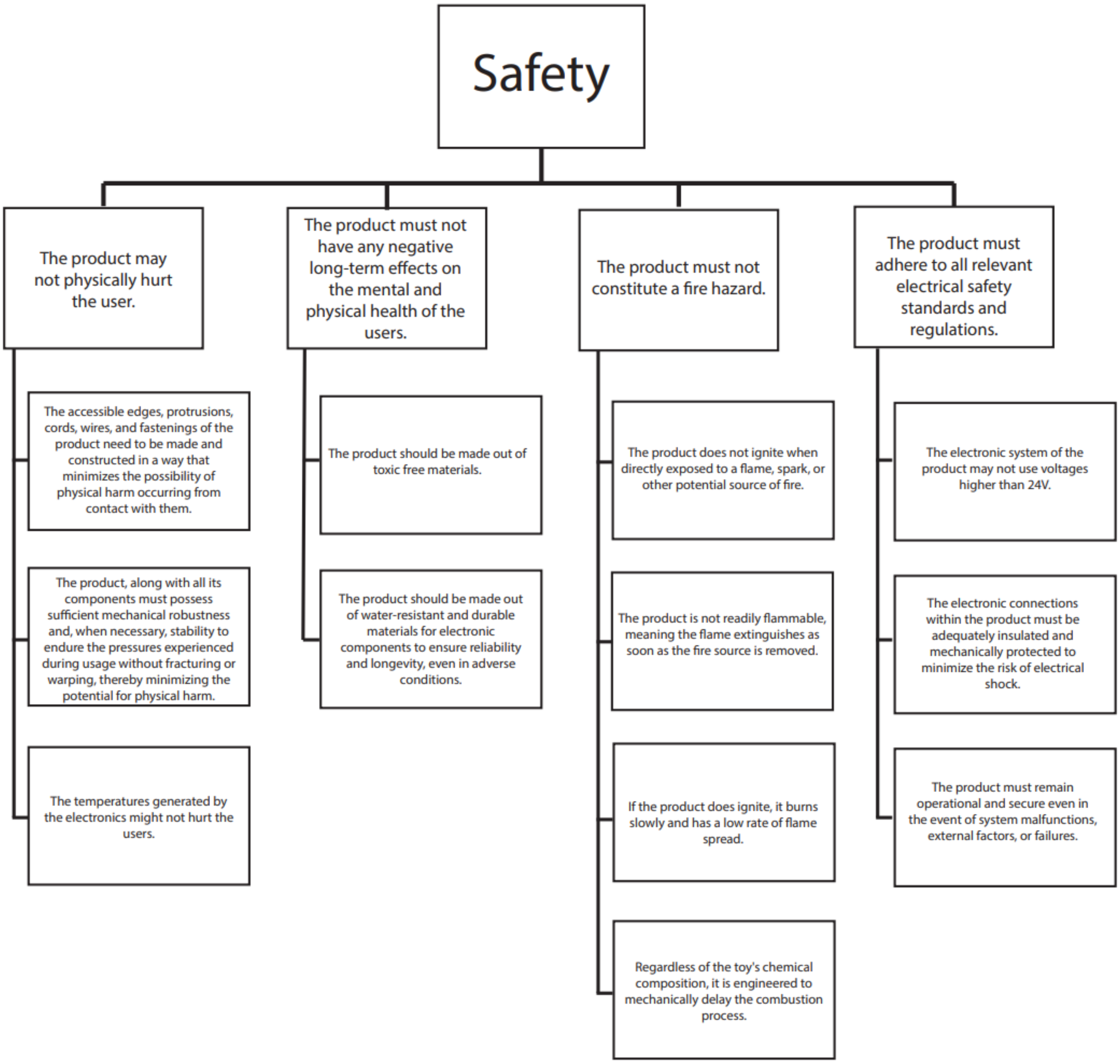

Figure 5.36: Detailed overview of values hierarchy.
The top layer shows the value Safety that I perceive as very important in this project. The second top layer consists out of norms formulated based on the value Safety. The layers beneath the two horizontal top layers are the requirements formulated based on the norms in the second layer.

These requirements created for this project should be followed but this faces challenges:

- Cost constraints: Balancing ethical considerations with budget limitations poses a significant challenge. Integrating safety features or sustainable materials is really important but it is also important that the product is affordable for everyone.
- Contradicting design requirements: Resolving conflicting design requirements can be challenging. For instance, ensuring water resistance while maintaining adequate ventilation for electronic components presents a dilemma. A creative solution must be found to reconcile these conflicting demands without compromising the overall functionality or safety of the product.
- Safety limitations: It is important that the product remains operational and secure even in the event of system malfunctions, external factors, or failures, but it is not always possible to guarantee that for a 100 %.

Markkula Toolkit Tool 5: Remembering the ethical benefits of creative work

In this section, Tool 5 from the Markkula Toolkit [56] is utilized to reflect ethically on creative work, particularly concerning the two potential solutions discussed in this chapter: the ambient sound visualizer and the Family Locator. The Markkula Toolkit aids in developing ethical design practices, with Tool 5 ”remembering the ethical benefits of creative work” emphasizing the benefits of creative work. This stands in contrast to most ethical reflections, which primarily focus on analyzing ethical risks. While ethical risks are crucial to address, it’s equally important to remember that the ultimate goal of ethical reflection is to achieve a positive outcome. Therefore, an ethical reflection is conducted, focusing mainly on the benefits these solutions could provide. This is done by answering questions that tool 5 of the Markkulla Toolkit offers.

- Question 1: Why are we doing this, and for what good ends?

  We, my client and me, are dedicated to helping deaf and hard-of-hearing children improve their sleep by making them feel more secure in their bedrooms. This issue is significant because two-thirds of people with hearing loss suffer from insomnia, as noted by Dearing [7]. In the Netherlands, 180 to 215 babies are born each year with a hearing impairment, according to Lanting [9]. Additionally, hearing loss can develop later in life, increasing the number of children affected by this condition. According to Alrousan et al. [57], this poses a substantial challenge for children, as their physiological and neurological systems are expected to undergo significant development during sleep. Therefore, addressing the sleeping difficulties experienced by children with hearing impairments is crucial.

  Improving sleep for these children also benefits their parents, as they experience fewer disturbances caused by their children’s insomnia.

Furthermore, there is limited research on the sleep problems encountered by deaf and hard-of-hearing children. By conducting this research, we aim to raise awareness about these issues. My research, including a distributed questionnaire, has shown that some people are unaware that hearing impairment can cause or exacerbate sleep problems in children. It is essential to spread this awareness to ensure that the unique needs of deaf and hard-of-hearing children are recognized and addressed.

- Question 2: Will society, the world, or our customers really be better off with this technology than without it? Or are we trying to generate inauthentic needs or manufactured desires, simply to justify a new product to sell?

  We are not trying to generate inauthentic needs or manufactured desires simply to justify a new product to sell. These two products are developed to help deaf and hard-of-hearing children, and potentially others who may find them useful. By designing this product, I do not receive any monetary compensation. This graduation project is offered through Ability Tech, a foundation that creates technology for people with disabilities to make their lives easier and improve their quality of life. Their aim is to help people, not to make money from them.

  Hypothetically, the world would be a better place with this technology, as it is designed to significantly help people without causing any foreseeable problems for others. By improving the sleep quality of deaf and hard-of-hearing children, we can contribute to their overall health and development. Sleep is crucial for children's physiological and neurological growth, and addressing the sleep challenges faced by those with hearing impairments is important. According to Alrousan et al. [57], sleep significantly impacts the development of children's systems, suggesting that these technologies could provide meaningful support for their well-being.

- Question 3: Has the ethical benefit of this technology remained at the center of our work and thinking?

  The ethical benefit of assisting deaf and hard-of-hearing children with sleep problems has consistently guided our efforts in developing prototypes tailored to their needs. The development process was a co-design effort, closely involving the child's mother, who approached Ability Tech seeking assistance in raising awareness for hearing impairment and aiding children with disabilities, motivated by her desire to support her daughter and the broader deaf and hard of hearing community.

  We dedicated significant effort to gathering insights from parents of children with hearing disabilities. We listened attentively to comprehend the specific challenges regarding sleep their children faced, the methods they had previously tried to address these challenges, and potential solutions that might prove effective. A questionnaire was administered to collect these valuable insights.

  Our primary goal has always been, and remains, to help the children. We explored multiple prototypes with the aim of fostering a feeling of closeness to their parents and other family members, thereby reducing bedtime anxiety and enhancing their sense of security. This, in turn, aims to mitigate feelings of fear and isolation, hypothetically leading to an improvement in their sleep quality. Our comprehensive and empathetic approach ensured that the ethical benefits of our technology were consistently prioritized.

- Question 4: What are we willing to sacrifice to do this right?

  As we strive to develop prototypes that prioritize safety, reliability, and sturdiness, we must recognize the constraints imposed by various factors. While our ultimate aim is to create products that are both sturdy and safe, achieving this goal can be challenging due to limitations such as time and budget.

  Our commitment to adhering to safety standards, as outlined by the European Union (EU) regarding toy safety [43], remains unwavering. However, it's essential to acknowledge that achieving 100 % safety and reliability may not always be feasible.

  Conflicting design requirements further complicate matters, necessitating creative solutions to balance durability and functionality. It's crucial to consider the potential consequences of product failure, such as dependency issues, which could inadvertently arise if the product malfunctions after use. For instance, if the product were to break or malfunction after a short period of use, the child may become overly reliant on it for comfort or security, potentially impeding their ability to develop healthy coping mechanisms.

  Despite these challenges, our dedication to prioritizing the safety, reliability, and well-being of the children remains persistent. We understand that sacrifices may be necessary, and we are committed to continually reassessing and evaluating our decisions throughout the design process to ensure that the best interests of the children are always upheld.

Ethical Theories

To provide guidance in engineering design, tree main ethical theories described by van de Poel and Royakkers in the book "Ethics, Technology, and Engineering "[2] are informed and elaborated on in this section. These theories offer different perspectives on how to assess the moral implications of design choices and prioritize ethical considerations throughout the design process. Parts of this elaboration is taken from the "Take Home Assignment" [55] that I handed in for the subject Reflection I.

The three main ethical theories that van de Poel and Royakkers describe in the book are utilitarianism, deontology and virtue ethics.

- **Utilitarianism** suggests that the right thing to do is whatever brings the most happiness or benefit to the largest number of people. It's about maximizing the overall good and minimizing the negative consequences of actions as much as possible. This theory can guide engineers in designing a product, a system or something else to focus on maximizing the overall good (happiness, well-being, accessibility, etc.) and to minimize the negative consequences (violence, discrimination, injustice, etc.) of their design as much as possible.

- **Deontology**, also known as Kantian ethics, asserts that the moral rightness of actions stems from following universal moral rules rather than considering their outcomes. The emphasis in this theory is placed on the attention behind an action and the adherence of the universal law, rather than the outcomes resulting from those actions. A core concept in this theory is autonomy, meaning that individuals should be capable of determining moral correctness through rational reflection. This applies to engineers as well; they can utilize this theory as a guide for their design by making choices and drawing conclusions through sound reasoning. In engineering practice, sound reasoning involves logical analysis of potential consequences, consideration of ethical implications, and adherence to moral principles such as respect for human dignity, fairness, and the promotion of societal well-being. Therefore, when engineers apply deontological principles, they are expected to engage in ethical decision-making that is both logically consistent and morally justifiable.

- **Virtue ethics**, differing from utilitarianism and Kantian theory, focuses on individuals' character traits rather than their actions or strict adherence to moral rules. It emphasizes the positive qualities individuals should develop, like honesty and courage, to lead morally honorable lives. This perspective stresses moral autonomy, empowering engineers in their design process to distinguish what constitutes virtuous behavior through their own reasoning and judgment. Consequently, engineers have the autonomy to cultivate virtues such as integrity, empathy, and responsibility, allowing them to make ethical decisions in alignment with their professional practice.

The theories mentioned above guide me too as a soon to be engineer in the design process of my graduation project. However, ethical theories also raise criticisms. Further explanation regarding an objection concerning utilitarianism in relation to the ambient sound visualizer is desired. One objection that may apply to that prototype is distributive justice.

If we look at whether the ambient sound visualizer should be developed, utilitarianism would probably contend against its development. Some individuals in the household may oppose the idea of having microphones installed due to privacy concerns, which can be seen as a negative consequence of the product's use. Thus, some might say that in this case the product does not contribute to the greatest happiness or benefit for the majority of people since the use of the product might involves negative consequences as well, for possibly quite a lot of people.

However, in this scenario, one person in the household might derive significant benefits from the product. If the implementation of this product facilitates improved sleep for deaf and hard of hearing children, it hypothetically stands to enhance their mental, physical, and developmental well-being. Again, this potential outcome would represent a significant benefit and might hold immense value. Additionally, other housemates also might benefit from the improved sleep of the deaf or hard of hearing child as well. If the child's sleep remains undisturbed, characterized by minimal awakenings and absence of crying, it is probable that other members of the household will also experience reduced disturbances, potentially leading to improved sleep quality for all. Still, housemates may experience slight discomfort due to privacy concerns. This unequal distribution of advantages (improved sleep quality) and disadvantages (privacy concerns) among individuals raises questions about distributive justice.

Despite this, I believe that in a case like this the overall happiness or benefit experienced by the individual user of the product, and potentially some other housemates, who benefits from the product outweighs the potential privacy concerns of the housemates. Although the product might not maximize happiness or benefit for the majority, it still aims to optimize the overall good and minimize the negative consequences of the products use as much as possible ultimately aligning with utilitarian principles.

5.2.4 Conclusion of ethical reflection

In this section, concluding remarks, design requirements, impact statements and limitations are recommendations for the future are elaborated on.

Ethical Conclusions

The following ethical conclusions were drawn, in subsection 2,3 and 4, from the ethical reflection:

- **Safety and Quality Prioritization**: Prioritizing safety and quality in product design is essential when developing toys or products for children. This aligns with ethical principles by ensuring the well-being of children, even if it increases costs. Implementing cost-effective safety measures that do not compromise quality is a viable approach.
- **Utilitarianism and Privacy Concerns**: While utilitarianism suggests that actions should maximize overall good, it also highlights the need to address privacy concerns associated with the ambient sound visualizer. Balancing benefits and potential negative consequences is crucial.
- **Ethical Cycle Evaluation**: The ethical cycle, including problem analysis and options for action, emphasized that safety and quality should be prioritized over cost considerations. A structured approach to ethical decision-making helps navigate these dilemmas.
- **Professional Ethical Principles**: Adhering to professional ethical principles, such as legal compliance, client confidentiality, fair treatment, transparency, and proper attribution, is fundamental to the project. These principles ensure ethical integrity throughout the design process.

Design requirements

Requirements:

1. (Ethical reflection – EU directives (Designing toys for children)) The accessible edges, protrusions, cords, wires, and fastenings of the product need to be made and constructed in a way that minimizes the possibility of physical harm occurring from contact with them.
2. (Ethical reflection – EU directives (Designing toys for children)) The product, along with all its components must possess sufficient mechanical robustness and, when necessary, stability to endure the pressures experienced during usage without fracturing or warping, thereby minimizing the potential for physical harm.
3. (Ethical reflection – EU directives (Designing toys for children)) The temperatures generated by the electronics must not hurt the users.
4. (Ethical reflection – EU directives (Designing toys for children)) The product should be made out of toxic free materials.
5. (Ethical reflection – EU directives (Designing toys for children)) The product should be made out of water-resistant and durable materials for electronic components to ensure reliability and longevity, even in adverse conditions.
6. (Ethical reflection – EU directives (Designing toys for children)) The product does not ignite when directly exposed to a flame, spark, or other potential source of fire.
7. (Ethical reflection – EU directives (Designing toys for children)) The product is not readily flammable, meaning the flame extinguishes as soon as the fire source is removed.
8. (Ethical reflection – EU directives (Designing toys for children)) If the product does ignite, it burns slowly and has a low rate of flame spread.
9. (Ethical reflection – EU directives (Designing toys for children)) Regardless of the toy's chemical composition, it is engineered to mechanically delay the combustion process.
10. (Ethical reflection – EU directives (Designing toys for children)) The electronic system of the product may not use voltages higher than 24V.
11. (Ethical reflection – EU directives (Designing toys for children)) The electronic connections within the product must be adequately insulated and mechanically protected to minimize the risk of electrical shock.
12. (Ethical reflection – EU directives (Designing toys for children)) The product must remain operational and secure even in the event of system malfunctions, external factors, or failures.

Limitations

Many aspects could have been approached differently. Alternative ethical theories and perspectives abound, offering endless possibilities for consideration. Similarly, a multitude of ethical dilemmas could have been explored during the ethical cycle, given the ever-expanding array of scenarios warranting reflection. Ethical reflection is boundless, although this report must adhere to finite constraints due to time limitations.

Moving forward, it would be beneficial to conduct multiple iterations of the ethical cycle, encompassing a comprehensive range of ethical dilemmas. Moreover, refining my personal code of conduct and perhaps comparing it with that of others could further enhance ethical practices. While the avenues for improvement are limitless, each instance of ethical reflection remains invaluable.

The future in society

In considering future shifts, it's essential to contemplate how advancements in technology could further address the challenges faced by individuals with disabilities, such as deaf and hard-of-hearing children. The project's focus on developing solutions to improve the sleep quality of these children highlights the importance of addressing their unique needs and challenges.

Looking ahead, there's potential for further innovation in this area, particularly in leveraging emerging technologies to create more effective and accessible solutions. For example, future iterations of the project could explore the integration of wearable devices or smart sensors to monitor sleep patterns and provide personalized interventions in real-time. Additionally, advancements in artificial intelligence and machine learning could be harnessed to enhance the efficacy of interventions by analyzing data and adapting strategies based on individual needs and preferences.

Moreover, as society becomes increasingly interconnected and technologically reliant, there's an opportunity to leverage technology to foster greater inclusivity and support for individuals with disabilities. By designing products and services that are universally accessible and inclusive, we can help break down barriers and promote equal participation in all aspects of life.

Furthermore, considering the broader societal implications, addressing the sleep difficulties of deaf and hard-of-hearing children not only improves their quality of life but also contributes to a more equitable and inclusive society. By prioritizing the needs of marginalized groups and advocating for greater awareness and support, we can work towards creating a society where everyone has the opportunity to thrive.

In conclusion, by continuing to innovate and collaborate, we can drive positive change and create a future where technology serves as a catalyst for inclusion and empowerment for individuals of all abilities.

5.3 Interview with interaction and product designer

On Wednesday, June 19th, 2024, from 12:00 until 13:30, I conducted an interview with Paco Busser, an interaction and product designer at RDGkompagne. RDGkompagne is the largest supplier in the Netherlands in the field of communication aids, adapted controls, and environmental controls for people with disabilities. The interview took place at RDGkompagne's office in Utrecht.

During our conversation, I presented two products: the Family Locator and the Ambient Sound Visualizer, and I shared the future plans for these devices. For the Ambient Sound Visualizer, the goal is to upgrade from a single microphone and a cardboard box base to a design featuring five microphones and a ball with a frame/base. For the Family Locator, the vision is to transition from a device requiring active user contribution to one that operates passively, tracking users in the background without their direct interaction.

Busser provided invaluable insights into the steps and requirements necessary to bring these products to market. He began by explaining that these devices are considered medical products, which I did not know before the interview. Introducing these devices as medical products requires obtaining CE marking; since they are not highly intensive medical devices, they fall under Class I, the lightweight class of medical devices. Every action taken in the design and production process must be well-documented, substantiated, and justified, highlighting the importance of thorough and transparent documentation. He stressed that it is crucial to document all decisions and support them with arguments derived from various types of research: market/trend analysis, technical/literature review, and user tests.

A comprehensive risk analysis is also crucial, with the understanding that some residual risk will always remain. Busser highlighted the importance of ensuring the products are of high quality and stability, and he advised preparing for potential issues by offering services such as a help desk or immediate product replacement. He suggested consulting the EU directives for Class I medical devices and ensuring all aspects of the product are production-ready. This includes having finalized designs and ensuring all components, like PCBs, are professionally designed rather than using temporary solutions like breadboards. Safety is paramount, with considerations such as eliminating sharp edges and ensuring all electrical components are properly fused.

Busser also emphasized the importance of market research to justify the products' value, especially when presenting the ideas to colleagues or potential manufacturers. He expressed enthusiasm for both products but stressed that they could only move forward once all designs were finalized and production-ready. He acknowledged the potential difficulty users might face when installing the Family Locator, suggesting a need for a more user-friendly implementation that doesn't require technical expertise and a lot of effort to get it working.

Moreover, he highlighted the importance of addressing privacy concerns, particularly for the Ambient Sound Visualizer. Ensuring that data is processed locally without being sent to the cloud, and clearly explaining these privacy measures to users, is essential.

In conclusion, Paco Busser advised focusing on thorough literature and technical research, conducting user tests, and paying close attention to privacy issues. He reiterated the importance of documenting all decisions and supporting them with arguments derived from market, technical, and user research. Additionally, he emphasized that research related to Class I EU medical device regulations needs to be conducted. He expressed hope for continued collaboration in the future and looked forward to seeing the progress of these products. This interview provided critical insights into the steps necessary to transform these innovative ideas into market-ready products, emphasizing the importance of compliance, safety, and user-centric design.

5.3.1 New Design Requirements from interview with interaction and product designer

During an interview with an interaction and product designer, several crucial design requirements were identified. These requirements focus on the necessary approaches and enhancements needed as the products prepare for market entry. Below is a list of essential design criteria to guide the development of a prototype.

- (Interaction and product designer – Interview) Both products must follow the EU directives for class 1 medical devices to obtain the CE marking, which is mandatory when they are placed on the market.
- (Interaction and product designer – Interview) Both products should be user-friendly and easy to install without requiring much effort.

5.4 Co-design process with client continues

After interruption of interviews and ethical reflections the co-design process continued.

Prototype improvements for Co-Design session three

After the conduction of a second round of co-design iterations, interview with an expert and ethical reflections the improvement process of the prototypes continued. This resulted in high-fidelity prototypes with designs nearing the final product stage. This last improvement round ensured that the prototypes are ready for real-world testing. Precise documenting on how to build both improved prototypes can be found in chapter 6.
For readable, a short explanation of the improvements will be given in this section.

The Family Locator

The Family Locator has been enhanced with new functionalities. If the remote of family member one disconnects, the user interface will now indicate this by blinking yellow LEDs around the profile picture. Additionally, all previously unconnected LED strips have been connected and placed around the pictograms, ensuring every pictogram is surrounded by an LED strip.

The Ambient Sound Visualizer

The Ambient Sound Visualizer has been enhanced with a completely new working prototype. A larger base and white ball were printed to accommodate future upgrades. The new base is designed to house a Raspberry Pi instead of a separate laptop, making it more compact and integrated. The base features rounded edges for safety, as shown in figures 5.37 and 5.38. The base includes five holes for microphones, three front holes for buttons, and holes for 3mm LEDs to indicate button activation. At the back, there is a hole for an on/off switch and another for a potentiometer. Not all buttons were connected yet, as the main objective was to get the LEDs to react to ambient sounds first.

When everything was assembled, it became clear that the USB microphones occupied a significant amount of space within the base. To manage this, a lunch box was attached to the bottom of the base to gather all the electronics.

Details on how this was realized can be found in Chapter 6.

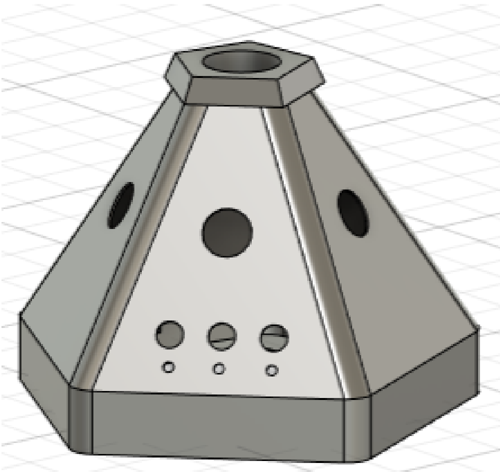

Figure 5.37: Design of front side of the base of the Ambient Sound Visualizer

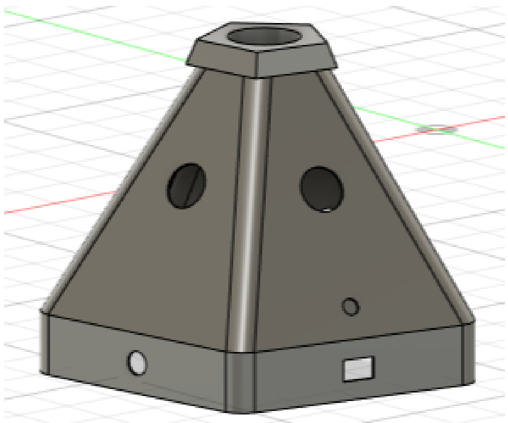

Figure 5.38: Design of back side of the base of the Ambient Sound Visualizer

5.4.1 Co-design session three

On Monday, July 1st, 2024, a brief co-design session was held with the client in the living room of her parents' house. The meeting took place from 2:30 PM to 2:50 PM, immediately following an evaluation session with the client's daughter, which the client could not attend due to work commitments.

The session began with a demonstration of the Ambient Sound Visualizer. The client expressed her satisfaction, stating, "It reacts really well." She was also pleased with the Family Locator, providing positive feedback overall. While there were no additional comments beyond the positive remarks, I noted that I would be making some adjustments to the Ambient Sound Visualizer, specifically refining the compartment at the bottom that houses some of the electronics.

The client inquired about her daughter's thoughts on the designs, and I confirmed that the overall response had been very positive. Although we did not discuss any new design requirements, we explored potential future developments for the products, leaving both the client and her daughter as very satisfied co-designers.

New design requirements from Co-design session three

There were no new design requirements that came to light in this co-design session

5.4.2 Conclusion

This section provides a comprehensive overview of the specification process for both prototypes, focusing on the design requirements. A comprehensive set of design requirements has been formulated, which can be categorized using the MoSCoW prioritization method [58]. This method organizes requirements into four main groups: Must, Should, Could, and Won't have.

- Must: Essential requirements that are critical for the solution's success and must be implemented.
- Should: Important requirements that contribute to the solution's success but are not absolutely essential.
- Could: Desirable requirements that enhance the solution but are not crucial.
- Won't have: Non-essential requirements that can be excluded without negative impact on the solution. These may be included at discretion.

All design requirements will be categorized according to this method. Each requirement will include a prefix indicating its origin for clarity. To enhance visual differentiation, distinct colors will be assigned to each origin, accompanied by a legend to illustrate the color distribution. **Legend (color = __origin__):**

- purple = Client
- blue = Assistive Technology Expert
- cyan = Self-Formulated
- violet = Interaction and Product Designer
- brown = Ethical Reflection - EU Directives (Designing Toys for Children)

5.4.3 Design Requirements Categorization

Must have:

1. (Ethical reflection – EU directives (Designing toys for children)) The accessible edges, protrusions, cords, wires, and fastenings of the product need to be made and constructed in a way that minimizes the possibility of physical harm occurring from contact with them.
2. (Ethical reflection – EU directives (Designing toys for children)) The product, along with all its components, must possess sufficient mechanical robustness and, when necessary, stability to endure the pressures experienced during usage without fracturing or warping, thereby minimizing the potential for physical harm.
3. (Ethical reflection – EU directives (Designing toys for children)) The temperatures generated by the electronics must not hurt the users.
4. (Ethical reflection – EU directives (Designing toys for children)) Both products must remain operational and secure even in the event of system malfunctions, external factors, or failures.
5. (Interaction and product designer – Interview) Both products must follow the EU directives for class 1 medical devices to obtain the CE marking, which is mandatory when they are placed on the market.

Should have:

1. Ethical Reflection - EU Directives (Designing Toys for Children) The product should be made out of toxic-free materials.
2. Ethical Reflection - EU Directives (Designing Toys for Children) The product should be made out of water-resistant and durable materials for electronic components to ensure reliability and longevity, even in adverse conditions.
3. Ethical Reflection - EU Directives (Designing Toys for Children) The electronic system of the product may not use voltages higher than 24V.
4. Ethical Reflection - EU Directives (Designing Toys for Children) The electronic connections within the product must be adequately insulated and mechanically protected to minimize the risk of electrical shock.
5. (Ethical reflection – EU directives (Designing toys for children)) The product does not ignite when directly exposed to a flame, spark, or other potential source of fire.
6. (Ethical reflection – EU directives (Designing toys for children)) The product is not readily flammable, meaning the flame extinguishes as soon as the fire source is removed.

7. (Ethical reflection – EU directives (Designing toys for children)) If the product does ignite, it burns slowly and has a low rate of flame spread.
8. (Ethical reflection – EU directives (Designing toys for children)) Regardless of the toy's chemical composition, it is engineered to mechanically delay the combustion process.
9. (Self formulated - State of the art) Both products must be adjustable to personal preferences and needs to make the user as comfortable as possible.
10. (Assistive technology expert - Interview) Both products should contribute to the reduction of the child's stress.
11. (Assistive technology expert - Interview) Both products should promote a sense of security.
12. (Self formulated - State of the art) Both products should include a designated place for storing hearing aids that is visible in the room and illuminated by lights.
13. (Self formulated - State of the art) Both products should provide users with clear feedback upon detecting and receiving information during communication.
14. (Self formulated - State of the art) Both products should be easy and intuitive for the user to use autonomously.
15. (Client – First co-design session) The user interface should use the pictograms that the client uses in their house for communication.
16. (Client – First co-design session) The user interface should use pictograms that are age-appropriate.
17. (Client – First co-design session) The ambient sound visualizer should have a dimmer to adjust the LED brightness.
18. (Client – First co-design session) The ambient sound visualizer should emit light that helps the child sleep rather than wake them up.
19. (Client – First co-design session) The ambient sound visualizer and the family locator could use the same color coding to maintain consistency with activities in different rooms.
20. (Client – First co-design session) The ambient sound visualizer might have a cry sensor to calm the child when needed.
21. (Client – Second co-design session) The Ambient Sound Visualizer should have a minimalist aesthetic and not be over-engineered.

Could have:

1. (Client - Second interview) Both products could be modular, allowing users to add only the necessary components.
2. (Client - Second interview) Both products could be sold as a package containing various parts, enabling users to personalize it according to their specific home environment.
3. (Client – First co-design session) The remote of the family locator could be an application, allowing family members to be tracked by their phone in the background instead of using a bulky remote.
4. (Client – First co-design session) The remote of the family locator could have a ”we are going to sleep” button to inform the child that the parents are going to sleep in a moment.
5. (Client – Second co-design session) The pictograms and profile pictures on the Family Locator could have NFC tags on the back of them, allowing the user interface layout to be personalized to one’s household and family situation.
6. (Assistive technology expert - Interview) Both products might use haptic feedback to provide the user with new information.

Won’t have:

1. -

6 REALISATION

In this chapter, the realization phase is presented, providing detailed documentation of the construction and functionality of the two prototypes: the Family Locator and the Ambient Sound Visualizer. This includes thorough explanations of the assembly, wiring schemes, designs, and other technical details necessary for replication. A comprehensive list of required components is provided, along with a step-by-step assembly guide.

6.1 Family Locator

The Family Locator is one of the final solutions that aims to improve the sleep quality of deaf and hard of hearing children that encounter sleeping difficulties. The Family Locator is shown in figure 6.1. It consists of separate devices: a user interface placed in the child's room and a remote kept close to family members. Ideally, each family member would have their own remote, but currently, there is only one. This remote has six buttons, each representing a different room. The user interface includes six pictograms (each representing/displaying a room) and two pictures (one for each parent) surrounded by LEDs. When a family member, such as Parent 1, presses a button to indicate their location in the house, the LEDs around the corresponding pictogram light up in the same color as the LEDs surrounding the picture of Parent 1. This way, the child knows where every family member is at any given time.

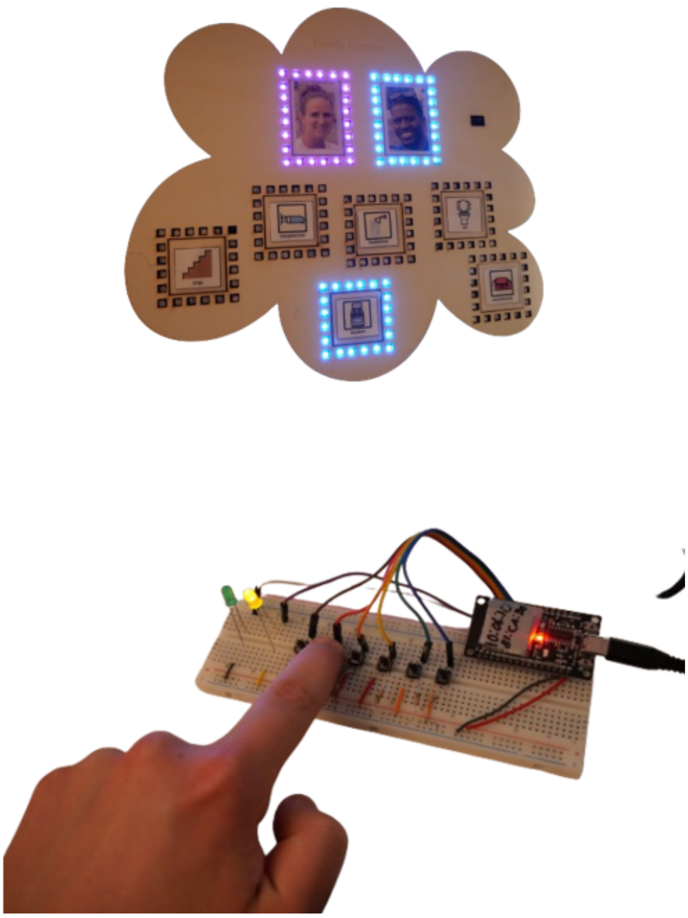

Figure 6.1: The final prototype of the Family Locator

Click here or use the link(`https://youtu.be/C18fvri47Tw`) to see a demo of the Family Locator.

6.1.1 Construction and Communication

The Family Locator remote consists of an ESP-32 micro controller that monitors the state of six buttons. When a button is pressed, the yellow LED lights up, indicating that the system has detected the button press. The green LED lights up when a message is successfully received by the user interface, informing the parent that the signal has reached the child's room.

When the remote is turned on, the ESP-32 continuously attempts to send a message to the ESP-32 in the user interface via a local WiFi connection. This message includes six boolean variables representing the states of the six buttons. The ESP-32 in the user interface reads these boolean values and processes them according to its programmed code. If one of the boolean values is high, the LEDs around the corresponding room will light up.

If the user interface fails to connect with the remote, the LEDs around the corresponding parent will blink yellow, as demonstrated in the accompanying video. The ESP-32 in the remote also verifies that the message sent to the user interface is received. If the message is successfully received, the green LED on the remote will light up.

The connections and communication protocols between the connections of both devices are shown in Figure 6.2

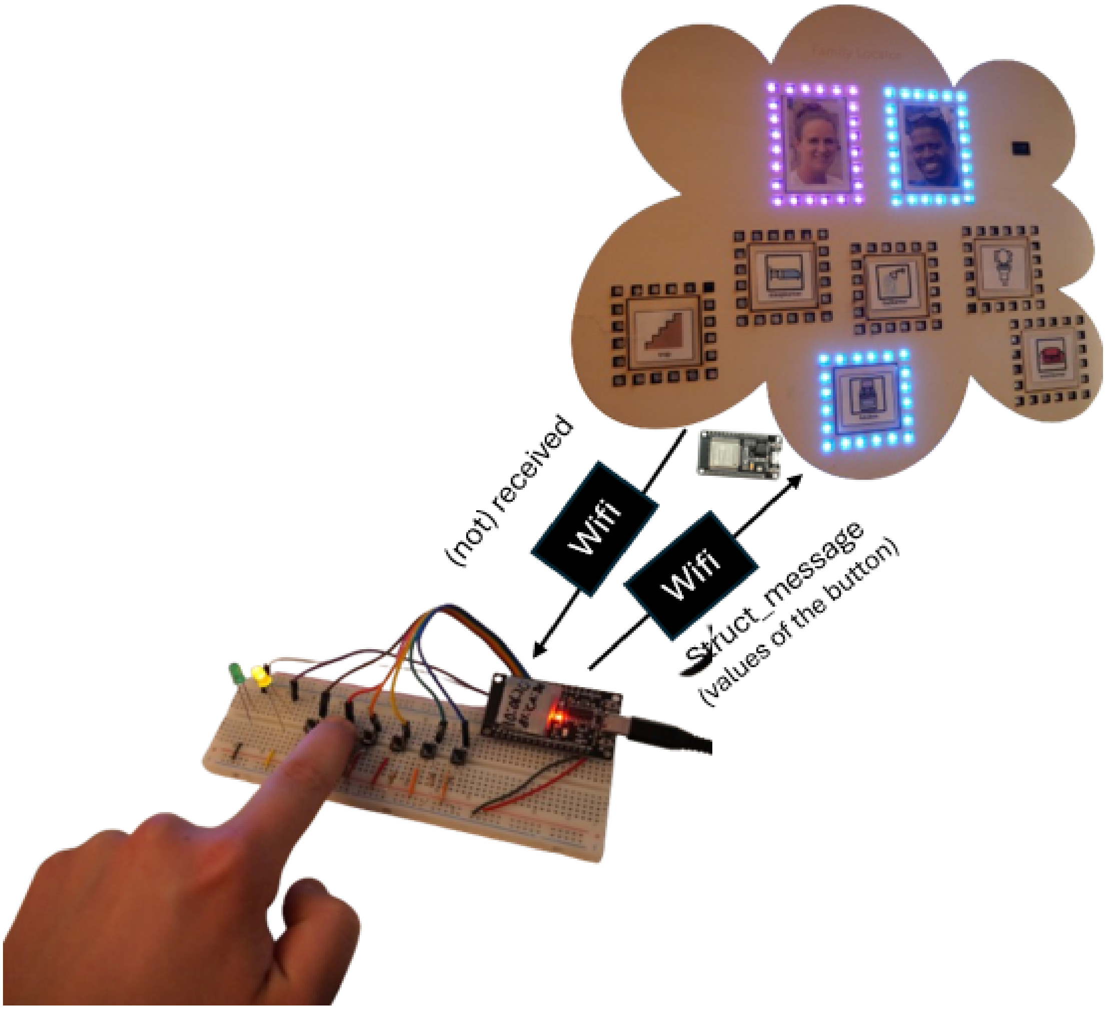

Figure 6.2: Visualization of all Family Locator components and their connections

Necessary components

- 6 x 5V programmable LED strips with 20 LEDs each
- 2 x 5V programmable LED strips with 24 LEDs each
- 2 x ESP-32 microcontrollers
- 6 x push buttons
- 1 x green 5mm LED
- 1 x yellow 5mm LED
- 6 x 10k Ω resistor (pull-down resistor)
- 1 x breadboard
- Multiple breadboard wires
- 2 x USB-C/micro-USB to USB-A connectors (depending on the ESP-32 port) for uploading code from a laptop
- 2 x power banks (to power the ESP-32s after uploading the code)
- Laser cut design file (`user interface family locator.pdf`) for the user interface and wood (plus access to a laser cutter)
- File containing the room pictograms (file is called `Pictograms.pdf`)
- Double-sided tape (to attach the pictograms to the user interface wood)
- Transparent silicon tape (to seal the pictograms)
- Code to upload to ESP-32 of the user interface (file is called `familyLocator_UserInterface.ino`, code can be found in section 10.3.3)
- Code to upload to ESP-32 of the remote (file is called `familyLocator_RemoteController.ino`, code can be found in section 10.3.1)
- Code to check the MAC addresses of both ESP-32s (called `check_mac_address.ino`10.3.2, code can be found in section 10.3.2) [59])

Step by step guide to assemble the Family Locator

First, the assembly of all technical components will be explained, of both the remote and the user interface. Following this, the assembly of the user interface layout will be explained.

Remote (transmitter)

1. **Upload code to remote ESP-32:**
   - Connect the remote ESP-32 to your computer using a USB-C/micro-USB to USB-A connector.
   - Open the Arduino IDE or preferred development environment.
   - Copy and paste the provided ESP Wi-Fi code from the `familyLocator_RemoteController.ino` into the IDE. item Modify the MAC address (`broadcastAddress[]`) to match the MAC address of the remote ESP-32. (If you don't know the MAC adress of the ESP-32 upload the code from the `check_mac_address.ino` file and read the description to find the mac address)
   - Upload the code to the remote ESP-32 microcontroller.
2. **Connect buttons and LEDs:**
   - Connect push buttons to the designated pins on the ESP-32 according to the wirwing scheme shown in figure Figure 6.3.

     Each button on the remote control corresponds to a specific room in the house as follows: Button 1, linked to pin 23, corresponds to the stairs; Button 2, connected to pin 22, corresponds to the bedroom; Button 3, allocated to pin 21, corresponds to the bathroom; Button 4, assigned to pin 19, corresponds to the toilet; Button 5, connected to pin 18, corresponds to the kitchen; and Button 6, linked to pin 5, corresponds to the living room.

     Additionally, each button requires a pull-down resistor connected from the ground line of the breadboard to the pin on the breadboard where the button's metal pin is connected to the ESP-32. Ensure that each button's metal pin is linked to this designated pin on the breadboard. Connect the breadboard's ground line to the GND pin of the ESP-32. One other metal pin per button should be connected to the breadboard's 5V line, which in turn should be connected to the ESP-32's Vin pin.
   - Connect the long leg of the yellow 5 mm LED to pin 17 and the short leg to the ground line on the breadboard and connect the long leg of the green 5 mm LED to pin 16 and the short leg to the ground line on the breadboard.
3. **Power configuration:**
   - Ensure the ESP-32 is powered using a power bank after uploading the code.
   - The yellow LED should indicate button press status when buttons are pressed. (The yellow LED will light up if a button on the breadboard is pressed)

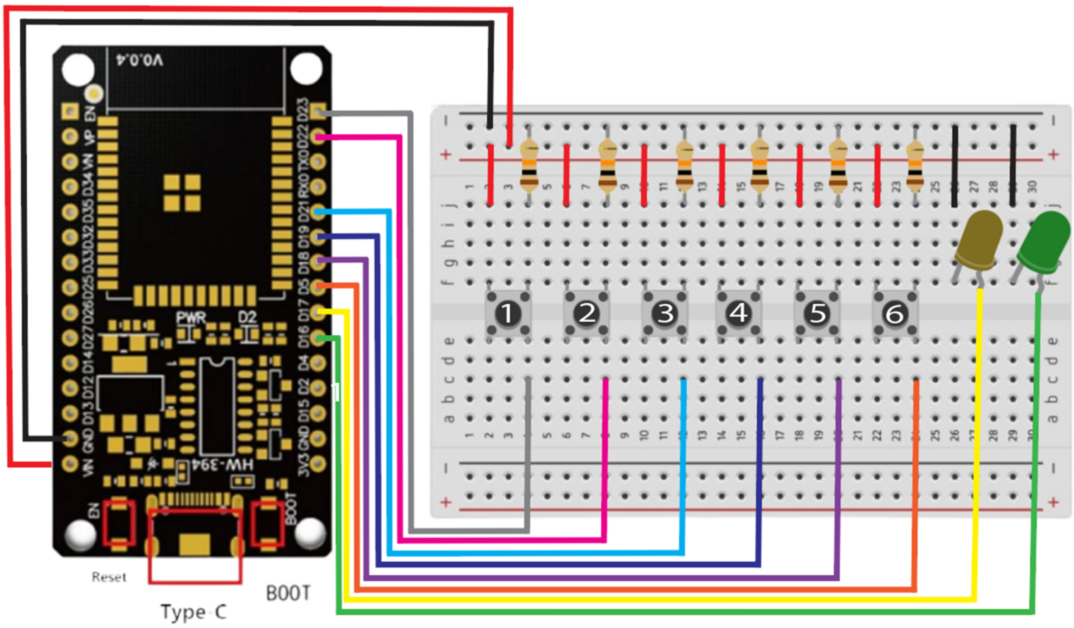

Figure 6.3: Wiring diagram parent locator remote

User interface (receiver)

1. **Upload code to user interface ESP-32:**

   - Connect the ESP-32 to your computer using a USB-C/micro-USB to USB-A connector.
   - Open the Arduino IDE or preferred development environment.
   - Copy and paste the provided ESP code from the `familyLocator_UserInterface.ino` file into the IDE.
   - Modify the MAC address (`broadcastAddress[]`) to match the MAC address of the remote ESP-32. (If you don't know the MAC adress of the ESP-32 upload the code from the `check_mac_address.ino` file and read the description to find the mac address)
   - Upload the code to the ESP-32 micro controller of the user interface.

2. **Connect LEDs:**

   - Connect the programmable LED strips to the designated pins on the ESP-32, as specified in Figure 6.4, illustrating the wiring diagram of the user interface components. Each LED strip is allocated to a specific room: LED strip 1 (connected to pin 14) for the stairs, strip 2 (pin 27) for the bedroom, strip 3 (pin 26) for the bathroom, strip 4 (pin 25) for the toilet, strip 5 (pin 33) for the kitchen, and strip 6 (pin 32) for the living room. Ensure all grounds are connected to the GND pin and all strips to a 5V line, which is then connected to the Vin pin of the ESP-32. strip P1 (pin 13) designates parent 1, and P2 (pin 12) designates parent 2.

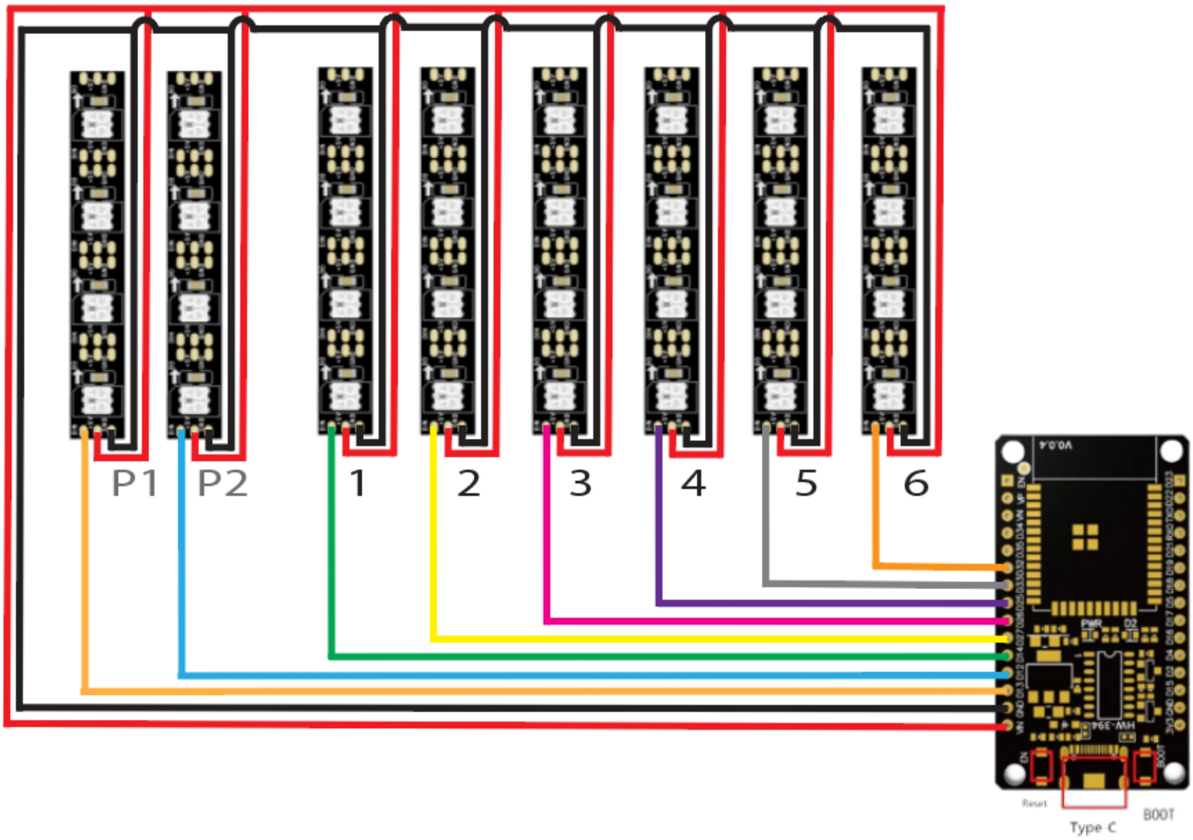

Figure 6.4: Wiring diagram of the connections between the components in the user interface.

3. **Verify connection:**
   - Ensure LEDs are properly connected and powered.
   - Test the ESP-32 by powering it with a suitable power bank.
4. **Configure and test:**
   - Once powered, the LEDs should reflect the status sent from the remote ESP-32.
   - Test button presses on the remote ESP-32 to confirm LED functionality.
   - Press buttons on the remote ESP-32 and verify LEDs on the user interface ESP-32 light up accordingly.
   - Check serial monitor for debug messages to ensure data transmission is successful.

Assembly of the User Interface Layout

- Use a laser cutter to cut the `user_interface_family_locator.pdf` file (see Figure 6.5) out of wood.
- Cut out the pictograms from the `Pictograms.pdf` file (see content of the file in figure 6.6, seal them with transparent silicone, and affix them to their corresponding locations on the user interface using double-sided tape. Refer to Figure 6.7 for the correct layout.

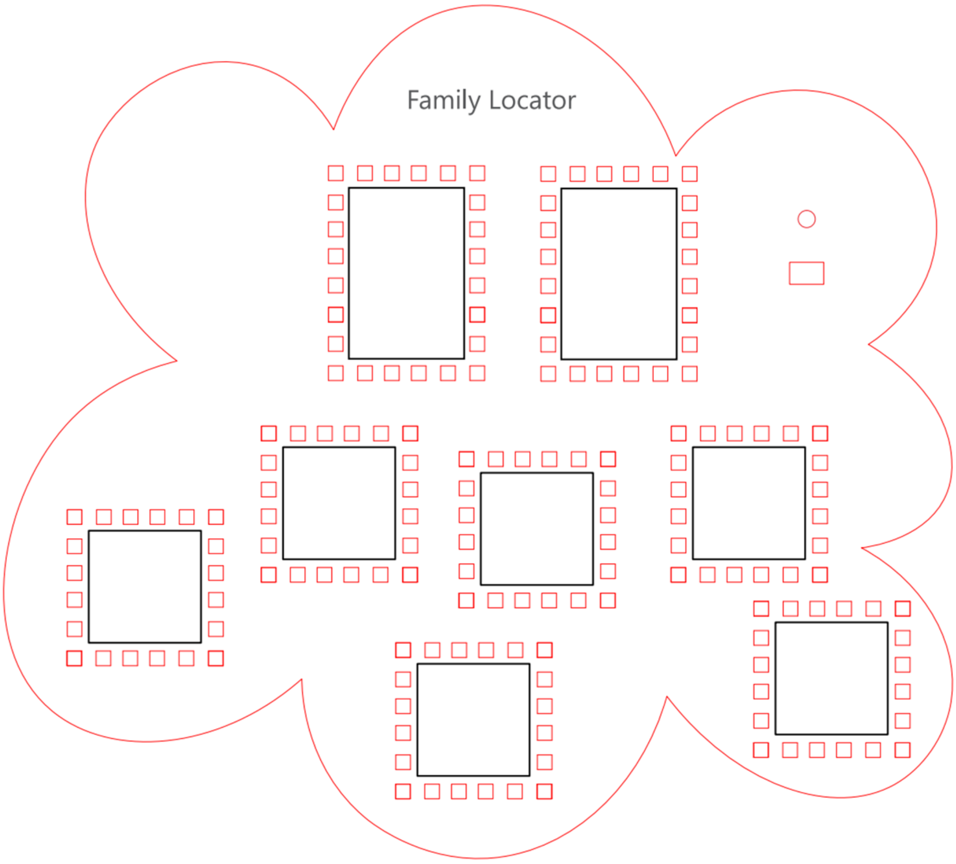

Figure 6.5: Design of final of the Family Locator's user interface.

Figure 6.6: Pictograms used in the final user interface. These pictograms are used by the client at home and were provided by her for integration into the user interface.

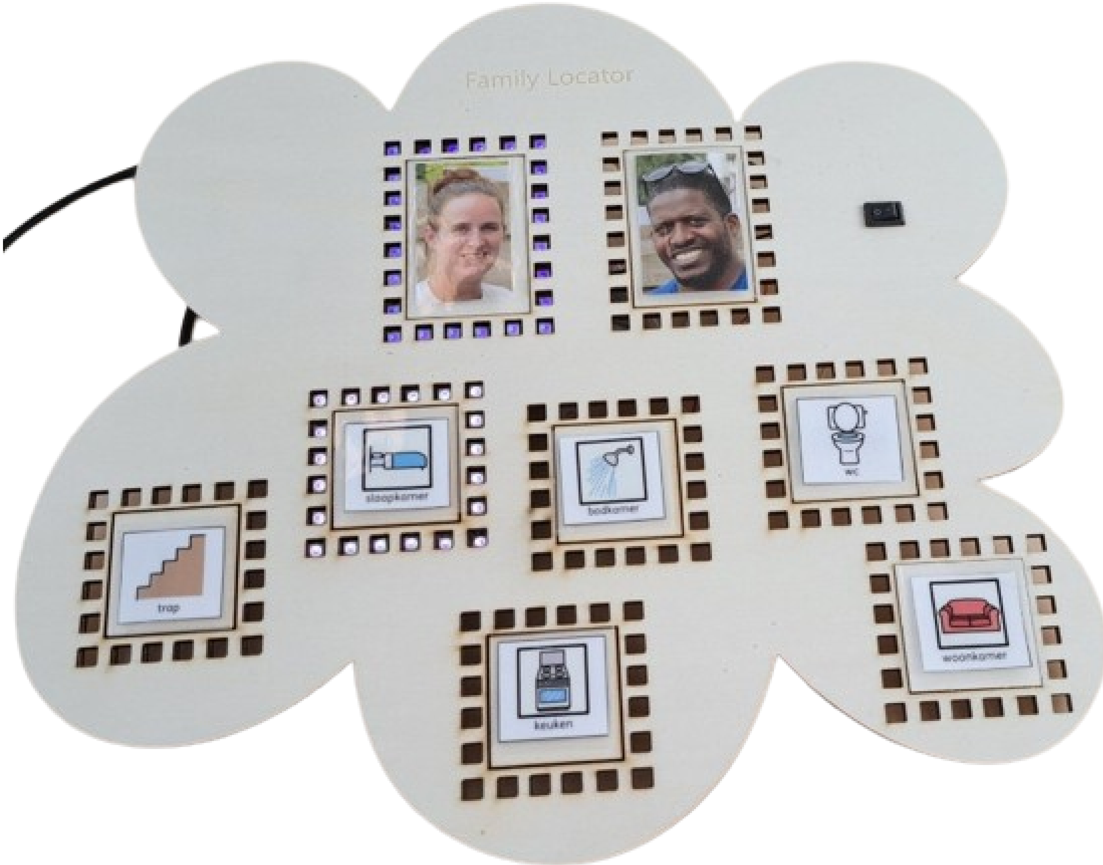

Figure 6.7: Layout of user interface

6.2 Ambient Sound Visualizer

The Ambient Sound Visualizer is one of the final solutions designed to enhance the sleep quality of deaf and hard-of-hearing children who experience sleeping difficulties. As depicted in Figure 6.8, the device comprises an LED ball with individually addressable LEDs one arranged within each triangle. Its base incorporates five microphones, one positioned on each side, alongside a potentiometer for adjusting LED brightness. Additionally, the top of the ball is flat and features five extra LEDs.

The device operates by capturing sounds through its microphones. When a microphone detects sound, the corresponding LEDs that side of the ball light up proportionately to the volume of the sound. Louder sounds result in brighter LEDs, providing a visual representation of ambient noise levels.

Figure 6.8: The final prototype of the Ambient Sound Visualizer

Click here or use the link(https://youtu.be/O1pKGMvQNu8) to see a demo of the Ambient Sound Visualizer.

6.2.1 Construction and Communication

The Ambient Sound Visualizer operates with a Python script running on a laptop, which processes audio signals from five directional microphones connected to a USB hub housed inside a lunch box beneath the LED ball's base. This script calculates the volume and frequency of each signal and transmits this data via serial communication to an ESP-32 microcontroller. The ESP-32 is linked to individually addressable LEDs and a potentiometer for adjusting maximum brightness across all LEDs.

Upon receiving data from the microphones, the ESP-32 processes the volume information to adjust the brightness of corresponding LEDs on the ball, providing a visual representation of sound intensity. Although frequency data is currently unused in the visualization, it is integrated for potential future enhancements.

Refer to Figure 6.9 for an overview of the connections within the Ambient Sound Visualizer.

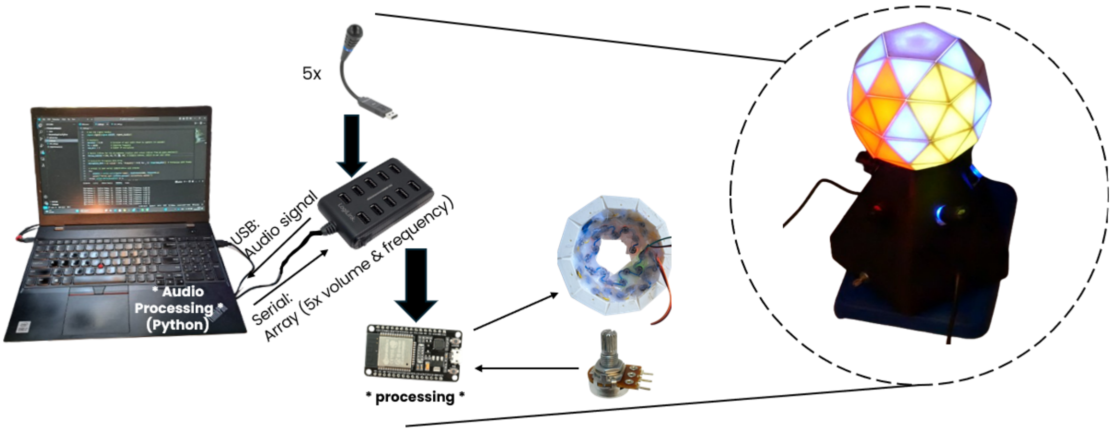

Figure 6.9: An overview of all the components and connections in the Ambient Sound Visualizer

Necessary components

1. 3 STL files of the ball design made by Whitey [3] and a 3D printer to print the files. The files can be found in the reference list or by clicking the following URL: `https://www.printables.com/model/40182-geodesick-rgb-led-spheres`.
2. STL file of the base
3. White filament.
4. Other filament for the base of the Ambient Sound Visualizer.
5. A bunch of individually addressable 5V LEDs.
6. 5x directional USB microphones.
7. ESP-32.
8. Potentiometer (10 kΩ).
9. Duct tape.
10. USB hub.
11. A laptop with a USB port that can be connected to the USB hub.
12. Lunch box.
13. Python code to run the whole system, see section 10.4.3.
14. Python code to see which microphones are connected, see section 10.4.2.
15. Code for ESP-32, see section 10.4.1.

Step by step guide to assemble the Ambient Sound Visualizer

1. 3D print all parts of the ball and base components using the STL files. Use white filament for the ball and any other filament for the base. Refer to `https://www.printables.com/model/40182-geodesick-rgb-led-spheres` designed by Whity [3] for specific printer settings.
2. Assemble each half of the ball separately. Glue all the rings of one half together and solder all the LEDs onto this half, ensuring each triangle has a slot for an LED. Repeat for the other half. For soldering tips, refer to Whity's design at `https://www.printables.com/model/40182-geodesick-rgb-led-spheres`. Connect the LEDs to the pins of the ESP-32 as shown in Figure 6.10 without powering the ESP-32. Ensure there are no connections between ground and 5V using a multimeter. If everything is good, connect the ESP-32 to the USB hub (and the USB hub to the laptop) and verify all LEDs work. Then, insulate them and their wires with hot glue. Finally, glue the two halves together, ensuring all wires exit through the bottom hole of the LED ball. See Figure 6.11.
3. Attach the directional USB microphones to the USB hub. Position the USB cables from the outside to the inside of the base and secure them with duct tape to keep them in place. Repeat this for all four microphones. Plug them into the USB hub.

4. Connect the potentiometer to the ESP-32 according to the wiring scheme shown in figure 6.10.
5. Place the USB hub inside the lunch box. Make a hole in the lid and connect the microphones to it.
6. Connect the ESP-32 to the LEDs and potentiometer.
7. Upload the ESP-32 code (see section 10.4.1) to the ESP-32 microcontroller. This code receives data from the laptop and controls the LED brightness.
8. Use the Python script (see section 10.4.2) to verify which microphones are connected to the USB hub and functioning properly.
9. Check which COM port the ESP-32 is connected to and adjust it in the Python code.
10. Run the Python code (see section 10.4.3) on the laptop. This code processes the audio signals from the microphones. The system should now be operational, capturing sounds and lighting up the corresponding LEDs based on the sound volume.

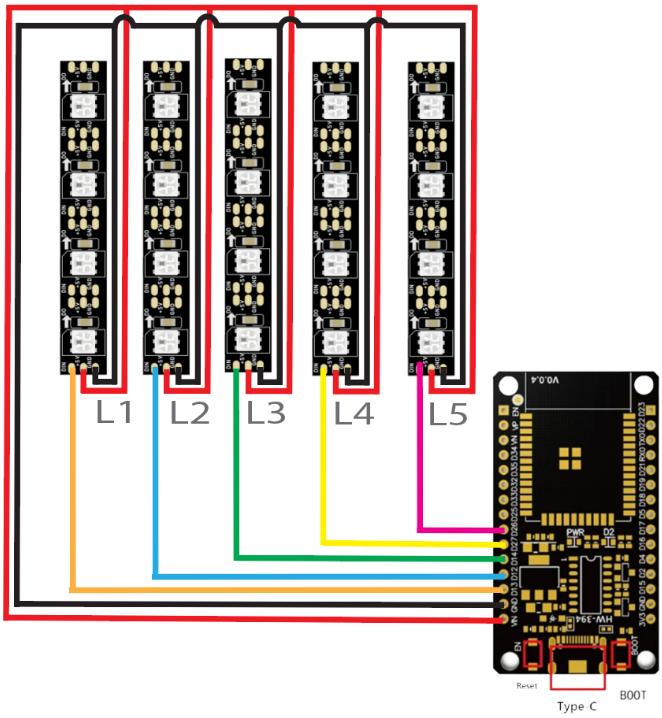

Figure 6.10: Wiring scheme of LED's inside the ball of the Ambient Sound Visualizer

Figure 6.11: LED ball assembly process: soldering LEDs and securing with hot glue

7 EVALUATION

7.1 User test

The user test was conducted on July 1, 2024, from 13:15 to 16:00 at the grandparents' home of the child of the client. The primary aim of this test was to evaluate the effectiveness and usability of two prototypes: the Ambient Sound Visualizer and the Family Locator. Specifically, the test sought to assess whether the Ambient Sound Visualizer emitted light that would wake up the child during sleep, whether the Family Locator's user interface utilized age-appropriate pictograms, and whether both products were intuitive enough for the child to use independently. By observing the child's interactions with these devices in a familiar environment, valuable insights into their functionality and appeal could be gained.

7.1.1 Test Procedure

The user test was designed to follow a structured yet flexible approach, ensuring the child could engage naturally with both prototypes:

- Test 1: Introducing the Ambient Sound Visualizer to the child, allowing the child to explore its features in a familiar environment.
- Test 2: Conducting a nap user test using the Ambient Sound Visualizer to assess its effectiveness in promoting sleep.
- Test 3: Performing a user test with the Family Locator, focusing on the understanding of pictograms.

7.1.2 Setup

Equipment:

The following equipment was utilized during the test:

- Tripod
- Panasonic Lumix G90
- GoPro Action Camera – Hero 10

Location Setup

To facilitate the tests, the following arrangements were implemented in accordance with the outlined procedures:

1. Test 1: This test was conducted in the kitchen. The Panasonic Lumix G90 was mounted on a tripod, positioned to capture the child seated at the dining table. A laptop and the Ambient Sound Visualizer were set up on the dining table, ensuring they were powered on and ready for use.
2. Test 2: This test took place in the guest room. The Ambient Sound Visualizer was connected to a laptop and placed beside the child's bed on a chair to ensure close proximity during the nap. The Panasonic Lumix G90 was positioned behind the chair, directed at the bed, while the GoPro was placed on a cabinet next to the bed. The GoPro was set to Wi-Fi mode for remote recording, allowing the observer to monitor the child from outside the room without interference (see Figure 7.1).
3. Test 3: This test was conducted in the living room and did not utilize any recording equipment.

7.1.3 Observations and Findings

The first user test commenced with the introduction of the Ambient Sound Visualizer in the grandparents' dining room. This initial phase aimed to familiarize the child with the prototype, allowing her to engage freely. The observer set the scene by showcasing a previous prototype to help build trust and comfort. The child expressed a clear preference for the color red and displayed interest in several other hues.

To minimize distractions during the test, the grandparents briefly left the room. During this time, the child interacted with the visualizer, creating sounds and responding to its features with enthusiasm. At one point, she became distracted by a cat outside, showcasing her curiosity and playful nature.

Following this introduction, the grandmother returned, and the child was guided upstairs for test 3, the nap user test. Upon entering the bedroom, the child immediately expressed delight in seeing the Ambient Sound Visualizer, smiling broadly as she approached it. The grandmother facilitated the child's sleep ritual, gently helping her settle down while the observer remained at a distance, monitoring through the streaming go pro camera on a phone close to the room.

As the grandmother exited the room, the child began to play with the Ambient Sound Visualizer, engaging in a soft singing routine that typically helped her drift off to sleep. The visualizer responded to her sounds, capturing her attention as she adjusted her position for a better view. Remarkably, despite various external noises, including loud footsteps and passing cars, as well as the light-emitting ball reacting to those sounds, the child fell asleep within approximately 20 minutes and remained undisturbed for an hour, even amidst the distractions of loud noises and emitted lights.

After one hour of sleep, the mother returned from work and gently woke the child. Throughout the monitoring period, the Ambient Sound Visualizer functioned effectively. However, after 40 minutes, the GoPro overheated and stopped recording (this was not a big issue since the child was already asleep). Unfortunately, the backup Panasonic camera also failed after 50 minutes due to battery depletion, which was discovered after the user test.

After the child awakened from her nap, a brief evaluation discussion was held with the client while the child worked on completing a puzzle nearby. The child then walked up to the observer, expressing curiosity and began talking as the observer held the Family Locator's user interface in hand.

As she engaged with the pictograms, her recognition skills were notable. She said, ”Hey, that is mama, papa, mama, papa!” When asked about the meaning of a specific pictogram, she correctly identified it as ”douche” (shower). We then continued with other pictograms.

She initially confused the pictogram for the living room with a chair, although it actually represented a couch. After clarifying its meaning, she demonstrated her understanding by correctly identifying it as the living room when asked again. She successfully recognized the pictograms for the shower and toilet without hesitation, clearly grasping their meanings. When presented with the bedroom pictogram, she also recognized it immediately, showcasing her familiarity with the symbols. This process highlighted not only her comprehension of the pictograms but also her engagement and enthusiasm for the task at hand.

Following that, the child displayed a keen interest in the on/off button (see figure 7.2), demonstrating an intuitive understanding of the interface's functionality. Although the LED features had not been activated during this session due to previous tests, the interaction was nonetheless informative and valuable.

Figure 7.1: Set up of user test 2 in bedroom.

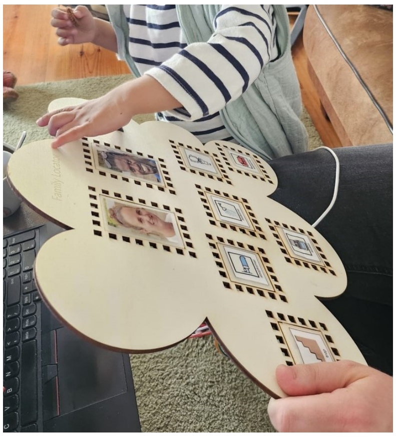

Figure 7.2: Child and user interface during test 3 with the Family Locator

7.1.4 Conclusion

The user tests provided valuable insights into the usability and effectiveness of the Ambient Sound Visualizer and the Family Locator. The evaluation successfully demonstrated that the Ambient Sound Visualizer emitted light that did not disrupt the child's sleep, she fell asleep within approximately 20 minutes and remained undisturbed for an hour. This was particularly noteworthy given the presence of light and various external distractions, confirming that the device effectively maintained a calming environment conducive to rest.

Furthermore, the assessment of the Family Locator's user interface revealed that the pictograms used were both age-appropriate and intuitive for the child. During the test, she exhibited impressive recognition skills, accurately identifying the meanings of several pictograms after minimal prompting. This highlighted her comprehension and engagement with the symbols, reinforcing that the interface is well-suited to her developmental level.

The child also demonstrated a keen interest in the Family Locator, particularly with the on/off button, further emphasizing the intuitive nature of the design. Her ability to navigate both prototypes independently showcased their user-friendly interfaces, allowing her to engage with the Ambient Sound Visualizer before her nap and interact effectively with the Family Locator afterward.

Overall, the findings indicate that both prototypes are progressing well toward meeting their design goals. While there are areas for improvement (such as ensuring the reliability of recording equipment) the results suggest that both the Ambient Sound Visualizer and the Family Locator hold significant promise for enhancing the user experience for children with hearing disabilities.

7.2 Design requirement evaluation

This evaluation chapter concludes by assessing whether the design requirements outlined in the specification phase (see Chapter 5) have been met. The evaluation will be presented both verbally and visually, with the following color codes: red for "not met," orange for "partially met," and green for "fully met." Each design requirement will be thoroughly elaborated upon. The requirements are categorized using the MoSCoW method [58], and each requirement is prefixed to indicate its origin for clarity. To enhance visual differentiation, bold formatting is assigned to each origin.

Must have:

1. **(Ethical reflection – EU directives (Designing toys for children))** The accessible edges, protrusions, cords, wires, and fastenings of the product need to be made and constructed in a way that minimizes the possibility of physical harm occurring from contact with them.
   Ambient Sound Visualizer: The design prioritizes safety by ensuring that all accessible edges are smooth and free of sharp corners to reduce the risk of injury.

Although a temporary lunch box was used underneath the base to house additional electronics due to time and space constraints, this does not compromise the overall safety. All cords are securely contained within the design, with the exception of a short USB cable connected to the laptop. This cable is securely glued in place and is intentionally kept very short to prevent it from being pulled out, thereby reducing the risk of choking or strangulation.
Family Locator: The Family Locator can be mounted on a wall, minimizing the risk of physical contact. All wires are concealed behind the user interface, making them neither visible nor accessible to children.

2. **(Ethical reflection – EU directives (Designing toys for children))** The product, along with all its components, must possess sufficient mechanical robustness and, when necessary, stability to endure the pressures experienced during usage without fracturing or warping, thereby minimizing the potential for physical harm.
   Ambient Sound Visualizer: The Ambient Sound Visualizer lacks robustness and stability due to the incorporation of temporary parts.
   Family Locator: The user interface of the Family Locator is robust and stable. However, the backside features several electronics mounted with duct tape as a temporary measure.

3. **(Ethical reflection – EU directives (Designing toys for children))** The temperatures generated by the electronics must not hurt the users.
   Ambient Sound Visualizer: A risk analysis has not yet been conducted for the Ambient Sound Visualizer.
   Family Locator:A risk analysis has not yet been conducted for the Family Locator.

4. **(Ethical reflection – EU directives (Designing toys for children))** Both products must remain operational and secure even in the event of system malfunctions, external factors, or failures.
   Ambient Sound Visualizer: The USB microphones in the ambient sound visualizer occasionally become disconnected. When this occurs, there is no specific indication that the disconnection has happened. Therefore, this requirement is not fully met as the device does not remain functional during these instances. However, it continues to maintain security.
   Family Locator: If the remote of one family member gets disconnected from the ESP-32 connected to the user interface, both devices indicate this malfunction. The remote stops showing a olive blinking light, and the user interface displays yellow blinking LEDs around the picture of the corresponding family member. While other malfunctions may occur, the system provides substantial feedback to the user and stays secure.

5. **(Interaction and product designer – Interview)** Both products must follow the EU directives for class 1 medical devices to obtain the CE marking, which is mandatory when they are placed on the market.

Ambient Sound Visualizer: These directives have not yet been researched, as this is a prototyping process and not yet a market launch process.
Family Locator: These directives have not yet been researched, as this is a prototyping process and not yet a market launch process.

Should have:

1. **(Ethical reflection – EU directives)** Both products should be made out of toxic-free materials.
   Ambient Sound Visualizer: The 3D-printed parts of the Ambient Sound Visualizer are made from PLA filament, which is biodegradable and non-toxic according to the RIVM [60]. However, the internal technology components are potentially not entirely free of toxic materials.
   Family Locator: The remote of the Family Locator lacks an encasing, making it unsafe to use due to the potential toxicity of the internal technology components. Additionally, the user interface is partly made of wood, which cannot be guaranteed to be toxin-free, and the technology on the back of the user interface also has the potential to contain toxic materials.

2. **Ethical Reflection - EU Directives (Designing Toys for Children)** Both products should be made out of water-resistant and durable materials for electronic components to ensure reliability and longevity, even in adverse conditions.
   Ambient Sound Visualizer: The Ambient Sound Visualizer is far from Waterproof.
   Family Locator:The Family Locator is far from Waterproof.

3. **(Ethical reflection – EU directives (Designing toys for children))** The electronic system of the product may not use voltages higher than 24V.
   Ambient Sound Visualizer: The electronic system of the Ambient Sound Visualizer does not use voltages higher than 24V. It operates on 5V. However, the laptop connected to its power supply can be connected to a wall socket that handles 220V-240V.
   Family Locator: The electronic system of the Family Locator does not use voltages higher than 24V. It operates on 5V.

4. **(Ethical reflection – EU directives (Designing toys for children))** The electronic connections within the product must be adequately insulated and mechanically protected to minimize the risk of electrical shock.
   Ambient Sound Visualizer: All electronic connections are insulated using plastic from wires, hot glue, or duct tape. No metallic connections are exposed, ensuring that the prototype cannot be accidentally touched in a way that would cause an electrical shock.
   Family Locator: All electronic connections are insulated using plastic from wires, hot glue, or duct tape. No metallic connections are exposed, preventing electrical

shock upon touching the prototype. An exception is made for the pins of the ESP, but these do not pose a risk of electrical shock when touched.

5. **(Ethical reflection – EU directives (Designing toys for children))** The product does not ignite when directly exposed to a flame, spark, or other potential source of fire.
   Ambient Sound Visualizer: A risk analysis has not yet been conducted for the Ambient Sound Visualizer.
   Family Locator:A risk analysis has not yet been conducted for the Family Locator.

6. **(Ethical reflection – EU directives (Designing toys for children))** The product is not readily flammable, meaning the flame extinguishes as soon as the fire source is removed.
   Ambient Sound Visualizer: A risk analysis has not yet been conducted for the Ambient Sound Visualizer.
   Family Locator:A risk analysis has not yet been conducted for the Family Locator.

7. **(Ethical reflection – EU directives (Designing toys for children))** If the product does ignite, it burns slowly and has a low rate of flame spread.
   Ambient Sound Visualizer: A risk analysis has not yet been conducted for the Ambient Sound Visualizer.
   Family Locator:A risk analysis has not yet been conducted for the Family Locator.

8. **(Ethical reflection – EU directives (Designing toys for children))** Regardless of the toy's chemical composition, it is engineered to mechanically delay the combustion process.
   Ambient Sound Visualizer: A risk analysis has not yet been conducted for the Ambient Sound Visualizer. However, during the design process, it was taken into account that the device should not pose a fire hazard.
   Family Locator: A risk analysis has not yet been conducted for the Family Locator. However, during the design process, it was taken into account that the device should not pose a fire hazard.

9. **(Self formulated - State of the art)** Both products must be adjustable to personal preferences and needs to make the user as comfortable as possible.
   Ambient Sound Visualizer: The Ambient Sound Visualizer features a potentiometer that allows adjustment of the LED brightness to the desired level.
   Family Locator: Pictograms and pictures can be replaced by others. However, it could benefit from a potentiometer to adjust brightness of LEDs.

10. **(Assistive technology expert - Interview)** Both products should contribute to the reduction of the child's stress.
    Ambient Sound Visualizer: This has not been tested yet.

Family Locator:This has not been tested yet.

11. **(Assistive technology expert - Interview)** Both products should promote a sense of security.
Sound Visualizer: This has not been tested yet.
Family Locator:This has not been tested yet.

12. **(Self formulated - State of the art)** Both products should include a designated place for storing hearing aids that is visible in the room and illuminated by lights.
Ambient Sound Visualizer: The Ambient Sound Visualizer meets this requirement with a flat top on the LED ball.
Family Locator: The Family Locator does not have a designated place to store hearing aids. However, the Ambient Sound Visualizer can be used in conjunction with the Family Locator, making a separate storage location unnecessary as the Ambient Sound Visualizer already provides this feature.

13. **(Self formulated - State of the art)** Both products should provide users with clear feedback upon detecting and receiving information during communication.
Ambient Sound Visualizer: The device indicates when the microphones detect noise. However, if the system malfunctions, it does not provide any alert or signal to indicate that it has stopped responding to sound.
Family Locator: The remote clearly indicates whether the signal sent by pressing a button has been received by the user interface, with the olive 5 mm LED blinking to confirm the connection. Additionally, the user interface provides a notification when the connection is lost, indicated by the LEDs around the connected family member's device blinking yellow.

14. **(Self formulated - State of the art)** Both products should be easy and intuitive for the user to use autonomously.
Ambient Sound Visualizer: Currently, the child cannot independently start the Ambient Sound Visualizer system. However, during the evaluation, the child demonstrated an understanding that making sounds changes the colors on the Ambient Sound Visualizer.
Family Locator: During the user tests, the child showcased a clear understanding of the pictures and pictograms. However, the product has not yet been tested in a real-life setting with the LEDs activated. It has only been assessed in a deactivated state.

15. **(Client – First co-design session)** The user interface should use the pictograms that the client uses in their house for communication.
Family Locator:The Family Locator features pictograms that the client and her daughter use at home.

16. **(Client – First co-design session)** The user interface should use pictograms that are age-appropriate.

    Family Locator: The Family Locator features pictograms that the client and her daughter use at home, ensuring they are suitable for the child's cognitive level and easily understood. This was validated during the evaluation phase. In future iterations, these pictograms can be modified to accommodate the varying cognitive levels of other children.

17. **(Client – First co-design session)**
    The ambient Sound Visualizer should have a dimmer to adjust the LED brightness.

    Ambient Sound Visualizer: The Ambient Sound Visualizer has a potentiometer that adjusts the maximum brightness of the LEDs in the ball

18. **(Client – First co-design session)** The ambient sound visualizer should emit light that helps the child sleep rather than wake them up.
    Ambient Sound Visualizer: This design requirement was tested during the evaluation phase, and the child did not wake up during the nap. This suggests that the Ambient Sound Visualizer did not disturb the child. However, a single test is not sufficient to draw reliable conclusions.

19. **(Client – First co-design session)** The ambient sound visualizer and the family locator could use the same color coding to maintain consistency with activities in different rooms.
    The Ambient Sound Visualizer and the Family Locator do not use the same color coding. The Family Locator concept has evolved since this initial design requirements was established. The color coding for the LEDs around the pictograms now illuminates according to the color associated with the parent on the Family Locator.

20. **(Client – First co-design session)** The ambient sound visualizer might have a cry sensor to calm the child when needed.
    Ambient Sound Visualizer: The ambient sound visualizer does not have a cry sensor to calm the child when needed.

21. **(Client – Second co-design session)** The Ambient Sound Visualizer should have a minimalist aesthetic and not be over-engineered.
    Ambient Sound Visualizer: This design requirement is subjective. However, a minimalistic approach has been adopted, focusing solely on the ambient sound aspect of the prototype without incorporating a disco function. Ambient sounds are visualized with a single color that is connected to a certain direction, maintaining consistency while reacting to the volume of the sounds.

Could have:

1. **(Client - Second interview)** Both products could be modular, allowing users to add only the necessary components.
   Ambient Sound Visualizer: The Ambient Sound Visualizer is not modular. However, it is highly minimalist, containing only the necessary components.
   Family Locator: The Family Locator is somewhat modular, allowing for the replacement of pictograms and pictures with other ones.

2. **(Client - Second interview)** Both products could be sold as a package containing various parts, enabling users to personalize it according to their specific home environment.
   Ambient Sound Visualizer: The prototype is not currently available for sale, and it does not come as a package with penalization components. The only customize feature is the brightness of the LEDs.
   Family Locator: The prototype is not currently available for sale and does not include personalization components as a package. However, the Family Locator allows for some customization if the user prints out different pictograms and pictures.

3. **(Client – First co-design session)** The remote of the family locator could be an application, allowing family members to be tracked by their phone in the background instead of using a bulky remote.
   Family Locator: The remote of the family locator is not an application that is running in the background. It is a physical bulky remote.

4. **(Client – First co-design session)** The remote of the family locator could have a ”we are going to sleep” button to inform the child that the parents are going to sleep in a moment. Family Locator: The remote of the family locator does not have a ”we are going to sleep” button

5. **(Client – Second co-design session)** The pictograms and profile pictures on the Family Locator could have NFC tags on the back of them, allowing the user interface layout to be personalized to one's household and family situation.
   Family Locator: The pictograms and profile pictures on the Family Locator do not have NFC tags on the back of them.

6. **(Assistive technology expert - Interview)** Both products might use haptic feedback to provide the user with new information.
   Ambient Sound Visualizer: The prototype does not use haptic feedback.
   Family Locator: The prototype does not use haptic feedback.

Won't have:

1. -

In conclusion, while not all design requirements have been met, it is important to recognize that these requirements primarily focus on ensuring the safety of the child during real-life usage. This does not imply that the concept is flawed. The purpose of this thesis is to design a solution that aims to improve the sleep quality of deaf and hard-of-hearing children who encounter sleeping difficulties, with design requirements integral to the process. It is understood that the solution and its requirements can exist as a concept and do not necessarily need to be fully realized at this stage.

The unmet requirements serve as both inspiration and a starting point for future development. These requirements can be utilized in future work to improve both prototypes into fully realized products. Although enhancing the products will take time, both the Ambient Sound Visualizer and the Family Locator already perform their intended tasks effectively. This sets a solid foundation for ongoing refinement and development to ensure the creation of safe and reliable products for deaf and hard-of-hearing children.

8 DISCUSSION & FUTURE WORK

Extensive research, concept generation phases, co-design sessions, and ethical reflections have culminated in the development of two solutions aimed at improving the sleep quality of deaf and hard-of-hearing children experiencing sleeping difficulties. The specific challenges addressed by these products were identified through an evaluation of 28 questionnaires completed by parents of deaf and hard-of-hearing children distributed via Facebook. While the responses were anonymous, the 20-minute completion time suggests genuine participation. For future research, interviewing more participants, both online and in person, will enhance the reliability of responses. Additionally, conducting studies that directly monitor the sleep processes of deaf and hard-of-hearing children could provide more robust scientific data.

The literature review that was conducted for this thesis identified anxiety and poor sleep hygiene as key factors contributing to sleep problems. While time constraints limited the depth of this review, further exploration of sleep hygiene theories and alternative solutions is recommended. Interviewing sleep experts to validate research findings and reasoning would also strengthen future studies.

The co-design process involved close collaboration with a mother and her child with a hearing disability, offering a nuanced understanding of the problem domain. However, this approach introduced some bias, as design preferences such as incorporating the daughter's favorite color, purple, influenced the process. Future research should conduct multiple user tests with different children to obtain more reliable evaluations of design requirements.

The Ambient Sound Visualizer and the Family Locator prototypes, while promising, did not fully meet safety requirements. Future research should ensure safety compliance and focus on identifying optimal lights and colors that promote sleep. For example, while the visualizer currently uses randomly selected colors, scientific research could determine colors more conducive to inducing sleep. Additionally, exploring alternatives such as vibration motors could extend usability to deaf-blind individuals.

The Family Locator prototype's remote requires an encasing to reduce its current bulkiness. Developing a more compact remote or smartphone application with background tracking could enhance user experience.

Both prototypes heavily rely on visual stimuli (LEDs). Future research should explore whether visual information is the most effective stimuli for deaf and hard-of-hearing children or if tactile or auditory signals might be more beneficial.

This research faces limitations, including a scarcity of studies focused on sleep problems among deaf and hard-of-hearing children and factors influencing these issues. The complexity of sleep necessitates tailored approaches to address individual differences and specific needs.

In conclusion, while this research has provided valuable insights and developed two promising solutions to improve the sleep quality of deaf and hard-of-hearing children, significant areas for future exploration remain. Addressing these complexities requires a multifaceted approach, including expanding participant demographics, delving deeper into sleep hygiene theories, and validating findings through expert consultation and empirical studies. These efforts will ensure interventions are not only safe and effective but also specifically catered to enhancing the overall well-being and quality of life for deaf and hard-of-hearing children.

9 CONCLUSION

The primary question this thesis aimed to address was: ”How to design a solution that aims to improve the sleep quality of deaf and hard-of-hearing children who experience sleeping difficulties?” To answer this, multiple sub-questions of significant importance were explored.

A literature review was conducted to determine the factors causing sleeping problems, with the main issues identified being anxiety and poor sleep hygiene. Anxiety in these children is primarily caused by the lack of sensory stimuli when they are in bed, as it can be dark and quiet. To gather more specific data, a questionnaire was conducted with deaf and hard-of-hearing children and their families. The results revealed that many children have difficulties falling asleep and wake up multiple times during the night. This information was crucial in understanding the specific problems faced by these children and informed the design of the proposed solutions. These insights led to the development of two potential solutions: the Ambient Sound Visualizer and the Family Locator.

The Ambient Sound Visualizer displays ambient sounds to alleviate the child's anxiety during the sleep process, helping them feel connected to the world beyond their room by providing more sensory stimuli through light and sound visualization. The Family Locator is a user interface placed in the bedroom that shows the locations of family members in the house, providing the child with additional information similar to what hearing children receive from ambient sounds.

These products were designed using a co-design approach, involving the mother and her child with a hearing disability, which allowed for extensive feedback, concept generation, and user testing. This co-design process provided a deep understanding of the problem domain and led to the identification of multiple design requirements. Additionally, two interviews with experts were conducted to gather more feedback and information about the design requirements, and an ethical reflection was included to ensure the solutions align with ethical standards.

Although the proposed solutions did not meet all the requirements identified during the evaluation, this does not indicate a flaw in the concept. The main focus of these requirements is to ensure the safety of the child during real-life usage. The purpose of this thesis was to design solutions that improve the sleep quality of deaf and hard-of-hearing children with sleeping difficulties, using the design requirements as a foundation. It is understood that the solution and its requirements can exist as a concept and do not need to be fully realized at this stage.

The unmet requirements serve as both inspiration and a starting point for future development. These requirements can be utilized in future work to enhance the prototypes into fully realized products. Although further enhancement will take time, both the Ambient Sound Visualizer and the Family Locator already perform their intended tasks effectively. This provides a solid foundation for ongoing refinement and development to ensure the creation of safe and reliable products for deaf and hard-of-hearing children.

REFERENCES

[1] A. H. Mader and W. Eggink, “A Design Process for Creative Technology,” in *Proceedings of the 16th International conference on Engineering and Product Design, E&PDE 2014*. The Design Society, Sep. 2014, pp. 568–573. [Online]. Available: https://research.utwente.nl/en/publications/a-design-process-for-creative-technology

[2] I. van de Poel and L. Royakkers, *Ethics, Technology, and Engineering*. Wiley, Mar. 2011.

[3] “Geodesic(k) RGB LED Spheres by Whity | Download free STL model.” [Online]. Available: https://www.printables.com/model/40182-geodesick-rgb-led-spheres

[4] “Ability Tech – Inclusive Innovation.” [Online]. Available: https://abilitytech.nl/

[5] C. Cirelli and G. Tononi, “Is Sleep Essential?” *PLOS Biology*, vol. 6, no. 8, p. e216, Aug. 2008, publisher: Public Library of Science. [Online]. Available: https://journals.plos.org/plosbiology/article?id=10.1371/journal.pbio.0060216

[6] V. Clement-Carbonell, I. Portilla-Tamarit, M. Rubio-Aparicio, and J. J. Madrid-Valero, “Sleep Quality, Mental and Physical Health: A Differential Relationship,” *International Journal of Environmental Research and Public Health*, vol. 18, no. 2, p. 460, Jan. 2021, number: 2 Publisher: Multidisciplinary Digital Publishing Institute. [Online]. Available: https://www.mdpi.com/1660-4601/18/2/460

[7] M. Dearing, “Correlations between Sleep and Hearing Loss,” Feb. 2022. [Online]. Available: https://myhearingcenters.com/blog/correlations-between-sleep-and-hearing-loss/

[8] E. Bathory and S. Tomopoulos, “Sleep Regulation, Physiology and Development, Sleep Duration and Patterns, and Sleep Hygiene in Infants, Toddlers, and Preschool-Age Children,” *Current Problems in Pediatric and Adolescent Health Care*, vol. 47, no. 2, pp. 29–42, Feb. 2017. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S1538544216301225

[9] C. I. Lanting, J. A. Deurloo, C. H. Wiefferink, and N. Uilenburg, “JGZ-richtlijn Vroegtijdige opsporing van gehoorverlies bij kinderen en jongeren (0 tot 18 jaar),” *JGZ Tijdschrift voor jeugdgezondheidszorg*, vol. 49, no. 4, pp. 77–80, Aug. 2017. [Online]. Available: https://doi.org/10.1007/s12452-017-0110-1

[10] e. te Walvaart, “AW: final version literature review: Eva te Walvaart,” Apr. 2024. [Online]. Available: https://canvas.utwente.nl/courses/14269/assignments/123275/submissions/49300

[11] National Sleep Foundation, “What Is Sleep Quality?” Oct. 2020. [Online]. Available: https://www.thensf.org/what-is-sleep-quality/

[12] D. J. Buysse, S. Ancoli-Israel, J. D. Edinger, K. L. Lichstein, and C. M. Morin, “Recommendations for a standard research assessment of insomnia,” *Sleep*, vol. 29, no. 9, pp. 1155–1173, Sep. 2006.

[13] D. J. Buysse, C. F. Reynolds, T. H. Monk, S. R. Berman, and D. J. Kupfer, “The Pittsburgh Sleep Quality Index: a new instrument for psychiatric practice and research,” *Psychiatry Research*, vol. 28, no. 2, pp. 193–213, May 1989.

[14] M. Fabbri, A. Beracci, M. Martoni, D. Meneo, L. Tonetti, and V. Natale, “Measuring Subjective Sleep Quality: A Review,” *International Journal of Environmental Research and Public Health*, vol. 18, no. 3, p. 1082, Jan. 2021, number: 3 Publisher: Multidisciplinary Digital Publishing Institute. [Online]. Available: https://www.mdpi.com/1660-4601/18/3/1082

[15] A. M. Gomes and M. C. Martins, “Child perception and parent’s perception about child sleep quality,” *Sleep Science*, vol. 14, no. 4, pp. 342–347, 2021. [Online]. Available: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8776258/

[16] J. J. Pilcher, D. R. Ginter, and B. Sadowsky, “Sleep quality versus sleep quantity: relationships between sleep and measures of health, well-being and sleepiness in college students,” *Journal of Psychosomatic Research*, vol. 42, no. 6, pp. 583–596, Jun. 1997.

[17] M. Hirshkowitz, K. Whiton, S. M. Albert, C. Alessi, O. Bruni, L. DonCarlos, N. Hazen, J. Herman, E. S. Katz, L. Kheirandish-Gozal, D. N. Neubauer, A. E. O’Donnell, M. Ohayon, J. Peever, R. Rawding, R. C. Sachdeva, B. Setters, M. V. Vitiello, J. C. Ware, and P. J. Adams Hillard, “National Sleep Foundation’s sleep time duration recommendations: methodology and results summary,” *Sleep Health*, vol. 1, no. 1, pp. 40–43, Mar. 2015.

[18] K. A. Carter, N. E. Hathaway, and C. F. Lettieri, “Common sleep disorders in children,” *American Family Physician*, vol. 89, no. 5, pp. 368–377, Mar. 2014.

[19] S. H. Sheldon, “Insomnia in children,” *Current Treatment Options in Neurology*, vol. 3, no. 1, pp. 37–50, Feb. 2001. [Online]. Available: https://doi.org/10.1007/s11940-001-0022-9

[20] K. Willcocks, “Top tips for better sleep for children with sensory disability,” Mar. 2023. [Online]. Available: https://www.nextsense.org.au/news-and-stories/top-tips-for-better-sleep-for-children-with-sensory-disability

[21] N. Clarke, D. Hoare, and E. Killan, “Evidence for an Association Between Hearing Impairment and Disrupted Sleep: Scoping Review,” *American Journal of Audiology*, vol. 28, Jul. 2019.

[22] National Deaf Children’s Society, “Behind the Silence: Why D/deaf children are falling behind in early years.” [Online]. Available: https://www.deafnessresourcecentre.org/news/deaf-children-falling-behind-peers-in-early-years/

[23] M. Moore, “Behavioral Sleep Problems in Children and Adolescents,” *Journal of Clinical Psychology in Medical Settings*, vol. 19, no. 1, pp. 77–83, Mar. 2012. [Online]. Available: https://doi.org/10.1007/s10880-011-9282-z

[24] J. Liu, X. Ji, E. Rovit, S. Pitt, and T. Lipman, “Childhood sleep: assessments, risk factors, and potential mechanisms,” *World Journal of Pediatrics*, pp. 1–17, Nov. 2022. [Online]. Available: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC9702880/

[25] T. J. Barkoukis, J. K. Matheson, R. Ferber, and K. Doghramji, *Therapy in Sleep Medicine E-Book*. Elsevier Health Sciences, Oct. 2011, google-Books-ID: AXapId-WIQ20C.

[26] “Baby oortjes – Informatieve site voor ouders van dove en slechthorende kinderen.” [Online]. Available: https://babyoortjes.nl/

[27] N. Uilenburg, “Interventies bij slechthorende kinderen.”

[28] C. Vaccari and M. Marschark, “Communication between parents and deaf children: implications for social-emotional development,” *Journal of Child Psychology and Psychiatry, and Allied Disciplines*, vol. 38, no. 7, pp. 793–801, Oct. 1997.

[29] “Ethics Committee | Faculty of Electrical Engineering, Mathematics and Computer Science (EEMCS).” [Online]. Available: https://www.utwente.nl/en/eemcs/research/ethics/

[30] E. van Heuvelen, “Interview with Eric van Heuvelen, assistive technology specialist at Bartimeus Doorn,” Mar. 2024.

[31] “Bartiméus.” [Online]. Available: https://www.pitbaarn.nl%2Fis%2Forganisatie%2F4875%2Finvis2%2Fbartimeus

[32] “Melatonin: What You Need To Know.” [Online]. Available: https://www.nccih.nih.gov/health/melatonin-what-you-need-to-know

[33] “Nachtlampjes | ZAZU,” Sep. 2021. [Online]. Available: https://www.zazu-kids.com/nl/nachtlampen/

[34] “lisa RF system.” [Online]. Available: https://www.humantechnik.com/en/products/wireless-alerting-systems/lisa-rf-system/

[35] “Slaaptrainers | ZAZU,” Sep. 2021. [Online]. Available: https://www.zazu-kids.com/nl/slaaptrainers/

[36] D. Jain, K. Mack, A. Amrous, M. Wright, S. Goodman, L. Findlater, and J. E. Froehlich, “HomeSound: An Iterative Field Deployment of an In-Home Sound Awareness System for Deaf or Hard of Hearing Users,” in *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems*, ser. CHI ’20. New York, NY, USA: Association for Computing Machinery, Apr. 2020, pp. 1–12. [Online]. Available: https://dl.acm.org/doi/10.1145/3313831.3376758

[37] Nour Mahmoud Bahbouh, N. M. Bahbouh, Ahmad Alkhodre, A. B. Alkhodre, Adnan Ahmed Abi Sen, A. A. A. Sen, Abdallah Namoun, A. Namoun, Sami S. Albouq, and S. S. Albouq, “A Cost Effective IoT-based System for Monitoring Baby Incidents by Deaf Parents,” *2019 International Conference on Advances in the Emerging Computing Technologies (AECT)*, 2020, mAG ID: 3085876025 S2ID: 56c887e499ab2fdc9bf15170fd4f9e151fb27262.

[38] “Voluit magazine.” [Online]. Available: https://bartimeusfonds.nl/voluit-magazine/

[39] I. van de Poel and L. Royakkers, “Ethics, Technology, and Engineering.”

[40] “What Is Codesign? — updated 2024,” Jun. 2024. [Online]. Available: https://www.interaction-design.org/literature/topics/codesign

[41] “Design Your Life.” [Online]. Available: https://dyl.utwente.nl/

[42] “(1) Paco Busser | LinkedIn.” [Online]. Available: https://www.linkedin.com/in/paco-busser-50624482/

[43] T. E. P. A. O. T. C. , “Directive 2009/48/EC of the European Parliament and of the Council of 18 June 2009 on the safety of toys (Text with EEA relevance)Text with EEA relevance,” Nov. 2019, legislative Body: OP_DATPRO. [Online]. Available: http://data.europa.eu/eli/dir/2009/48/2019-11-18/eng

[44] C. PRV, “Wetgeving speelgoed - Speelgoed - NVWA,” Sep. 2016, last Modified: 2024-01-05T16:26 Publisher: Ministerie van Landbouw, Natuur en Voedselkwaliteit. [Online]. Available: https://www.nvwa.nl/onderwerpen/speelgoed/regels-en-wetgeving-speelgoed

[45] T. I. C. of Design, “professional code of conduct for designers,” Sep. 2020. [Online]. Available: https://www.theicod.org/storage/app/media/resources/ICO_Professional_Code_of_Conduct.pdf

[46] “Privacy: personal data | Personal data in research | Cyber Safety.” [Online]. Available: https://www.utwente.nl/en/cyber-safety/privacy/guideline-for-research/

[47] “General Data Protection Regulation (GDPR) | Cyber Safety.” [Online]. Available: https://www.utwente.nl/en/cyber-safety/privacy/gdpr/

[48] "IEEE Code of Ethics." [Online]. Available: https://www.ieee.org/about/corporate/governance/p7-8.html

[49] J. Hulstijn and B. Burgemeestre, "Design for the Values of Accountability and Transparency," in *Handbook of Ethics, Values, and Technological Design: Sources, Theory, Values and Application Domains*, J. van den Hoven, P. E. Vermaas, and I. van de Poel, Eds. Dordrecht: Springer Netherlands, 2014, pp. 1–25. [Online]. Available: https://doi.org/10.1007/978-94-007-6994-6_12-1

[50] W. e. S. Ministerie van Volksgezondheid, "Incapacitated adults - Human subjects - The Central Committee on Research Involving Human Subjects," Sep. 2018, last Modified: 2018-10-19T15:42 Publisher: Ministerie van Volksgezondheid, Werlzijn en Sport. [Online]. Available: https://english.ccmo.nl/human-subjects/informed-consent/incapacitated-adults

[51] "Ethical Review - Computer & Information Science (CIS)." [Online]. Available: https://ethicalreview.utsp.utwente.nl/index.html

[52] "Code of Ethics | National Society of Professional Engineers." [Online]. Available: https://www.nspe.org/resources/ethics/code-ethics

[53] B. Turvey and S. Crowder, *Ethical Justice: Applied Issues for Criminal Justice Students and Professionals*, 1st ed. Academic Press, Jun. 2013. [Online]. Available: https://doi.org/10.1016/C2011-0-07155-7

[54] I. Van De Poel, "Translating Values into Design Requirements," in *Philosophy and Engineering: Reflections on Practice, Principles and Process*, D. P. Michelfelder, N. McCarthy, and D. E. Goldberg, Eds. Dordrecht: Springer Netherlands, 2013, vol. 15, pp. 253–266, series Title: Philosophy of Engineering and Technology. [Online]. Available: http://link.springer.com/10.1007/978-94-007-7762-0_20

[55] E. te Walvaart, "Take Home Assignment: Eva te Walvaart," Apr. 2024. [Online]. Available: https://canvas.utwente.nl/courses/14269/assignments/121952/submissions/49300

[56] S. Vallow, D. McKenna, and R. McKenna, "ETHICS IN TECH PRACTICE: A Toolkit." [Online]. Available: https://canvas.utwente.nl/courses/14269/files/4268726?wrap=1

[57] G. Alrousan, A. Hassan, A. A. Pillai, F. Atrooz, and S. Salim, "Early Life Sleep Deprivation and Brain Development: Insights From Human and Animal Studies," *Frontiers in Neuroscience*, vol. 16, p. 833786, May 2022. [Online]. Available: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC9111737/

[58] monday.com, "The MoSCoW prioritization method explained," Sep. 2022. [Online]. Available: https://monday.com/blog/project-management/moscow-prioritization-method/

[59] “Get ESP32/ESP8266 MAC Address and Change It (Arduino IDE) | Random Nerd Tutorials,” Jan. 2020. [Online]. Available: https://randomnerdtutorials.com/get-change-esp32-esp8266-mac-address-arduino/

[60] Grrr.nl, “PLA.” [Online]. Available: https://waarzitwatin.nl/stoffen/pla

10 APPENDIX

10.1 Questionaire for parents about sleeping difficulties of children with an hearing impairment

Vragenlijst over slaapproblemen van kinderen met een gehoorbeperking

Hallo,

Wat fijn dat u bij deze vragenlijst bent beland! Bent u een ouder/verzorgen van één of meerdere kinderen met een gehoorbeperking? Dan zou ik u willen vragen om mij te helpen door deze vragenlijst in te vullen.

Ik ben Eva te Walvaart, studeer Creative Technology aan Universiteit Twente en ik doe onderzoek naar de slaapproblemen die veel dove en slechthorende kinderen ondervinden. Het doel van dit onderzoek is om een oplossing voor dit probleem te ontwikkelen in de vorm van een product/prototype. Het doel van deze vragenlijst in het specifiek is om achtergrondinformatie te verzamelen over dit probleem domein.

Er zitten geen risico's, consequenties of voordelen vast aan het deelnemen aan dit onderzoek. Het onderzoeksproject is beoordeeld en goedgekeurd door de Ethische Commissie Informatie- en Informatica van Universiteit Twente. Er wordt geen informatie achtergehouden, u heeft de mogelijkheid om vragen over te slaan door " - " of " x " in te vullen en om uw ingezonden antwoorden terug te trekken tot één week na het inzenden van de antwoorden.

Alle informatie die u invult wordt geanonimiseerd en alleen gebruikt voor onderzoeksdoeleinden. U wordt gevraagd om een vragenlijst in te vullen, deze zal ongeveer 15 minuten duren. Door dit vragenformulier in te vullen en op te sturen, geeft u toestemming voor het gebruik van de ingezonden informatie in dit onderzoek. Uiteindelijk zal het onderzoek gepubliceerd worden in het archief van alle bachelor afstudeer projecten van de studie Creative Technology van Universiteit Twente.

1. Bent u ouder/verzorger van één of meerdere kinderen met een gehoorbeperking? Zo ja, geef toelichting per kind over de leeftijd, geslacht en over welke gehoorbeperking het gaat.

2. Bent u ouder van één of meerdere kinderen zonder gehoorbeperking? Zo ja, geef toelichting per kind over de leeftijd en geslacht.

3. Heeft u zelf ook een gehoorbeperking? Zo ja, licht toe welke gehoorbeperking en of u gebruik maakt van een hoortoestel of CI.

4. Ondervindt (of ondervond) één van uw kinderen slaapproblemen?
Zo ja:
1. Licht toe wat voor slaapproblemen, graag met een indicatie qua tijd/aantal als dat van toepassing is.
(bijvoorbeeld: valt moeilijk in slaap (duur) , wordt vaak wakker (aantal), slaapwandelen, anders...)
2. Licht toe of er verschil zit in deze problemen in de nacht of tijdens een middagdutje.
3. Heeft u iets geprobeerd om het probleem te verhelpen? Zo ja, heeft het geholpen of niet?
4. Weet u misschien wat de mogelijke oorzaak is van het slaapprobleem?
5. Wat doet u als u merkt dat uw kind niet kan slapen?
6. Slaapt uw kind in zijn eentje op zijn eigen kamer?

5. Hoelang slaapt/slapen uw kind/kinderen in totaal per nacht en per middagdutje?

6. Heeft uw kind een hoortoestel of CI? Zo ja,
slaapt uw kind met zijn hoortoestel/CI op?
Zo nee:
1. Waar ligt deze als uw kind slaapt?
2. Kan uw kind het hoortoestel/CI zelf op doen?
3. Wanneer en hoe wordt het hoortoestel/de CI afgedaan?

7. Houd u een bepaalde slaaproutine aan als u uw kind met een gehoorbeperking naar bed gaat? Zo ja, beschrijf deze.

8. Is er iets dat u nog graag kwijt wil?

9. Zou ik u mogen emaillen als ik vragen heb over de antwoorden die u heeft gegeven? Zo ja, vul dan een e-mailadres in.

Heel erg bedankt voor het invullen van de vragenlijst.

Als u vragen heeft over het onderzoek, benieuwd bent naar de uitkomst of uw ingezonden informatie terug wil trekken kunt u mij altijd bereiken door de mailen naar e.a.m.tewalvaart@student.utwente.nl

Als u vragen heeft over uw rechten als onderzoeksdeelnemer, of informatie wilt verkrijgen, vragen wilt stellen of zorgen over dit onderzoek wilt bespreken met iemand anders dan de onderzoeker(s), neem dan contact op met de secretaris van de Commissie Ethiek Informatie & Informatica: ethicscommittee-CIS@utwente.nl

10.2 Ethical reflection report: Developing an Ethical Solution for Sleeping Problems Encountered by Deaf and Hard of Hearing Children

This ethical reflection report is submitted for the Reflection II course, a component of the graduation curriculum in Creative Technology. A part of this report is used in chapter 3 and chapter 5.

Please note that this document is an inserted PDF version of the report, with numbered references corresponding to those in the provided list, rather than the reference list of this thesis. The cited sections of this report, excluding the appendix, adhere to the reference list of this thesis.

Reflection II - Report

Developing an Ethical Solution for Sleeping Problems Encountered by Deaf and Hard of Hearing Children

Eva te Walvaart

University of Twente
Bachelor: Creative Technology
Date: June 7, 2024

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1 DESCRIPTION OF THE PROJECT AND VISION STATEMENT

1.1 Graduation project description

Individuals who are deaf or hard of hearing often experience difficulties with sleeping, two-thirds of people with hearing loss has insomnia according to Dearing [3]. Alrousan et al. [4] claim that this poses a significant challenge for children as both their physiological and neurological systems are expected to undergo substantial development during their sleep. In the Netherlands, the prevalence of deafness or hearing impairment among newborns is estimated to be 1 to 2 per 1000, equating to between 180 and 215 babies a year according to Lanting[5]. Hearing loss may also arise during later stages of life, thereby contributing to an augmented total count of children affected by hearing impairment. Hence, it is crucial to address the sleeping difficulties experienced by children with hearing impairments. Therefore, the objective of my graduation project is to create a functional prototype that addresses the sleeping difficulties of deaf and hard of hearing children.

Regarding the progress of my graduation project so far, I have finished my background research, including a literature review and an analysis of a self-posed questionnaire. The literature review was conducted to research the specific factors that influence the sleep of children in general, with a particular focus on deaf and hard of hearing children. The conclusion of the literature review is that anxiety emerges as a significant factor affecting sleep in deaf and hard of hearing children, while poor sleep hygiene, influenced by parental behavior, significantly contributes to sleep difficulties in both hearing-impaired and hearing children. Interventions such as sensory stimulation to reduce anxiety and parental education to promote good sleep hygiene are recommended.

Additionally, a self-made questionnaire was conducted to research the specific problems that occur before, during, or after sleep for deaf and hard of hearing children. From the analysis of the questionnaire, it can be concluded that particular problems that deaf and hard of hearing children generally encounter are: having difficulties falling asleep, waking up multiple times at night, and experiencing fear or anxiety. This is probably caused by the lack of sensory stimuli and the absence of trusted people during the sleeping process.

These conclusions, from both the literature review and the conducted questionnaire, are very valuable for the process of developing a solution for the sleeping problems that many deaf and hard of hearing children encounter.

Currently, the process of developing solutions is in progress. Intensive processes of brainstorming, ideation, co-design (a collaborative design method where designers collaborate with non-designers, [6]) , and convergent filtering resulted in two different possible solutions: the Ambient Sound Visualizer and the Family Locator.

The Ambient Sound Visualizer is designed to visualize ambient sounds, primarily during the night when the child is trying to sleep. This LED ball will be placed on the bedside table. It aims to recreate the conditions that hearing children experience when lying in bed, for deaf and hard of hearing children. According to The National Deaf Children's Society [7], lying in a dark room combined with the removal of hearing aids during the night leads to a significant decrease in sensory stimuli, causing anxiety, which subsequently negatively influences sleep quality. Therefore, the Ambient Sound Visualizer increases sensory stimuli to reduce anxiety. Additionally, it creates a connection between the child and the environment around the bedroom beyond just their own bedroom. While its primary use is during the night, it can also be used during the day, for example to help the child become familiar with the product.

The solution consists of an LED ball that emits light on specific areas in different colors and brightness levels, with microphones capturing the ambient sound. The location of the emitted light on the ball is determined by a processor that processes sound captured from specific directions by the different microphones on the product. The color of the emitted light is determined by the frequency of the sound using the visual light spectrum, allowing the child to see different sounds and eventually recognize them by their visualization. This recognition is reinforced by what they learn during the day when they see the source of sounds while wearing their hearing aids and observe the corresponding changes on the LED ball. The brightness of the emitted light depends on the volume of the captured sound, with louder sounds producing brighter light and softer sounds producing dimmer light.

The Family Locator is a completely different solution. This device will be placed near the child's bed and will use LEDs and pictograms to display the real-time location of their parents. Parents will carry a small box (5 x 10 cm) in their pocket, which receives signals from small transmitters placed in different rooms. This box sends messages to the user interface near the child's bed, showing in which room the parents are. Hearing children can hear their parents and family members walking up the stairs, going to the toilet, or taking a shower, which provides a sense of safety by indicating the presence of others. Deaf or hard of hearing children, however, may not hear these sounds, resulting in a feeling of isolation confined to their bedroom. This solution aims to recreate the safe and connected feeling that hearing children experience. Knowing their parents' locations should help the child feel secure and reduce anxiety, thereby potentially reducing sleep problems

1.2 Why I chose this challenge

My journey into this project began in September 2023 when I joined Ability Tech as a volunteer. Ability Tech [8] is a foundation that creates technology to improve the quality of life for people with disabilities. As a Creative Technology student, with a passion for technology and a desire to help people, I found myself in the perfect place to contribute to meaningful projects. Towards the end of that year, a mother reached out to Ability Tech with a request: to develop a product specifically tailored to the needs of deaf and hard-of-hearing children. Despite her ideas, she lacked the technical expertise to bring them to life. As we, the mother and me, delved into the project, conducting extensive research and engaging in numerous client meetings, it became clear that the focus should be on addressing the sleep problems faced by these children. This project, initiated by the mother/my client, had no prior history but began this semester with a clear mission in mind.

This challenge holds profound societal implications and presents an opportunity to drive positive change for a marginalized group. Deaf and hard-of-hearing children confront unique obstacles, including significant sleep disturbances that can impede their development and overall well-being. By tackling these issues, we potentially not only enhance the lives of these children and their families but also contribute to the creation of a more inclusive and fair society. We strive to raise awareness about the specific needs of this demographic and advocate for greater support and resources. By prioritizing and by focusing on he sleep health of deaf and hard-of-hearing children, we take a crucial stride toward establishing an environment characterized by equal opportunities and conducive conditions for optimal child development.

2 CODE OF ETHICS

2.1 Ethical landscape

Throughout the design process of the two prototypes, several ethical dilemmas emerged. With an ethical dilemma being defined by Turvey et al. [9] as an ethical issue that is impossible to solve, since it is not possible to satisfy two ethical principles at the same time. In this section, one ethical dilemma unique to each prototype and one shared ethical dilemma will be elaborated on.

One ethical dilemma that emerged during the design process of the Ambient Sound Visualizer is balancing over-stimulation with autonomy. During the sleep process, children are not yet familiar with the information and light the prototype provides, which could lead to over-stimulation. However, hearing children cannot simply turn off their hearing either. Should the child have the ability to turn the prototype off? If so, how? If there were an option to turn it off, how would it work, and would the child understand how to use it?

One ethical dilemma that emerged during the design process of the Family Locator is ensuring the balance between security and dependence. Additionally, there's the concern that a child's trust could be impacted if the product provides inaccurate information. The goal of the product is to help children feel the proximity of their parents and subsequently become more relaxed, which aids in improving their sleep. However, if the product were to malfunction and not work for a couple of days, it raises the question of whether the child might become more anxious compared to the level of anxiety before the use of the product. Hearing children can sense the proximity of their parents and other household members through sound. However, deaf and hard of hearing children may not have this ability. While the product aims to provide security for children with hearing impairments, there's a concern that over reliance on the Family Locator could potentially worsen a child's fear of separation if the device malfunctions. Additionally, there's a risk of dependency, where the child may struggle to sleep without the reassurance of the locator, highlighting the delicate balance between support and independence in children.

An ethical dilemma that emerged during the design process of both prototypes is safety. Children are very vulnerable and often do not know the possible consequences of their actions. While the prototype is in the room together with the child during sleep, no one else is present in the room. If the child decides to put the product in their mouth, lick it or throw it, it must be safe. No toxic substances should be released and no fire should occur. But there are electronics involved so it is very difficult to get this done, especially with a prototype that has to be made in a fairly short time.

2.2 My own code of ethics

In this section, I elaborate on my self-written code of ethics according to the ”code of conduct” posed in chapter 2 of the book ”Ethics, Technology, and Engineering” written by van der Poel et al. [10], which consists of professional ethical principles that I believe are important as a professional designing technologies for children with disabilities and their caregivers. I will explain how I adhere to these principles and why they are relevant to the design process of the prototypes.

1. **Legal compliance**: As a designer, I will comply with all legal obligations in the Netherlands related to the development of safe toys for children. All toys produced for children in the Netherlands must meet specific obligations and directives set forth in the Official Journal of the European Union [11], according to The Dutch Food and Commodities Authority [12]. Additionally, adequate product testing will be reviewed by the Ethics Committee of Computer & Information Science at the University of Twente [13] before testing the prototypes.

   This principle, based on the code of conduct outlined by The International Council of Design in ”The Professional Code of Conduct for Designers” [14], is essential to producing an ethically sound product. Products must be produced ethically and must be safe, especially for a vulnerable target group like children, who may not always be aware of the consequences of their actions. For instance, if they decide to put the product in their mouth, it should not expose them to toxic substances or electrical hazards.

2. **Client Confidentiality**: As a designer I will respect the confidentiality of my client, ensuring that any private information is protected. I will never expose private information without explicit consent of the client. As a bachelor student doing research at the University of Twente it is an obligation to act responsible and to protect the personal data that is collected [15]. The way information, data and consent will be collected and protected according to the General Data Protection Regulation, the European privacy law [16]. This will reviewed by the Ethics Committee of Computer & Information Science from the University of Twente [13] before collecting any information, data or permissions. Information letters and consent forms will be used to inform the client and to collect informed consent. This principle, Client Confidentiality, is based on the code of conduct outlined by The International Council of Design's in ”The Professional Code of Conduct for designers” [14] and important since the information collected involves very confidential information such as the child's medical diagnoses.

3. **Fair and respectful treatment**: As an engineer, I will treat the participants in my research fairly and with respect, avoiding harassment, discrimination, and injury. This principle is based on the code of conduct outlined in [17].

   A part of the target audience consists of disabled children, and it is important to respect and protect them. They are vulnerable. This should be explicitly taken into account in all aspects of the design and testing processes, ensuring their safety, dignity, and well-being are prioritized at all times.

4. **Transparency and accountability**: As a designer, I will maintain transparency throughout the design process by openly communicating with my client. Additionally, I will take full responsibility for my actions and decisions. This principle is based on the code of conduct outlined in the handbook of Ethics, Values, and Technological Design written by Hulstijn et al. [18].

   Adittionally, Transparency means being open and clear about my design process, decisions, and any issues that arise. Accountability means taking responsibility for my actions and their outcomes. These principles are crucial for building trust with my client and ensuring ethical practices throughout the project.

During my co-design process, I will primarily interact with my client, the mother of a child with a hearing disability, but also occasionally with her child in the company of the mother. Transparency is essential, especially when vulnerable children are involved, to ensure that the parents are fully informed and that the child's safety and well-being are prioritized.

According to the Central Committee on Research Involving Human Subjects [19], children younger than sixteen years old must have a legal representative in research, which in this case is the child's mother. It is vital to ensure that nothing happens against the will of the parent or the child. This transparency will be maintained according to the guidelines set by the Ethics Committee of Computer & Information Science from the University of Twente [20].

Additionally, transparency and accountability are relevant to my project because they help build trust between me, the designer, and the client. This trust is essential for effective collaboration and for ensuring that the design meets the needs and expectations of the user. By being transparent, I ensure that the client is fully informed about the design process and any decisions made. By being accountable, I take responsibility for any issues that arise and work to resolve them promptly and ethically.

These principles influenced my design by ensuring that I keep open lines of communication with the client, provide regular updates on the progress of the project, and document all decisions and actions taken. This approach helps to ensure that the final product is safe, effective, and meets the needs of the user.

5. **Attribution and Acknowledgement**: As an engineer, I will credit the creators and designers of technologies or parts that I use, and I will avoid plagiarism. This principle is based on the code of Ethics for Engineers written by the National Society of Professional Engineers [21].

   Attribution means giving proper credit to the original creators of any work or ideas that I use in my project. Acknowledgement involves recognizing the contributions of others to my work.

   I will ensure that all sources, inspirations, and contributions are properly attributed and acknowledged, reflecting the collaborative nature of engineering work and the respect for intellectual property and effort. Proper citation and acknowledgment of the work of others not only show respect for their contributions but also maintain the integrity of the profession and the advancement of knowledge.

   For example, if I utilize a specific design framework or tool developed by another engineer or researcher, I will explicitly mention their contribution in my documentation and presentations. Additionally, if I create something myself and use it for purposes other than my graduation project, I will also mention my own contributions. This practice not only gives credit where it is due but also allows others to trace the origins of certain methodologies and potentially collaborate further.

   These principles are relevant to my project as they ensure that all contributions are properly recognized, which is essential for maintaining ethical standards and fostering a collaborative environment. They influenced my design by ensuring that all borrowed ideas and tools are properly credited, and that the contributions of all team members and collaborators are acknowledged.

3 ENGAGING THE DESIGN PROCESS THROUGH MORAL VALUES AND ETHICAL DECISION MAKING

This chapter will elaborate on the assessment of my graduation project according to the ethical cycle of Van de Poel et al. described in Chapter 5 ”The Ethical Cycle” of the book ”Ethics, Technology, and Engineering”[1]. Additionally, this type of design cycle will be compared to the Creative Technology design model designed by Mader et al. [2] that is utilized most of the time during my study Creative Technology. Figure 4.1 displays a detailed diagram of the ethical cycle, its phases and its sub-step, figure 3.2 displays a detailed diagram of the Creative Technology Design consisting out of its steps.

The Ethical Cycle consists out of 5 phases: Moral problem statement, Problem analysis, Options for action, Ethical evaluation and Reflection. All these steps will be elaborated on in this chapter.

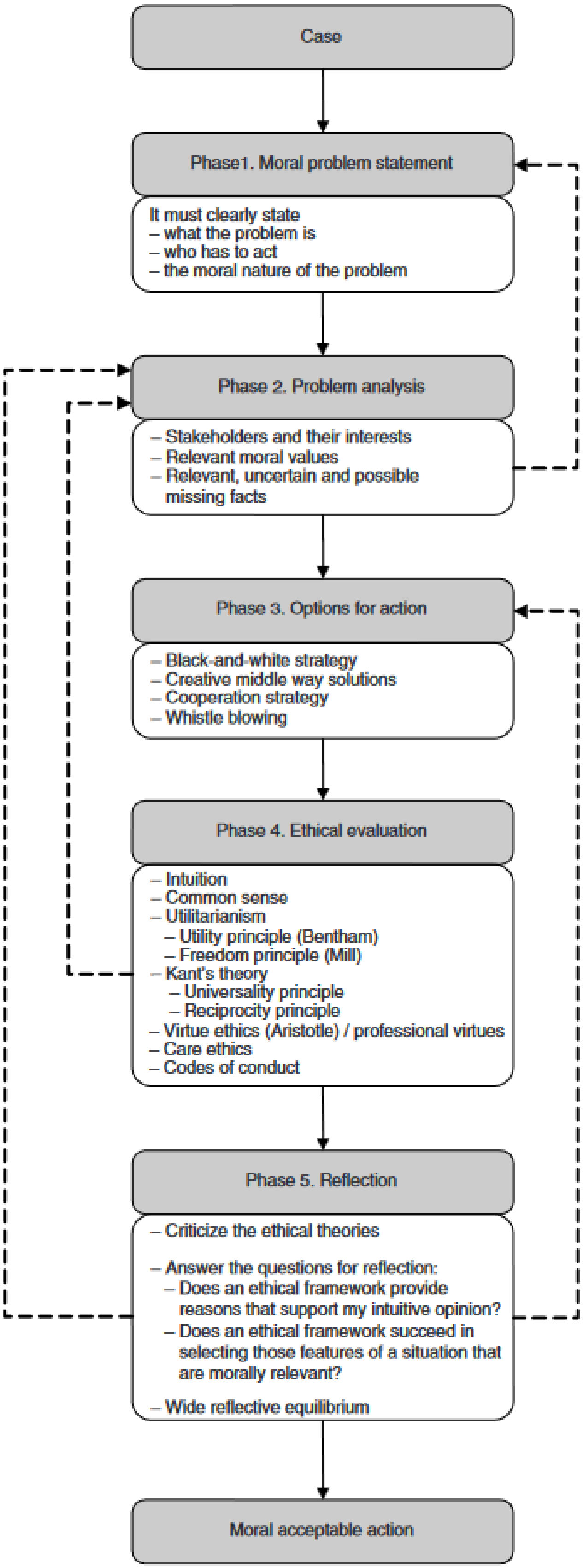

Figure 3.1: Detailed overview of the ethical cycle from Van de poel et al. [1] consisting out of 5 different phases.

3.1 Phase 1: Moral problem statement

This phase analyses the following questions to clarify the moral problem statement.

- **What is the problem?:**

  One of the ethical dilemmas in this project revolves around the trade-off between low-cost production and ensuring safety and quality. This problem is crucial because it impacts both the affordability and the well-being of the end users.

- **Who has to act?:**

  The key stakeholders in this scenario are the design and engineering team (comprising myself and the mother of the child, as we are collaborating in a co-design process), Ability Tech (the foundation where I work as a volunteer and the source of the project request), and potential production companies interested in manufacturing and marketing the product if it proves successful after testing.

- **What is the moral nature of this project?:**

  The moral problem centers on whether it is ethically justifiable to compromise on safety and quality to achieve lower production costs. This dilemma involves balancing utilitarian benefits (greater product accessibility) against deontological principles (duty to ensure safety and quality).

3.2 Phase 2: Problem analysis

To clarify the problem, an analysis will be done in this phase by first looking at all the stakeholders and their interests, then explicitly mention the relevant moral values and finish with mentioning the relevant, uncertain, and possible missing facts.

- **Stakeholders and their interests:**

  – **The design and Engineering Team (my client and me)**
    Interested in creating a reliable, high-quality, safe product that meets all technical and safety standards that helps deaf and hard of hearing to improve their sleep process.

  – **Ability Tech**
    Focused on fulfilling project requests aimed at enhancing the quality of life for people with disabilities while supporting the development process.

  – **End Users**
    Parents of the children for whom the product is designed prioritize safety, reliability, pedagogical soundness, and effectiveness in addressing their child's sleep problems. As for the children, they may not fully understand or articulate their motivations, but the product should ultimately make them feel safe.

  – **Potential Production Companies:** Interested in the feasibility of manufacturing and marketing the product if it proves successful after testing.

- **Relevant Moral Values:**

  – **Safety:**
    Ensuring the product does not pose any harm to the users.

  – **Quality:**
    Maintaining high standards in the product's performance and durability.

- **Reliability:**
  Guaranteeing consistent performance and durability.
- **Responsibility:**
  Upholding ethical duties towards users and society.
- **Effectiveness:**
  Successfully addressing the intended problem of improving sleep for children.
- **Inclusivity:**
  Considering the needs and well-being of people with disabilities.
- **Affordability:** Making the product accessible to a larger audience by keeping costs low.

- **Relevant, uncertain, and possible missing facts:**
  - **Relevant facts:**
    The costs associated with different levels of safety and quality.
  - **Uncertain facts:**
    The actual impact of cost reduction on safety and quality.
  - **Possible missing facts:**
    Long-term consequences of compromised safety and quality on brand reputation and user trust.

3.3 Phase 3: Options for Action

This phase explores potential solutions to address the ethical dilemma. Various strategies are considered, ranging from straightforward choices to more nuanced, collaborative approaches, ensuring a thorough examination of possible actions.

- **Black-and-white strategy:**
  - **Option 1:** Prioritize safety and quality regardless of cost implications.
  - **Option 2:** Focus on minimizing costs, accepting potential reductions in safety and quality.
- **Creative middle way solutions:**
  - **Option 3:** Implement cost-effective safety measures that do not significantly compromise quality.
  - **Option 4:** Develop a tiered product line with varying levels of safety and quality at different price points.
- **Cooperation strategy:**
  Engage with stakeholders to collaboratively find a balance between cost, safety, and quality. This might involve transparent discussions about the trade-offs and seeking consensus on acceptable compromises.
- **Whistle blowing:**
  If it becomes evident that cost-cutting measures significantly endanger user safety, whistle blowing might be considered to alert regulatory bodies or the public about the potential risks.

3.4 Phase 4: Ethical Evaluation

In this phase, the moral acceptability of the various options outlined in Phase 3 is systematically evaluated. This evaluation entails the application of a self-authored code of ethics, coupled with the utilization of diverse ethical theories. Through this analytical process, these options are evaluated from multiple ethical standpoints, fostering a comprehensive assessment aimed at upholding ethical integrity and moral accountability in decision-making.

3.4.1 Moral principles used to evaluate options of actions

- **Legal Compliance:**
  - **Option 1:** Prioritizing safety and quality aligns with legal compliance by ensuring the product meets all safety regulations.
  - **Option 2:** Focusing on minimizing costs might risk non-compliance with safety standards, potentially leading to legal issues.
  - **Option 3:** Implementing cost-effective safety measures ensures compliance without significantly compromising quality.
  - **Option 4:** Developing a tiered product line must ensure all tiers meet basic safety regulations to comply with legal standards.
- **Client Confidentiality:**
  - **All Options:** Ensure that any private information about the client or end users is protected throughout the design and evaluation process. This principle does not directly influence the choice between options but must be maintained regardless of the chosen action.
- **Fair and Respectful Treatment:**
  - **Option 1:** Treating participants with respect is upheld by prioritizing their safety and quality of the product.
  - **Option 2:** Reducing safety and quality could potentially harm users, thus violating the principle of fair and respectful treatment.
  - **Option 3:** Balancing cost-effective safety measures respects the well-being of users without unnecessary expense.
  - **Option 4:** Offering different tiers allows for respect of user choice and financial capability, provided all tiers meet basic safety and quality standards.
- **Transparency and Accountability:**
  - **Option 1:** Maintaining high transparency about the prioritization of safety and quality builds trust.
  - **Option 2:** Transparency about cost-cutting measures and their impact on safety is crucial but may negatively affect accountability if safety is compromised.
  - **Option 3:** Clear communication about the implementation of cost-effective safety measures ensures accountability.
  - **Option 4:** Transparency about the different safety and quality levels in the tiered product line is essential for informed user choice.
- **Attribution and Acknowledgement:**

- **All Options:** Properly crediting all sources and contributors is necessary throughout the design process. This principle supports ethical practices but does not directly impact the evaluation of the options for action.

After careful evaluation of the ethical implications of the options presented in phase 3, it is evident that prioritizing safety and quality (Option 1) aligns most closely with the professional ethical principles outlined in my code of ethics. While cost considerations are important, compromising on safety and quality could lead to potential harm to the end users, which conflicts with the principle of fair and respectful treatment. Additionally, maintaining transparency about the prioritization of safety and quality helps build trust with stakeholders and ensures accountability for the design decisions made.

Therefore, the recommended approach would be to prioritize safety and quality while exploring cost-effective measures (Option 3) to minimize production expenses without compromising on essential aspects of the product. This approach allows for the development of a reliable, high-quality product that meets the needs of the target users while also addressing budget constraints and ensuring legal compliance and ethical integrity throughout the design process.

3.4.2 Moral theories used to evaluate options of actions

The moral acceptability of the various options mentioned in Phase 3 can also be evaluated using ethical theories, namely utilitarianism, deontology, and virtue ethics. The definitions of these theories can be found in the section ”Ethical theories” in chapter 4.

- **Utilitarian Evaluation:**
  - **Option 1:** Prioritizing safety and quality aligns with utilitarian principles by potentially maximizing overall well-being. This option ensures that the product meets safety regulations and provides a reliable solution for improving sleep in children with disabilities, hypothetically optimizing the overall well-being. Utilitarianism dictates doing whatever brings the most happiness or benefit to the largest number of people, making Option 1 ethically favorable in this context.
  - **Option 2:** Focusing solely on minimizing costs might lead to negative consequences, such as compromising safety and quality, which could outweigh any potential benefits in terms of affordability. This approach may not align with utilitarian principles, as it could result in negative impacts on the well-being of children, making this option less favorable from a utilitarian perspective.
  - **Option 3:** Implementing cost-effective safety measures balances the need for affordability with the goal of ensuring safety and quality, potentially maximizing overall happiness by providing a reasonably priced solution that meets essential standards. This approach aligns well with utilitarian principles, as it aims to optimize overall happiness by providing a solution that is both affordable and safe, thus making it the most favorable option from a utilitarian perspective.
  - **Option 4:** Developing a product line with different levels offers flexibility and accessibility but must ensure that all levels meet basic safety and quality standards to prevent potential harm to users. This approach considers diverse needs and preferences, in line with utilitarian principles. However, it is important to acknowledge that offering different levels of products carries risks, especially if users may not be fully aware of the potential consequences of cheaper options. This is particularly relevant for products aimed at children, as they may not be able to fully comprehend the potential risks. Therefore, it is crucial to prioritize safety and quality across all levels of the product line to safeguard the well-being of users, especially children. However, due to the potential risks associated with varying levels of products and the possibility

of users not fully understanding the consequences, this option may not be the most favorable.

- **Deontological Evaluation:**
  - **Option 1:** Prioritizing safety and quality reflects a deontological approach by adhering to universal moral rules that prioritize the well-being and safety of users, regardless of cost considerations. Making this option the most favorable option regarding deontological evaluation.
  - **Option 2:** Prioritizing cost reduction over safety and quality may violate deontological principles by neglecting the obligation to safeguard the safety and well-being of users. Therefore, this option is not in alignment with deontological principles, which emphasize the importance of fulfilling moral duties and obligations.
  - **Option 3:** Implementing cost-effective safety measures demonstrates a commitment to fulfilling ethical obligations while seeking practical solutions, balancing the duty to ensure safety with the need for affordability. This option, while pragmatic, may involve trade-offs in safety and quality to some extent, potentially deviating from strict deontological principles. Therefore, from a deontological perspective, while this option may be acceptable, it may not fully align with the uncompromising duty to prioritize safety and quality above all else.
  - **Option 4:** Developing a tiered product line requires ensuring that each tier meets basic safety and quality standards, reflecting a deontological perspective by upholding ethical duties towards users and society. This underscores the notion that safety is paramount and should not be compromised, regardless of the product's tier or features.

- **Virtue Ethics Evaluation:**
  - **Option 1:** Prioritizing safety and quality exemplifies virtuous behavior by demonstrating integrity, responsibility, and a commitment to excellence in engineering design. This option reflects the virtues of integrity, responsibility, and excellence, making it a favorable choice from a virtue ethics perspective. Virtue ethics emphasizes the development of positive character traits, such as honesty and courage, which are evident in Option 1's focus on safety and quality. By prioritizing these virtues, engineers uphold moral autonomy and cultivate ethical decision-making aligned with their professional practice. Making this the most favorable option following virue ethics.
  - **Option 2:** Focusing solely on cost reduction may undermine virtuous qualities by neglecting the importance of safety and quality in product development. This option contradicts virtues such as integrity and responsibility, as it prioritizes cost over the well-being of users and the quality of the product, making it less favorable from a virtue ethics standpoint. Virtue ethics encourages engineers to cultivate positive character traits like integrity and responsibility, which are compromised in Option 2's cost-focused approach.
  - **Option 3:** Implementing cost-effective safety measures showcases virtuous behavior by finding a balance between economic considerations and ethical responsibilities, demonstrating caution and practical wisdom in decision-making. This option demonstrates virtues such as caution and practical wisdom by balancing economic concerns with ethical responsibilities, making it a favorable choice from a virtue ethics perspective, but not the most favorable option compared to option 1. Engineers exercise moral autonomy by prioritizing safety and quality while considering cost-effectiveness, aligning their actions with the virtues of integrity and responsibility but sacrificing the absolute commitment to safety that option 1 provides. While option 3

embodies virtues such as prudence and practical wisdom, it may involve some degree of compromise in safety standards to achieve cost-effectiveness, which may not fully align with the uncompromising dedication to safety upheld by option 1. Therefore, while option 3 reflects virtuous behavior in decision-making, it may not be the most favorable choice when prioritizing safety and quality above all else.

– **Option 4:** Developing a tiered product line, while aiming to accommodate diverse needs and provide affordable solutions, must ensure that all tiers meet the same rigorous safety and quality standards. However, there is a risk that safety may be compromised in the pursuit of cost-effectiveness, especially in the lower-priced versions. This potential trade-off between safety and affordability may not align with the virtues of responsibility and consideration for diverse needs advocated by virtue ethics, which emphasizes the cultivation of positive character traits such as integrity, empathy, and responsibility. While Option 4 demonstrates empathy and consideration for user needs, the potential sacrifice of safety in the cheaper versions raises ethical concerns, making it less favorable from a virtue ethics standpoint compared to Option 1.

3.4.3 Conclusion

Based on the evaluation using various ethical theories and the self-authored code of ethics, Option 1 emerges as the most favorable overall, as it prioritizes safety and quality in line with multiple ethical perspectives. However, it's worth noting that Option 3 closely follows as a strong contender, particularly favored by utilitarianism. Option 3 strikes a balance between cost-effectiveness and ethical responsibilities, making it a compelling choice from a utilitarian standpoint. Despite this, Option 1 excels in meeting the criteria set forth by all ethical theories and the code of ethics. Therefore, while Option 1 may be the most comprehensive choice, Option 3 aligns more closely with utilitarian principles and presents a viable alternative solution.

3.5 Phase 5: Reflection

In this phase, a critical examination of the ethical evaluation conducted in Phase 4 is undertaken. The ethical theories employed and their alignment with intuitive judgments regarding the posed ethical dilemma are evaluated, aiming to assess whether they adequately capture the moral nuances of the situation.

The code of ethics formulated for Phase 4 provided a structured framework for evaluating various options. However, upon reflection, it becomes apparent that this code may not comprehensively address all ethical considerations. While it addresses elements such as legal compliance and fair client treatment, it may overlook other pertinent values or fail to prioritize certain ethical principles. Thus, a revision of the code may be necessary to ensure it effectively encompasses the ethical responsibilities incumbent upon engineers.

The ethical theories utilized, including utilitarianism, deontology, and virtue ethics, are evaluated for their efficacy. While utilitarianism facilitates a focus on maximizing overall well-being, it occasionally disregards individual rights. Deontology, with its emphasis on moral duties, may prove too inflexible in practical scenarios. Meanwhile, virtue ethics, centered on character traits, may lack clear directives for action.

Upon introspection of intuitive judgments, it becomes evident that ethical frameworks do not invariably align perfectly with personal instincts. While these frameworks furnish valuable tools for ethical decision-making, they may not fully encompass all factors deemed significant. Achieving equilibrium between personal judgments, ethical theories, and pragmatic considerations remains an ongoing effort.

In conclusion, while the ethical evaluation conducted in Phase 4 serves as a commendable starting point, a critical stance is imperative. Through continual refinement of ethical frameworks and eligibility to diverse viewpoints, engineers can strive toward enhanced ethical responsibility in their professional practice.

3.6 Differences of The Creative Technology Design process compared to the Ethical Cycle of Van de Poel et al. [1]

There is a difference between the Ethical Cycle of Van de Poel et al. [1] and the Creative Technology Design process, displayed in figure 3.1 and figure 3.2 in this chapter.

The approach of the 'Ethical Cycle', created by Van de Poel et al. [1], starts with describing the moral problem by asking a moral question that meets three conditions.

1. It must clearly state what the problem is.
2. It must state who has to act.
3. The moral nature of the problem needs to be articulated.

Following that comes the problem analysis, where the relevant elements of the moral problem are described by three important elements.

1. The stakeholders and their interests
2. The moral values that are relevant in the situation.
3. The relevant facts.

This is different from the CreaTe design process, which starts with a problem analysis and background research before the actual Creative Technology design process, as displayed in figure 3.2, comes to light. Before the CreaTe design process begins, one must first research the reason for the design question that will be handled in the design process, what exactly is the problem for which something needs to be designed. During the design process one often finds out that moral problems play a role. These were not known at the beginning, at least not in my project. Therefore, it is not possible to describe an ethical problem before it arises.

The approach that I took was to first start following the Create problem analysis steps, where I investigated the design request and the problem that needed to be addressed. During the design process I realised that there are moral problems involved. I then started with taking a look at the Ethical Cycle and conducted a problem analysis again, but this time the 'ethical cycle' problem analysis that is addressing an ethical problem instead of a design question. Then I adjusted my design process to solve the moral problems as much as possible so that the most ethical product is designed in the most ethical way possible.

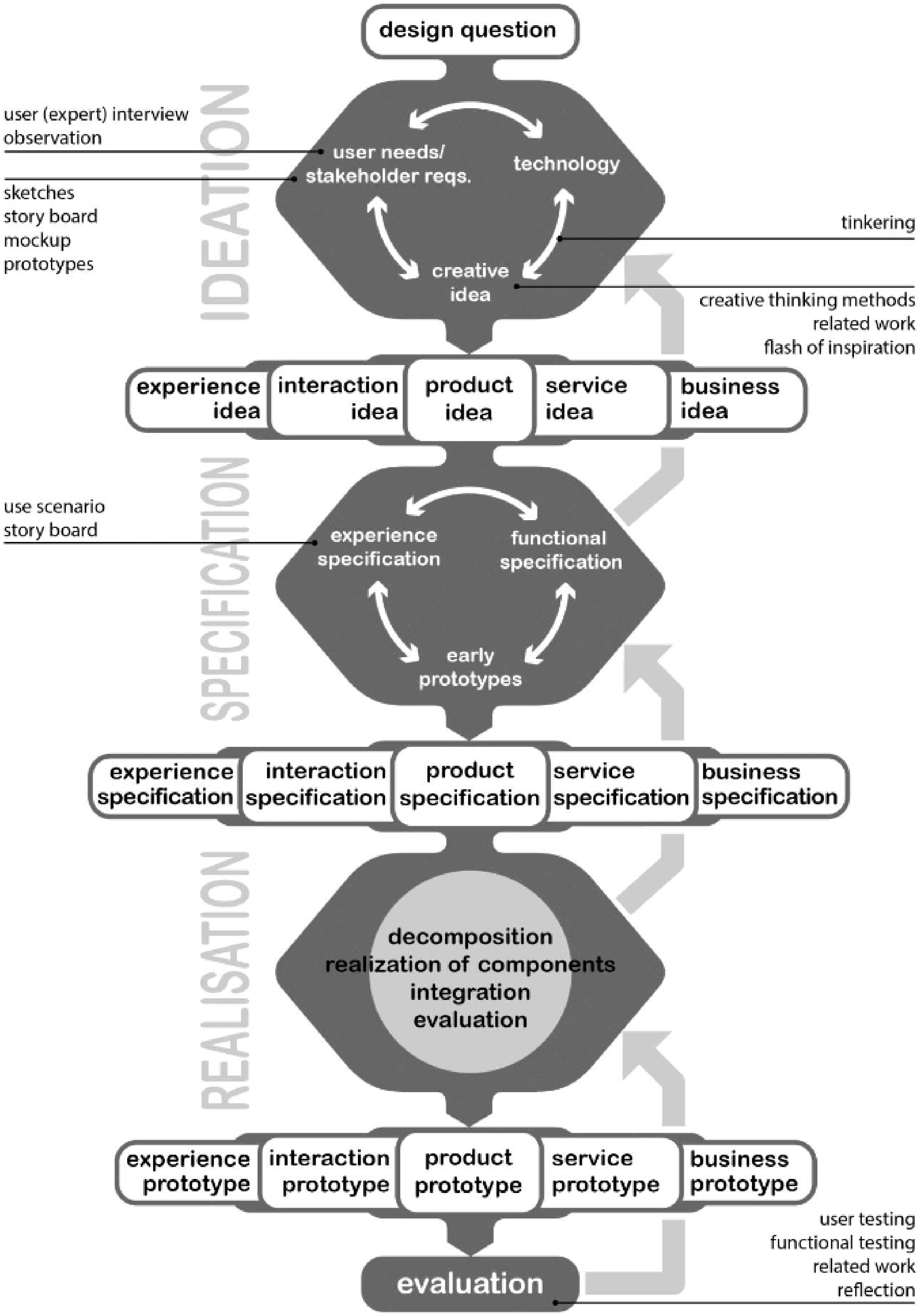

Figure 3.2: Detailed overview of the design process of Creative Technology from Mader et al. [2]

4 APPLIED ETHICS

In this chapter, specific moral reasoning and ethical problem solving, regarding the graduation project, is conducted by the use of specific tools that were provided during the reflection course that took place in module 11 and 12 of the study program Creative Technology. First ethical theories are used to elaborate on a part of this

4.1 Translating Values into design requirements

In this section, certain design choices and design requirements that are made regarding my graduation project will be argued. These choices are inspired by the method used in Chapter 20 ”Translating Values into Design Requirements” written by Van De Poel [22] from the book ”Philosophy and Engineering: Reflections on Practice, Principles and Process”. This section provides designers a method to create design requirements based upon moral values. Parts of this section are taken from the Take home assignment [23] from the course Reflection I and adjusted accordingly to the received feedback. The posed values, norms and requirements can bee seen in the detailed overview of the value hierarchy in figure 4.1, it shows how the value layers interrelate.

In my graduation project I am making a product for deaf and hard of hearing children that addresses their possible sleeping problems. As this is a vulnerable target group, because they are children and have a disability, it is especially important to live up to certain values and thus establish design requirements for this product. One of the values that I perceive as very important is safety, see the top layer of figure 4.1. This can be ensured through the establishment of design requirements by examining directives related to products and toys for children, such as those outlined by the European Parliament and Council [11]. These directives, formulated by the European Union, aim to guarantee that the produced toys for children in the European Union adhere to some of the most stringent safety standards globally, particularly with regard to the use of chemicals in toys.

The first step in the method of creating requirements by looking at moral norms and values is to write down the norms and values. This is shown in the following list, and in the second top layer in figure 4.1 consisting out of norms based upon the directives formulated by the European Parliament and Council[11].

The main norms are as follows:

1. The product may not physically hurt the user.
2. The product must not have any negative long-term effects on the mental and physical health of the users.
3. The product must not constitute a fire hazard.
4. The product must adhere to all relevant electrical safety standards and regulations.

The next step is drawing requirements from the proposed norms and values. They can be found in the following section and in figure 4.1 in the layers beneath the two top layers. The numbers in front of a particular norm of the above list corresponds to the number in front of the related requirement(s) in the list below.

Requirements:

1. (a) The accessible edges, protrusions, cords, wires, and fastenings of the product need to be made and constructed in a way that minimizes the possibility of physical harm occurring from contact with them.
   (b) The product, along with all its components must possess sufficient mechanical robustness and, when necessary, stability to endure the pressures experienced during usage without fracturing or warping, thereby minimizing the potential for physical harm.
   (c) The temperatures generated by the electronics might not hurt the users.
2. (a) The product should be made out of toxic free materials.
   (b) The product should be made out of water-resistant and durable materials for electronic components to ensure reliability and longevity, even in adverse conditions.
3. (a) The product does not ignite when directly exposed to a flame, spark, or other potential source of fire.
   (b) The product is not readily flammable, meaning the flame extinguishes as soon as the fire source is removed.
   (c) If the product does ignite, it burns slowly and has a low rate of flame spread.
   (d) Regardless of the toy's chemical composition, it is engineered to mechanically delay the combustion process.
4. (a) The electronic system of the product may not use voltages higher than 24V.
   (b) The electronic connections within the product must be adequately insulated and mechanically protected to minimize the risk of electrical shock.
   (c) The product must remain operational and secure even in the event of system malfunctions, external factors, or failures.

These requirements created for this project should be followed but this faces challenges:

- Cost constraints: Balancing ethical considerations with budget limitations poses a significant challenge. Integrating safety features or sustainable materials is really important but it is also important that the product is affordable for everyone.
- Contradicting design requirements: Resolving conflicting design requirements can be challenging. For instance, ensuring water resistance while maintaining adequate ventilation for electronic components presents a dilemma. A creative solution must be found to reconcile these conflicting demands without compromising the overall functionality or safety of the product.
- Safety limitations: It is important that the product remains operational and secure even in the event of system malfunctions, external factors, or failures, but it is not always possible to guarantee that for a 100 %.

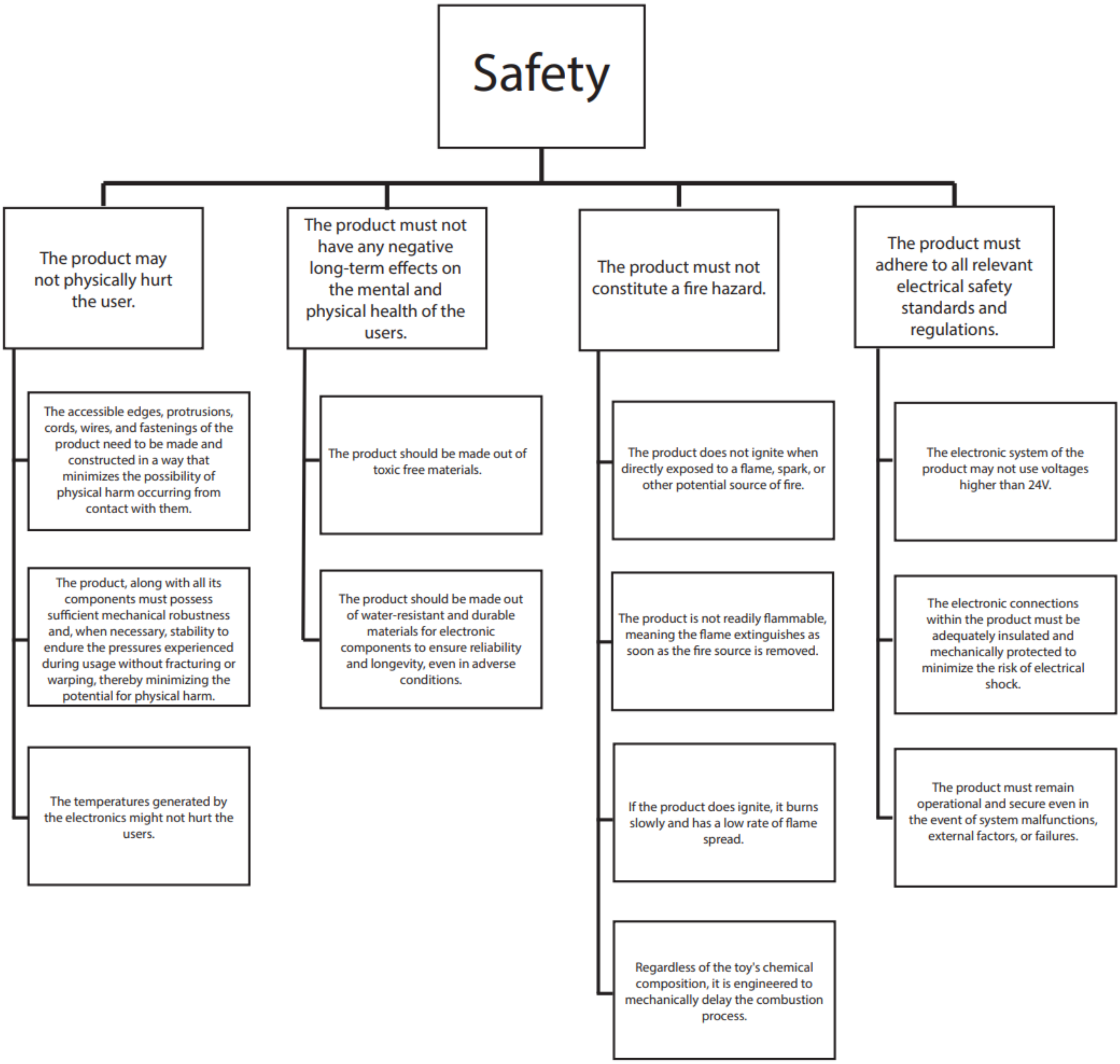

Figure 4.1: Detailed overview of values hierarchy.
The top layer shows the value Safety that I perceive as very important in this project. The second top layer consists out of norms formulated based on the value Safety. The layers beneath the two horizontal top layers are the requirements formulated based on the norms in the second layer.

4.2 Markkula Toolkit Tool 5: Remembering the ethical benefits of creative work

In this section, Tool 5 from the Markkula Toolkit [24] is utilized to reflect ethically on creative work, particularly concerning the two potential solutions discussed in Chapter 1: the ambient sound visualizer and the Family Locator. The Markkula Toolkit aids in developing ethical design practices, with Tool 5 ”remembering the ethical benefits of creative work” emphasizing the benefits of creative work. This stands in contrast to most ethical reflections, which primarily focus on analyzing ethical risks. While ethical risks are crucial to address, it's equally important to remember that the ultimate goal of ethical reflection is to achieve a positive outcome. Therefore, an ethical reflection is conducted, focusing mainly on the benefits these solutions could provide. This is done by answering questions that tool 5 of the Markkulla Toolkit offers.

- Question 1: Why are we doing this, and for what good ends?

  We, my client and me, are dedicated to helping deaf and hard-of-hearing children improve their sleep by making them feel more secure in their bedrooms. This issue is significant because two-thirds of people with hearing loss suffer from insomnia, as noted by Dearing [3]. In the Netherlands, 180 to 215 babies are born each year with a hearing impairment, according to Lanting [5]. Additionally, hearing loss can develop later in life, increasing the number of children affected by this condition. According to Alrousan et al. [4], this poses a substantial challenge for children, as their physiological and neurological systems are expected to undergo significant development during sleep. Therefore, addressing the sleeping difficulties experienced by children with hearing impairments is crucial.

  Improving sleep for these children also benefits their parents, as they experience fewer disturbances caused by their children's insomnia.

  Furthermore, there is limited research on the sleep problems encountered by deaf and hard-of-hearing children. By conducting this research, we aim to raise awareness about these issues. My research, including a distributed questionnaire, has shown that some people are unaware that hearing impairment can cause or exacerbate sleep problems in children. It is essential to spread this awareness to ensure that the unique needs of deaf and hard-of-hearing children are recognized and addressed.

- Question 2: Will society, the world, or our customers really be better off with this technology than without it? Or are we trying to generate inauthentic needs or manufactured desires, simply to justify a new product to sell?

  We are not trying to generate inauthentic needs or manufactured desires simply to justify a new product to sell. These two products are developed to help deaf and hard-of-hearing children, and potentially others who may find them useful. By designing this product, I do not receive any monetary compensation. This graduation project is offered through Ability Tech, a foundation that creates technology for people with disabilities to make their lives easier and improve their quality of life. Their aim is to help people, not to make money from them.

  Hypothetically, the world would be a better place with this technology, as it is designed to significantly help people without causing any foreseeable problems for others. By improving the sleep quality of deaf and hard-of-hearing children, we can contribute to their overall health and development. Sleep is crucial for children's physiological and neurological growth, and addressing the sleep challenges faced by those with hearing impairments is important. According to Alrousan et al. [4], sleep significantly impacts the development of children's systems, suggesting that these technologies could provide meaningful support for their well-being.

- Question 3: Has the ethical benefit of this technology remained at the center of our work and thinking?

  The ethical benefit of assisting deaf and hard-of-hearing children with sleep problems has consistently guided our efforts in developing prototypes tailored to their needs. The development process was a co-design effort, closely involving the child's mother, who approached Ability Tech seeking assistance in raising awareness for hearing impairment and aiding children with disabilities, motivated by her desire to support her daughter and the broader deaf and hard of hearing community.

We dedicated significant effort to gathering insights from parents of children with hearing disabilities. We listened attentively to comprehend the specific challenges regarding sleep their children faced, the methods they had previously tried to address these challenges, and potential solutions that might prove effective. A questionnaire was administered to collect these valuable insights.

Our primary goal has always been, and remains, to help the children. We explored multiple prototypes with the aim of fostering a feeling of closeness to their parents and other family members, thereby reducing bedtime anxiety and enhancing their sense of security. This, in turn, aims to mitigate feelings of fear and isolation, hypothetically leading to an improvement in their sleep quality. Our comprehensive and empathetic approach ensured that the ethical benefits of our technology were consistently prioritized.

- Question 4: What are we willing to sacrifice to do this right?

  As we strive to develop prototypes that prioritize safety, reliability, and sturdiness, we must recognize the constraints imposed by various factors. While our ultimate aim is to create products that are both sturdy and safe, achieving this goal can be challenging due to limitations such as time and budget.

  Our commitment to adhering to safety standards, as outlined by the European Union (EU) regarding toy safety [11], remains unwavering. However, it's essential to acknowledge that achieving 100 % safety and reliability may not always be feasible.

  Conflicting design requirements further complicate matters, necessitating creative solutions to balance durability and functionality. It's crucial to consider the potential consequences of product failure, such as dependency issues, which could inadvertently arise if the product malfunctions after use. For instance, if the product were to break or malfunction after a short period of use, the child may become overly reliant on it for comfort or security, potentially impeding their ability to develop healthy coping mechanisms.

  Despite these challenges, our dedication to prioritizing the safety, reliability, and well-being of the children remains persistent. We understand that sacrifices may be necessary, and we are committed to continually reassessing and evaluating our decisions throughout the design process to ensure that the best interests of the children are always upheld.

4.3 Ethical Theories

To provide guidance in engineering design, tree main ethical theories described by van de Poel and Royakkers in the book "Ethics, Technology, and Engineering "[1] are informed and elaborated on in this section. These theories offer different perspectives on how to assess the moral implications of design choices and prioritize ethical considerations throughout the design process. Parts of this elaboration is taken from the "Take Home Assignment" [23] that I handed in for the subject Reflection I.

The three main ethical theories that van de Poel and Royakkers describe in the book are utilitarianism, deontology and virtue ethics.

- **Utilitarianism** suggests that the right thing to do is whatever brings the most happiness or benefit to the largest number of people. It's about maximizing the overall good and minimizing the negative consequences of actions as much as possible. This theory can guide engineers in designing a product, a system or something else to focus on maximizing the overall good (happiness, well-being, accessibility, etc.) and to minimize the negative consequences (violence, discrimination, injustice, etc.) of their design as much as possible.

- **Deontology**, also known as Kantian ethics, asserts that the moral rightness of actions stems from following universal moral rules rather than considering their outcomes. The emphasis in this theory is placed on the attention behind an action and the adherence of the universal law, rather than the outcomes resulting from those actions. A core concept in this theory is autonomy, meaning that individuals should be capable of determining moral correctness through rational reflection. This applies to engineers as well; they can utilize this theory as a guide for their design by making choices and drawing conclusions through sound reasoning. In engineering practice, sound reasoning involves logical analysis of potential consequences, consideration of ethical implications, and adherence to moral principles such as respect for human dignity, fairness, and the promotion of societal well-being. Therefore, when engineers apply deontological principles, they are expected to engage in ethical decision-making that is both logically consistent and morally justifiable.
- **Virtue ethics**, differing from utilitarianism and Kantian theory, focuses on individuals' character traits rather than their actions or strict adherence to moral rules. It emphasizes the positive qualities individuals should develop, like honesty and courage, to lead morally honorable lives. This perspective stresses moral autonomy, empowering engineers in their design process to distinguish what constitutes virtuous behavior through their own reasoning and judgment. Consequently, engineers have the autonomy to cultivate virtues such as integrity, empathy, and responsibility, allowing them to make ethical decisions in alignment with their professional practice.

The theories mentioned above guide me too as a soon to be engineer in the design process of my graduation project. However, ethical theories also raise criticisms. Further explanation regarding an objection concerning utilitarianism in relation to the ambient sound visualizer is desired. One objection that may apply to that prototype is distributive justice.

If we look at whether the ambient sound visualizer should be developed, utilitarianism would probably contend against its development. Some individuals in the household may oppose the idea of having microphones installed due to privacy concerns, which can be seen as a negative consequence of the product's use. Thus, some might say that in this case the product does not contribute to the greatest happiness or benefit for the majority of people since the use of the product might involves negative consequences as well, for possibly quite a lot of people.

However, in this scenario, one person in the household might derive significant benefits from the product. If the implementation of this product facilitates improved sleep for deaf and hard of hearing children, it hypothetically stands to enhance their mental, physical, and developmental well-being. Again, this potential outcome would represent a significant benefit and might hold immense value. Additionally, other housemates also might benefit from the improved sleep of the deaf or hard of hearing child as well. If the child's sleep remains undisturbed, characterized by minimal awakenings and absence of crying, it is probable that other members of the household will also experience reduced disturbances, potentially leading to improved sleep quality for all. Still, housemates may experience slight discomfort due to privacy concerns. This unequal distribution of advantages (improved sleep quality) and disadvantages (privacy concerns) among individuals raises questions about distributive justice.

Despite this, I believe that in a case like this the overall happiness or benefit experienced by the individual user of the product, and potentially some other housemates, who benefits from the product outweighs the potential privacy concerns of the housemates. Although the product might not maximize happiness or benefit for the majority, it still aims to optimize the overall good and minimize the negative consequences of the products use as much as possible ultimately aligning with utilitarian principles.

5 THEORETICAL DISCUSSION

This chapter synthesizes how the two proposed solutions serve as drivers of transformation and next to that a wrap up of section 2,3 and 4 will be provided.

5.1 Drivers of transformation

The Ambient Sound Visualizer and the Family Locator serve as potential significant drivers of change. These technologies have the potential to profoundly impact the lives of deaf and hard-of-hearing children by addressing their unique sleep disturbances. If these products succeed in improving or even solving the sleeping problems of these children, the consequences will be far-reaching.

This challenge holds profound societal implications and presents an opportunity to drive positive change for a marginalized group. Deaf and hard-of-hearing children confront unique obstacles, including significant sleep disturbances that can impede their development and overall well-being. By tackling these issues, we potentially not only enhance the lives of these children and their families but also contribute to the creation of a more inclusive and fair society.

This project strives to raise awareness about the specific needs of this demographic and advocate for greater support and resources. By prioritizing the sleep health of deaf and hard-of-hearing children, crucial stride toward establishing an environment is taken characterized by equal opportunities and conducive conditions for optimal child development. This aligns with the broader goals of promoting inclusivity and equality, thereby driving societal transformation.

5.2 Wrap up

My graduation project focused on creating functional prototypes that address the sleeping difficulties of deaf and hard-of-hearing children. Developing products for children involves numerous ethical dilemmas, such as balancing affordability with ensuring safety and quality.

To navigate these dilemmas, I created a code of conduct, evaluated the ethical landscape, followed an ethical cycle, and utilized ethical theories. These steps helped me identify the most ethically sound approaches to the challenges. The term ”solution” is used cautiously, as ethical dilemmas do not have definitive solutions; rather, they often involve choosing the most ethically justifiable option. The evaluation of the ethical cycle led to the conclusion that safety and quality should be prioritized, regardless of cost implications. As a contingency, it is considered implementing cost-effective safety measures that do not significantly compromise quality.

Moreover, the activity of deriving ethical values and converting them into design requirements was instrumental in creating an ethically sound design plan. It was also valuable to remember the ethical benefits of the prototypes. Identifying ethical risks is crucial, but acknowledging the positive impact a product can have on society is equally important. Prioritizing the safety, reliability, and well-being of the children remains paramount, even though achieving 100% safety may not always be feasible. I recognize that sacrifices may be necessary, and continually reassessing and evaluating the decisions throughout the design process will be committed to ensure that the best interests of the children are always upheld.

6 CONCLUDING REMARKS, IMPACT STATEMENT, LIMITATIONS & LOOKING FORWARD

In this chapter, concluding remarked, impact statements, limitations are recommendations for the future are elaborated on.

6.1 Ethical Conclusions

The following ethical conclusions were drawn, in section 2,3 and 4, from the ethical reflection:

- **Safety and Quality Prioritization**: Prioritizing safety and quality in product design is essential when developing toys or products for children. This aligns with ethical principles by ensuring the well-being of children, even if it increases costs. Implementing cost-effective safety measures that do not compromise quality is a viable approach.
- **Utilitarianism and Privacy Concerns**: While utilitarianism suggests that actions should maximize overall good, it also highlights the need to address privacy concerns associated with the ambient sound visualizer. Balancing benefits and potential negative consequences is crucial.
- **Ethical Cycle Evaluation**: The ethical cycle, including problem analysis and options for action, emphasized that safety and quality should be prioritized over cost considerations. A structured approach to ethical decision-making helps navigate these dilemmas.
- **Professional Ethical Principles**: Adhering to professional ethical principles, such as legal compliance, client confidentiality, fair treatment, transparency, and proper attribution, is fundamental to the project. These principles ensure ethical integrity throughout the design process.

6.2 Lessons learned

The most significant lesson I learned from ethically reflecting on my graduation project and reflecting in general is that there are numerous ethical theories, each offering different perspectives on what is considered ethically the best. Initially, I believed that my personal judgment, combined with national and European regulations, was sufficient to determine what is ethically right and wrong. However, through reflection, I realized this is not always the case, as multiple situations present contradictory requirements.

Moreover, before engaging deeply with the subject of Reflection, I believed that it was not always necessary to delve thoroughly into ethical values. I thought that as a person, engineer, and designer, my intentions to do the best for everyone would suffice. However, I now understand the importance of deeply reflecting on ethical considerations, as more ethical dilemmas come to light when actively engaging with and reflecting on ethics.

For example, developing technology without considering its potential discriminatory effects is easy. Through this project, I learned the importance of inclusivity in design. One of my core values is that everyone should feel accepted, regardless of disability, skin color, size, or any other characteristic. This project has instilled in me the necessity to always strive to be as inclusive as possible in my work.

For example, in the process of developing technology, it is common to overlook its potential discriminatory impacts on certain groups. As highlighted by Wittkower [25], neglecting to address biases in technology can exacerbate inequality. This realization has heightened my awareness of the significance of inclusivity. With the conviction that everyone deserves acceptance, irrespective of their differences, I am now dedicated to ensuring that my work actively fosters inclusivity and fairness.

6.3 Limitations

Many aspects could have been approached differently. Alternative ethical theories and perspectives abound, offering endless possibilities for consideration. Similarly, a multitude of ethical dilemmas could have been explored during the ethical cycle, given the ever-expanding array of scenarios warranting reflection. Ethical reflection is boundless, although this report must adhere to finite constraints due to time limitations.

Moving forward, it would be beneficial to conduct multiple iterations of the ethical cycle, encompassing a comprehensive range of ethical dilemmas. Moreover, refining my personal code of conduct and perhaps comparing it with that of others could further enhance ethical practices. While the avenues for improvement are limitless, each instance of ethical reflection remains invaluable.

6.4 The future in society

In considering future shifts, it's essential to contemplate how advancements in technology could further address the challenges faced by individuals with disabilities, such as deaf and hard-of-hearing children. The project's focus on developing solutions to improve the sleep quality of these children highlights the importance of addressing their unique needs and challenges.

Looking ahead, there's potential for further innovation in this area, particularly in leveraging emerging technologies to create more effective and accessible solutions. For example, future iterations of the project could explore the integration of wearable devices or smart sensors to monitor sleep patterns and provide personalized interventions in real-time. Additionally, advancements in artificial intelligence and machine learning could be harnessed to enhance the efficacy of interventions by analyzing data and adapting strategies based on individual needs and preferences.

Moreover, as society becomes increasingly interconnected and technologically reliant, there's an opportunity to leverage technology to foster greater inclusivity and support for individuals with disabilities. By designing products and services that are universally accessible and inclusive, we can help break down barriers and promote equal participation in all aspects of life.

Furthermore, considering the broader societal implications, addressing the sleep difficulties of deaf and hard-of-hearing children not only improves their quality of life but also contributes to a more equitable and inclusive society. By prioritizing the needs of marginalized groups and advocating for greater awareness and support, we can work towards creating a society where everyone has the opportunity to thrive.

In conclusion, by continuing to innovate and collaborate, we can drive positive change and create a future where technology serves as a catalyst for inclusion and empowerment for individuals of all abilities.

REFERENCES

[1] I. van de Poel and L. Royakkers, *Ethics, Technology, and Engineering*. Wiley, Mar. 2011.

[2] A. H. Mader and W. Eggink, "A Design Process for Creative Technology," in *Proceedings of the 16th International conference on Engineering and Product Design, E&PDE 2014*. The Design Society, Sep. 2014, pp. 568–573. [Online]. Available: https://research.utwente.nl/en/publications/a-design-process-for-creative-technology

[3] M. Dearing, "Correlations between Sleep and Hearing Loss," Feb. 2022. [Online]. Available: https://myhearingcenters.com/blog/correlations-between-sleep-and-hearing-loss/

[4] G. Alrousan, A. Hassan, A. A. Pillai, F. Atrooz, and S. Salim, "Early Life Sleep Deprivation and Brain Development: Insights From Human and Animal Studies," *Frontiers in Neuroscience*, vol. 16, p. 833786, May 2022. [Online]. Available: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC9111737/

[5] C. I. Lanting, J. A. Deurloo, C. H. Wiefferink, and N. Uilenburg, "JGZ-richtlijn Vroegtijdige opsporing van gehoorverlies bij kinderen en jongeren (0 tot 18 jaar)," *JGZ Tijdschrift voor jeugdgezondheidszorg*, vol. 49, no. 4, pp. 77–80, Aug. 2017. [Online]. Available: https://doi.org/10.1007/s12452-017-0110-1

[6] "What Is Codesign? — updated 2024," Jun. 2024. [Online]. Available: https://www.interaction-design.org/literature/topics/codesign

[7] National Deaf Children's Society, "Behind the Silence: Why D/deaf children are falling behind in early years." [Online]. Available: https://www.deafnessresourcecentre.org/news/deaf-children-falling-behind-peers-in-early-years/

[8] "Ability Tech – Inclusive Innovation." [Online]. Available: https://abilitytech.nl/

[9] B. Turvey and S. Crowder, *Ethical Justice: Applied Issues for Criminal Justice Students and Professionals*, 1st ed. Academic Press, Jun. 2013. [Online]. Available: https://doi.org/10.1016/C2011-0-07155-7

[10] I. van de Poel and L. Royakkers, "Ethics, Technology, and Engineering."

[11] T. E. P. A. O. T. C. , "Directive 2009/48/EC of the European Parliament and of the Council of 18 June 2009 on the safety of toys (Text with EEA relevance)Text with EEA relevance," Nov. 2019, legislative Body: OP_DATPRO. [Online]. Available: http://data.europa.eu/eli/dir/2009/48/2019-11-18/eng

[12] C. PRV, "Wetgeving speelgoed - Speelgoed - NVWA," Sep. 2016, last Modified: 2024-01-05T16:26 Publisher: Ministerie van Landbouw, Natuur en Voedselkwaliteit. [Online]. Available: https://www.nvwa.nl/onderwerpen/speelgoed/regels-en-wetgeving-speelgoed

[13] "Ethics Committee | Faculty of Electrical Engineering, Mathematics and Computer Science (EEMCS)." [Online]. Available: https://www.utwente.nl/en/eemcs/research/ethics/

10.3 All codes utilized in the Family Locator

10.3.1 Remote

```
/*
 * This code implements a remote control for the Family Locator system,
   connecting via Wi-Fi.
 * The remote features one green LED, one yellow LED, and six buttons, all
   powered by an ESP32.
 * Each button corresponds to the presence of a family member in specific
   rooms of the house.
 * When a button is pressed, the yellow LED lights up, and the user interface
    displays the corresponding room.
 * Upon successful message receipt by the user interface, the green LED
   blinks, providing visual feedback.
 * Messages containing various variables are transmitted over the Wi-Fi
   connection.
 */

//------------------------- ESP wifi
   ----------------------------------------------

#include <esp_now.h>
#include <WiFi.h>

// REPLACE WITH THE MAC Address of your receiver (Other ESP-32)
uint8_t broadcastAddress[] = { 0xC8, 0x2E, 0x18, 0xF7, 0xF1, 0x7C };

typedef struct struct_message {
  int deviceNumber; //to identify the family member
  //incomming booleans corresponding to different rooms
  int valueButtonOne;
  int valueButtonTwo;
  int valueButtonTree;
  int valueButtonFour;
  int valueButtonFive;
  int valueButtonSix;

} struct_message;

// Variable to store if sending data was successful
String success;
boolean deliveredMessage = false;

// Create a struct_message called thingsToSend to hold sensor readings
struct_message thingsToSend;

esp_now_peer_info_t peerInfo;


// Callback when data is sent
void OnDataSent(const uint8_t *mac_addr, esp_now_send_status_t status) {
  Serial.print("\r\nLast Packet Send Status:\t");
```

```
  Serial.println(status == ESP_NOW_SEND_SUCCESS ? "Delivery Success" : "
    Delivery Fail");
  if (status == 0) {
    success = "Delivery Success :)";
    deliveredMessage = true;
  } else {
    success = "Delivery Fail :(";
    deliveredMessage = false;
  }
}
//------------------------- remote
    ---------------------------------------------

const int deviceNumber = 1; //remote of family member one
const int pinButtonOne = 23;
const int pinButtonTwo = 22;
const int pinButtonTree = 21;
const int pinButtonFour = 19;
const int pinButtonFive = 18;
const int pinButtonSix = 5;

const int ledPinSend = 17;
const int ledPinDeliverySucces = 16;

int valueButtonOne;
int valueButtonTwo;
int valueButtonTree;
int valueButtonFour;
int valueButtonFive;
int valueButtonSix;


void setup() {
  Serial.begin(115200);
  //-------- WIFI - ESP --------
  // Set device as a Wi-Fi Station
  WiFi.mode(WIFI_STA);

  // Init ESP-NOW
  if (esp_now_init() != ESP_OK) {
    Serial.println("Error initializing ESP-NOW");
    return;
  }

  // Once ESPNow is successfully Init, we will register for Send CB to
  // get the status of Trasnmitted packet
  esp_now_register_send_cb(OnDataSent);

  // Register peer
  memcpy(peerInfo.peer_addr, broadcastAddress, 6);
  peerInfo.channel = 0;
  peerInfo.encrypt = false;

  // Add peer
```

```
  if (esp_now_add_peer(&peerInfo) != ESP_OK) {
    Serial.println("Failed to add peer");
    return;
  }


  //Remote
  pinMode(pinButtonOne, INPUT);
  pinMode(pinButtonTwo, INPUT);
  pinMode(pinButtonTree, INPUT);
  pinMode(pinButtonFour, INPUT);
  pinMode(pinButtonFive, INPUT);
  pinMode(pinButtonSix, INPUT);

  pinMode(ledPinSend, OUTPUT);
  pinMode(ledPinDeliverySucces, OUTPUT);
}

void loop() {
  manageButtonsAndLED();
  sentMessage();
  delay(100);
}

void sentMessage() {
  // Send message via ESP-NOW
  //might be a problem, it is not updated yet, the things to send (something
    with blablabla.blablablal)
  esp_err_t result = esp_now_send(broadcastAddress, (uint8_t *)&thingsToSend,
     sizeof(thingsToSend));

  if (result == ESP_OK) {
    Serial.println("Sent with success");
  } else {
    Serial.println("Error sending the data");
  }
}


void manageButtonsAndLED() {
  thingsToSend.deviceNumber = deviceNumber;
  thingsToSend.valueButtonOne = digitalRead(pinButtonOne);
  thingsToSend.valueButtonTwo = digitalRead(pinButtonTwo);
  thingsToSend.valueButtonTree = digitalRead(pinButtonTree);
  thingsToSend.valueButtonFour = digitalRead(pinButtonFour);
  thingsToSend.valueButtonFive = digitalRead(pinButtonFive);
  thingsToSend.valueButtonSix = digitalRead(pinButtonSix);

  Serial.print("device number:");
  Serial.println(thingsToSend.deviceNumber);
  Serial.print("valueButtonOne: ");
  Serial.println(thingsToSend.valueButtonOne);
  Serial.print("valueButtonTwo: ");
```

```
  Serial.println(thingsToSend.valueButtonTwo);
  Serial.print("valueButtonTree: ");
  Serial.println(thingsToSend.valueButtonTree);
  Serial.print("valueButtonFour: ");
  Serial.println(thingsToSend.valueButtonFour);
  Serial.print("valueButtonFive: ");
  Serial.println(thingsToSend.valueButtonFive);
  Serial.print("valueButtonSix: ");

  Serial.println(thingsToSend.valueButtonSix);

  if (thingsToSend.valueButtonOne != 0 || thingsToSend.valueButtonTwo != 0 ||
     thingsToSend.valueButtonTree != 0 || thingsToSend.valueButtonFour != 0
    || thingsToSend.valueButtonFive != 0 || thingsToSend.valueButtonSix != 0)
     {
    // }|| valueButtonFive != 0) {
    digitalWrite(ledPinSend, HIGH);
    if (deliveredMessage) {
      digitalWrite(ledPinDeliverySucces, HIGH);
    }
  } else {
    digitalWrite(ledPinSend, LOW);
  }

  if (!deliveredMessage) {
    digitalWrite(ledPinDeliverySucces, LOW);
  }
}
```

10.3.2 Full code of mac adress definer

```
    to // Complete Instructions to Get and Change ESP MAC Address: https://
   RandomNerdTutorials.com/get-change-esp32-esp8266-mac-address-arduino/

#include "WiFi.h"

void setup(){
  Serial.begin(115200);
  WiFi.mode(WIFI_MODE_STA);
  Serial.println(WiFi.macAddress());
}

void loop(){

}
```

10.3.3 Full code of user interface

```
//------------------------- ESP wifi
    ------------------------------------------
#include <esp_now.h>
#include <WiFi.h>

// REPLACE WITH THE MAC Address of your receiver (OTHER BOARD)
uint8_t broadcastAddress[] = { 0x10, 0x06, 0x1C, 0x81, 0xCA, 0xD0 };



// Define variables to store incoming readings
int incomingDeviceNumber; //represents which family member is sending a
    message
  //incomming booleans corresponding to different rooms
int incomingValueButtonOne;
int incomingValueButtonTwo;
int incomingValueButtonTree;
int incomingValueButtonFour;
int incomingValueButtonFive;
int incomingValueButtonSix;


// Variable to store if sending data was successful
String success;


esp_now_peer_info_t peerInfo;

typedef struct struct_message {
  int deviceNumber;
  int valueButtonOne;
  int valueButtonTwo;
  int valueButtonTree;
  int valueButtonFour;
  int valueButtonFive;
  int valueButtonSix;
} struct_message;



// Create a struct_message to hold incoming sensor readings
struct_message incomingReadings;

// Variable to track the last time data was received
unsigned long lastReceivedTime = 0;
const unsigned long timeoutPeriod = 1000;  // Timeout period in milliseconds
    (5 seconds)


// Callback when data is received
void OnDataRecv(const uint8_t *mac, const uint8_t *incomingData, int len) {
```

```
  memcpy(&incomingReadings, incomingData, sizeof(incomingReadings));

  lastReceivedTime = millis(); // Update the last received time

  Serial.print("Bytes received: ");
  Serial.println(len);
  incomingDeviceNumber = incomingReadings.deviceNumber;
  incomingValueButtonOne = incomingReadings.valueButtonOne;
  incomingValueButtonTwo = incomingReadings.valueButtonTwo;
  incomingValueButtonTree = incomingReadings.valueButtonTree;
  incomingValueButtonFour = incomingReadings.valueButtonFour;
  incomingValueButtonFive = incomingReadings.valueButtonFive;
  incomingValueButtonSix = incomingReadings.valueButtonSix;


  Serial.print("incomingDeviceNumber");
  Serial.println(incomingDeviceNumber);
  Serial.print("incomingValueButtonOne");
  Serial.println(incomingValueButtonOne);
  Serial.print("incomingValueButtonTwo");
  Serial.println(incomingValueButtonTwo);
  Serial.print("incomingValueButtonTree");
  Serial.println(incomingValueButtonTree);
  Serial.print("incomingValueButtonFour");
  Serial.println(incomingValueButtonFour);
  Serial.print("incomingValueButtonFive");
  Serial.println(incomingValueButtonFive);
  Serial.print("incomingValueButtonSix");
  Serial.println(incomingValueButtonSix);
}

//------------------------- remote
    ---------------------------------------------



#include <FastLED.h>

//pins of LEDstrips
#define TRAP_LEDS_PIN 14
#define SLAAPKAMER_LEDS_PIN 27
#define BADKAMER_LEDS_PIN 26
#define WC_LEDS_PIN 25
#define KEUKEN_LEDS_PIN 33
#define WOONKAMER_LEDS_PIN 32
#define FAMILY_MEMBER_1_PIN 13
#define FAMILY_MEMBER_2_PIN 12

//number of LEDs per LEDstrip
#define NUM_PICTO_LEDS 23
#define NUM_PROFILE_PICTURE_LEDS 27

//colors of different rooms
CRGB trapColor = CRGB(0, 255, 0);
```

```
CRGB slaapkamerColor = CRGB(0, 0, 255);
CRGB badkamerColor = CRGB(255, 0, 0);
CRGB wcColor = CRGB(0, 0, 0);
CRGB keukenColor = CRGB(255, 0, 0);
CRGB woonKamerColor = CRGB(255, 0, 0);
CRGB standbyColor = CRGB(10, 10, 10);


//colors of the family members
CRGB familyMember1Color = CRGB(127, 0, 153);  //Purple
CRGB familyMember2Color = CRGB(0, 234, 255);
CRGB errorColor = CRGB(123, 80, 0);
bool errorLedEmitting = false;

#define BRIGHTNESS 10  // Max brightness is 255
CRGB trapLEDS[NUM_PICTO_LEDS];
CRGB slaapkamerLEDS[NUM_PICTO_LEDS];
CRGB badkamerLEDS[NUM_PICTO_LEDS];
CRGB wcLEDS[NUM_PICTO_LEDS];
CRGB keukenLEDS[NUM_PICTO_LEDS];
CRGB woonkamerLEDS[NUM_PICTO_LEDS];

CRGB familyMember1[NUM_PROFILE_PICTURE_LEDS];
CRGB familyMember2[NUM_PROFILE_PICTURE_LEDS];

// error settings
int startMillis = 0;

int period = 1000; // Duration in milliseconds before showing an error
    message if no messages are received (1 second)


void setup() {
  Serial.begin(9600);
  //-------------------------- ESP wifi
    ----------------------------------------------

  // Set device as a Wi-Fi Station
  WiFi.mode(WIFI_STA);

  // Init ESP-NOW
  if (esp_now_init() != ESP_OK) {
    Serial.println("Error initializing ESP-NOW");
    return;
  }

  // Register peer
  memcpy(peerInfo.peer_addr, broadcastAddress, 6);
  peerInfo.channel = 0;
  peerInfo.encrypt = false;

  // Add peer
  if (esp_now_add_peer(&peerInfo) != ESP_OK) {
```

```
    Serial.println("Failed to add peer");
    return;
  }
  // Register for a callback function that will be called when data is
    received
  esp_now_register_recv_cb(OnDataRecv);

  //------------------------- user interface
    ---------------------------------------------

  //led settings
  FastLED.addLeds<WS2812, TRAP_LEDS_PIN, GRB>(trapLEDS, NUM_PICTO_LEDS);
  FastLED.addLeds<WS2812, SLAAPKAMER_LEDS_PIN, GRB>(slaapkamerLEDS,
    NUM_PICTO_LEDS);
  FastLED.addLeds<WS2812, BADKAMER_LEDS_PIN, GRB>(badkamerLEDS,
    NUM_PICTO_LEDS);
  FastLED.addLeds<WS2812, WC_LEDS_PIN, GRB>(wcLEDS, NUM_PICTO_LEDS);
  FastLED.addLeds<WS2812, KEUKEN_LEDS_PIN, GRB>(keukenLEDS, NUM_PICTO_LEDS);
  FastLED.addLeds<WS2812, WOONKAMER_LEDS_PIN, GRB>(woonkamerLEDS,
    NUM_PICTO_LEDS);

  FastLED.addLeds<WS2812, FAMILY_MEMBER_1_PIN, GRB>(familyMember1,
    NUM_PROFILE_PICTURE_LEDS);
  FastLED.addLeds<WS2812, FAMILY_MEMBER_2_PIN, GRB>(familyMember2,
    NUM_PROFILE_PICTURE_LEDS);

//to debug - to see if all LEDstrips are working
  // for (int i; i < NUM_PICTO_LEDS; i++) {
  //   trapLEDS[i] = trapColor;
  //   slaapkamerLEDS[i] = slaapkamerColor;
  //   badkamerLEDS[i] = badkamerColor;
  //   wcLEDS[i] = wcColor;
  //   keukenLEDS[i] = keukenColor;
  //   woonkamerLEDS[i] = woonKamerColor;
  // }

  FastLED.setBrightness(BRIGHTNESS);
  FastLED.clear();  // clear all pixel data

  //set up parents
  for (int i; i < NUM_PROFILE_PICTURE_LEDS; i++) {
    familyMember1[i] = familyMember1Color;
    familyMember2[i] = familyMember2Color;
  }
  FastLED.show();

  startMillis = millis();
}

void loop() {

  manageLEDs();
  //checks if the connection with the remote is lost
  if (millis() - lastReceivedTime > timeoutPeriod) {
```

```
    onConnectionLost();
    Serial.println("connection lost");
  } else {
    resetParentColor(); //turns off (yellow blinking) error light
  }
}



void onConnectionLost() { //turns off (yellow blinking) error light
  unsigned long currentMillis = millis();        // Get the current "time" (
    actually the number of milliseconds since the program started)
  if (currentMillis - startMillis >= period) {  // Test whether the period
    has elapsed
    for (int i = 0; i < NUM_PROFILE_PICTURE_LEDS; i++) {
      if (errorLedEmitting) {
        familyMember1[i] = familyMember1Color;   // Turn off the LED
      } else {
        familyMember1[i] = errorColor;   // Set the LED to the error color
      }
    }
    errorLedEmitting = !errorLedEmitting;   // Toggle the error LED state
    Serial.println("Error LED toggled");
    startMillis = currentMillis;   // Save the start time of the current LED
    state
  }
  FastLED.show();   // Update the LED strip
}

void resetParentColor() { //turn off the yellow blinking error light
  for (int i = 0; i < NUM_PROFILE_PICTURE_LEDS; i++) {
    familyMember1[i] = familyMember1Color;
  }
}



void manageLEDs() {
  Serial.print("incomingDeviceNumber: ");
  Serial.println(incomingDeviceNumber);

//manage the LEDs for the remote of family member 1
  if (incomingDeviceNumber == 1) {
    if (incomingValueButtonOne == 1) {
      for (int i = 0; i < NUM_PICTO_LEDS; i++) {
        trapLEDS[i] = familyMember1Color;
      }
    } else {
      for (int i = 0; i < NUM_PICTO_LEDS; i++) {
        trapLEDS[i] = standbyColor;
      }
    }
```

```
    if (incomingValueButtonTwo == 1) {
      for (int i = 0; i < NUM_PICTO_LEDS; i++) {
        slaapkamerLEDS[i] = familyMember1Color;
      }
    } else {
      for (int i = 0; i < NUM_PICTO_LEDS; i++) {
        slaapkamerLEDS[i] = standbyColor;
      }
    }

    if (incomingValueButtonTree == 1) {
      for (int i = 0; i < NUM_PICTO_LEDS; i++) {
        badkamerLEDS[i] = familyMember1Color;
      }
    } else {
      for (int i = 0; i < NUM_PICTO_LEDS; i++) {
        badkamerLEDS[i] = standbyColor;
      }
    }


    if (incomingValueButtonFour == 1) {
      for (int i = 0; i < NUM_PICTO_LEDS; i++) {
        wcLEDS[i] = familyMember1Color;
      }
    } else {
      for (int i = 0; i < NUM_PICTO_LEDS; i++) {
        wcLEDS[i] = standbyColor;
      }
    }

    if (incomingValueButtonFive == 1) {
      for (int i = 0; i < NUM_PICTO_LEDS; i++) {
        if (i <= int(0.5 * NUM_PICTO_LEDS)) {
          keukenLEDS[i] = familyMember1Color;
        } else {
          keukenLEDS[i] = familyMember2Color;
        }
      }
    } else {
      for (int i = 0; i < NUM_PICTO_LEDS; i++) {
        keukenLEDS[i] = familyMember2Color;
      }
    }

    if (incomingValueButtonSix == 1) {
      for (int i = 0; i < NUM_PICTO_LEDS; i++) {
        woonkamerLEDS[i] = familyMember1Color;
      }
    } else {
      for (int i = 0; i < NUM_PICTO_LEDS; i++) {
        woonkamerLEDS[i] = standbyColor;
      }
```

```
      }
    }

    FastLED.show();
}
```

10.4 All codes utilized in the Ambient Sound Visualizer

10.4.1 ESP-32 Arduino code

```
// This code for the ESP32 handles incoming serial communication from a
    Python script that processes data from five microphones.
// Each microphone captures sound, and the Python script sends the
    corresponding volume and frequency values for each to this ESP-32.
// The ESP32 translates this incoming data into LED light patterns positioned
    around a sphere, illuminating the area where sound is detected.
// The brightness of the LEDs reflects the volume level, providing a dynamic
    visual representation of the audio input.
// Future enhancements will integrate frequency data to further enrich the
    visualization.


// --------------------- LEDS ---------------------
#include <FastLED.h>

//Each layer of the LED ball correspond to a ring. with layer one being the
    top ring of the LED ball
#define PIN_LAYER_ONE 13
#define PIN_LAYER_TWO 12
#define PIN_LAYER_TREE 14
#define PIN_LAYER_FOUR 27
#define PIN_LAYER_FIVE 26

#define NUM_TOP_LEDS 5       //the first ring
#define NUM_SMALL_RING 15    //ring 2 and 5
#define NUM_BIG_RING 20      //ring 3 and 4


#define BRIGHTNESS 200   // Max brightness is 255

CRGB layerOneLeds[NUM_TOP_LEDS];
CRGB layerTwoLeds[NUM_SMALL_RING];
CRGB layerTreeLeds[NUM_BIG_RING];
CRGB layerFourLeds[NUM_BIG_RING];
CRGB layerFiveLeds[NUM_SMALL_RING];


// Boolean variables for LED settings (to be implemented in the future)
// These will be controlled by buttons
```

```
bool ambientSoundMode = true;
bool sleepRoutineMode = false;
bool partyMode = false;

// --------------------- Potentiometer ---------------------
int potMeterPin = 25;
int potMeterValue;

// --------------------- Receive data from python ---------------------


// Define constants
const int MAX_MICROPHONES = 5;  // Maximum number of microphones

// Variables to store data
float volume[MAX_MICROPHONES];
float frequency[MAX_MICROPHONES];

//constant
const float volumeTreshold = 0.1;

// Function to parse incoming data
void parseData(String data) {
  // Example expected data format: "Microphone 1 - Volume: 0.50, Frequency: 1000.00 Hz"
  int micIndex = data.substring(11, 12).toInt();  // Extract microphone index from string
  int spaceIndex1 = data.indexOf("Volume:");
  int commaIndex = data.indexOf(",", spaceIndex1);
  volume[micIndex - 1] = data.substring(spaceIndex1 + 8, commaIndex).toFloat();  // Extract volume

  int spaceIndex2 = data.indexOf("Frequency:");
  frequency[micIndex - 1] = data.substring(spaceIndex2 + 11).toFloat();  // Extract frequency
}

// Function to handle incoming data and print values
void handleIncomingData() {
  if (Serial.available() > 0) {
    String data = Serial.readStringUntil('\n');  // Read incoming data
    parseData(data);                              // Parse and store data
  }
}

// Function to print microphone volumes and control LEDs for each side
void manageAmbientSoundVisualization(int initPotMeterValue) {

  Serial.print("Microphone Volumes: ");


  float dimFactor = float(initPotMeterValue / (16.0 * 1024.0));
  Serial.println(dimFactor);
```

```
  for (int i = 0; i < MAX_MICROPHONES; ++i) {
    Serial.print(volume[i]);
  }

  // The LED ball is divided into five sides, each representing an area where audio is captured. The corresponding LEDs for each section were determined through careful mapping.
  //side A
  if (volume[3] > volumeTreshold) {
    //adjust acoording to the correct layout
    manageLEDsSideA(potMeterValue, float(volume[3]));
  } else {
    manageLEDsSideA(0.0, volume[3]);
  }

  //side B
  if (volume[0] > volumeTreshold) {
    //adjust acoording to the correct layout
    manageLEDsSideB(potMeterValue, float(volume[0]));
  } else {
    manageLEDsSideB(0.0, 0.0);
  }

  //side C
  if (volume[2] > volumeTreshold) {
    //adjust acoording to the correct layout
    manageLEDsSideC(potMeterValue, float(volume[2]));
  } else {
    manageLEDsSideC(0.0, 0.0);
  }

  //side D
  if (volume[1] > volumeTreshold) {
    //adjust acoording to the correct layout
    manageLEDsSideD(potMeterValue, float(volume[1]));
  } else {
    manageLEDsSideD(0.0, 0.0);
  }

  //side E
  if (volume[4] > volumeTreshold) {
    //adjust acoording to the correct layout
    manageLEDsSideE(potMeterValue, float(volume[4]));
  } else {
    manageLEDsSideE(0.0, 0.0);
  }
}

void setup() {
  Serial.begin(115200);  // Initialize serial communication

  // --------------------- LEDS ---------------------
  FastLED.addLeds<WS2812, PIN_LAYER_ONE, GRB>(layerOneLeds, NUM_TOP_LEDS);
  FastLED.addLeds<WS2812, PIN_LAYER_TWO, GRB>(layerTwoLeds, NUM_SMALL_RING);
```

```
  FastLED.addLeds<WS2812, PIN_LAYER_TREE, GRB>(layerTreeLeds, NUM_BIG_RING);
  FastLED.addLeds<WS2812, PIN_LAYER_FOUR, GRB>(layerFourLeds, NUM_BIG_RING);
  FastLED.addLeds<WS2812, PIN_LAYER_FIVE, GRB>(layerFiveLeds, NUM_SMALL_RING)
    ;

  FastLED.setBrightness(BRIGHTNESS);
  FastLED.clear(); // clear all pixel data
  Serial.print("set up done");
}

void loop() {
  potMeterValue = measurePotMeterValue();
  handleIncomingData();                    // Handle incoming data and parse
  manageAmbientSoundVisualization(potMeterValue);  // Print microphone
    volumes and control LED
  manageTopAndInbetween(potMeterValue);
  FastLED.show();
}

int measurePotMeterValue() {
  int newPotMeterValue = analogRead(potMeterPin);
  Serial.print("newPotMeterValue: ");
  Serial.println(newPotMeterValue);
  return newPotMeterValue;
}


void manageLEDsSideA(int initPotMeterValue, float initVolume) {
  float dimFactor = float(initPotMeterValue / 1024.0);
  float volumeFactor = float(initVolume);
  Serial.println(dimFactor);

  int rColor = int(volumeFactor * dimFactor * 255);
  int gColor = int(volumeFactor * dimFactor * 0);
  int bColor = int(volumeFactor * dimFactor * 0);

  //sideA
  layerTwoLeds[1] = CRGB(rColor, gColor, bColor);
  // }
  for (int i = 17; i < 20; i++) {
    layerTreeLeds[i] = CRGB(rColor, gColor, bColor);

  }
  for (int i = 15; i < 18; i++) {
    layerFourLeds[i] = CRGB(rColor, gColor, bColor);
  }
  for (int i = 3; i < 6; i++) {
    layerFiveLeds[i] = CRGB(rColor, gColor, bColor);
  }
  FastLED.show();
}

void manageLEDsSideB(int initPotMeterValue, float initVolume) {
  float dimFactor = float(initPotMeterValue / 1024.0);
```

```
  float volumeFactor = float(initVolume);
  Serial.println(dimFactor);

  int rColor = int(volumeFactor * dimFactor * 255);
  int gColor = int(volumeFactor * dimFactor * 255);
  int bColor = int(volumeFactor * dimFactor * 0);


  //sideB
  for (int i = 3; i < 5; i++) {
    layerTwoLeds[i] = CRGB(rColor, gColor, bColor);
  }
  for (int i = 13; i < 16; i++) {
    layerTreeLeds[i] = CRGB(rColor, gColor, bColor);
  }
  for (int i = 11; i < 14; i++) {
    layerFourLeds[i] = CRGB(rColor, gColor, bColor);
  }
  for (int i = 6; i < 9; i++) {
    layerFiveLeds[i] = CRGB(rColor, gColor, bColor);
  }
  FastLED.show();
}

void manageLEDsSideC(int initPotMeterValue, float initVolume) {
  float dimFactor = float(initPotMeterValue / 1024.0);
  float volumeFactor = float(initVolume);
  Serial.println(dimFactor);

  int rColor = int(volumeFactor * dimFactor * 0);
  int gColor = int(volumeFactor * dimFactor * 255);
  int bColor = int(volumeFactor * dimFactor * 0);


  //sideC
  for (int i = 6; i < 8; i++) {
    layerTwoLeds[i] = CRGB(rColor, gColor, bColor);
  }
  for (int i = 9; i < 12; i++) {
    layerTreeLeds[i] = CRGB(rColor, gColor, bColor);
    // layerTreeLeds[9] = CRGB(255, 255, 255);
  }
  for (int i = 7; i < 10; i++) {
    layerFourLeds[i] = CRGB(rColor, gColor, bColor);
  }
  for (int i = 9; i < 12; i++) {
    layerFiveLeds[i] = CRGB(rColor, gColor, bColor);
  }
  FastLED.show();
}

void manageLEDsSideD(int initPotMeterValue, float initVolume) {
  float dimFactor = float(initPotMeterValue / 1024.0);
  float volumeFactor = float(initVolume);
```

```
  Serial.println(dimFactor);

  int rColor = int(volumeFactor * dimFactor * 0);
  int gColor = int(volumeFactor * dimFactor * 0);
  int bColor = int(volumeFactor * dimFactor * 255);

  //sideD
  for (int i = 9; i < 11; i++) {
    layerTwoLeds[i] = CRGB(rColor, gColor, bColor);
  }
  for (int i = 5; i < 8; i++) {
    layerTreeLeds[i] = CRGB(rColor, gColor, bColor);
  }
  for (int i = 3; i < 6; i++) {
    layerFourLeds[i] = CRGB(rColor, gColor, bColor);
  }
  for (int i = 12; i < 15; i++) {
    layerFiveLeds[i] = CRGB(rColor, gColor, bColor);
  }
  FastLED.show();
}

void manageLEDsSideE(int initPotMeterValue, float initVolume) {
  float dimFactor = float(initPotMeterValue / 1024.0);
  float volumeFactor = float(initVolume);
  Serial.println(dimFactor);

  int rColor = int(volumeFactor * dimFactor * 0);
  int gColor = int(volumeFactor * dimFactor * 255);
  int bColor = int(volumeFactor * dimFactor * 255);

  //sideE
  for (int i = 12; i < 14; i++) {
    layerTwoLeds[i] = CRGB(rColor, gColor, bColor);
  }
  for (int i = 1; i < 4; i++) {
    layerTreeLeds[i] = CRGB(rColor, gColor, bColor);
  }

  layerFourLeds[1] = CRGB(rColor, gColor, bColor);
  layerFourLeds[0] = CRGB(rColor, gColor, bColor);
  layerFourLeds[19] = CRGB(rColor, gColor, bColor);
  for (int i = 0; i < 3; i++) {
    layerFiveLeds[i] = CRGB(rColor, gColor, bColor);
  }
  FastLED.show();
}


void manageTopAndInbetween(int initPotMeterValue) {
  float dimFactor = float(initPotMeterValue / 1024.0);
  Serial.println(dimFactor);
  int rColor = int(dimFactor * 50);
  int gColor = int(dimFactor * 21);
```

```
  int bColor = int(dimFactor * 225);

  //top
  for (int i = 0; i < NUM_TOP_LEDS; i++) {
    layerOneLeds[i] = CRGB(rColor, gColor, bColor);
  }

  //layer Iwo
  layerTwoLeds[2] = CRGB(rColor, gColor, bColor);
  layerTwoLeds[5] = CRGB(rColor, gColor, bColor);
  layerTwoLeds[8] = CRGB(rColor, gColor, bColor);
  layerTwoLeds[11] = CRGB(rColor, gColor, bColor);
  layerTwoLeds[14] = CRGB(rColor, gColor, bColor);


  //layer tree
  layerTreeLeds[20] = CRGB(rColor, gColor, bColor);
  layerTreeLeds[16] = CRGB(rColor, gColor, bColor);
  layerTreeLeds[12] = CRGB(rColor, gColor, bColor);
  layerTreeLeds[8] = CRGB(rColor, gColor, bColor);
  layerTreeLeds[4] = CRGB(rColor, gColor, bColor);
  layerTreeLeds[0] = CRGB(rColor, gColor, bColor);


  //layer four
  layerFourLeds[18] = CRGB(rColor, gColor, bColor);
  layerFourLeds[14] = CRGB(rColor, gColor, bColor);
  layerFourLeds[10] = CRGB(rColor, gColor, bColor);
  layerFourLeds[6] = CRGB(rColor, gColor, bColor);
  layerFourLeds[2] = CRGB(rColor, gColor, bColor);

  FastLED.show();
}
```

10.4.2 Python code (microphone test script)

```python
#This scipt can be used to see which microphone devices are connected
import sounddevice as sd
print(sd.query_devices())
```

10.4.3 Python code (Ambient sound capturing)

```python
import sounddevice as sd
import numpy as np
import serial
import signal
import sys
```

```python

# Global flag to indicate if the program should exit
running = True

# Function to handle Ctrl+C
def signal_handler(sig, frame):
    global running
    print('\nYou pressed Ctrl+C! Exiting gracefully...')
    running = False
    if 'arduino' in globals():
        arduino.close()  # Close the serial connection if open
    sys.exit(0)  # Exit the script

# Set the signal handler
signal.signal(signal.SIGINT, signal_handler)

# Constants
duration = 0.05        # Duration of each audio chunk to capture (in seconds)
fs = 44100             # Sampling frequency
num_mics = 5           # Number of microphones

# Device indices for the microphones (replace with actual indices from sd.query_devices())
device_indices = [46, 56, 57, 54, 55]  # Example indices, adjust as per your setup

# Initialize microphone data array
microphone_data = [{'volume': 0.0, 'frequency': 0.0} for _ in range(num_mics)]  # Initialize with floats

# Attempt to open serial communication with Arduino
try:
    arduino = serial.Serial(port='COM33', baudrate=115200, timeout=0.1)
    print(f"Serial port {arduino.portstr} successfully opened.")
except serial.SerialException as e:
    print(f"Failed to open serial port COM: {e}")
    sys.exit(1)  # Exit with error code 1 if serial port cannot be opened

# Function to measure the peak amplitude (volume)
def measure_volume(audio_chunk):
    peak_value = np.max(np.abs(audio_chunk))
    return peak_value

# Function to capture audio and update microphone data
def capture_audio_and_update():
    global microphone_data, running, arduino

```

```python
    while running:
        for mic_index in range(num_mics):
            try:
                # Record audio for the specified duration
                audio_chunk = sd.rec(int(duration * fs), samplerate=fs,
                ↪  channels=1,
                                     device=device_indices[mic_index],
                                     ↪  dtype='float64', blocking=True)
                audio_chunk = audio_chunk.flatten()

                # Calculate peak volume and peak frequency
                peak_value = measure_volume(audio_chunk)
                freq = np.fft.rfftfreq(len(audio_chunk), d=1/fs)
                magnitude = np.abs(np.fft.rfft(audio_chunk))
                peak_freq = freq[np.argmax(magnitude)]

                # Print values in terminal with device index
                print(f"Microphone {mic_index + 1} - Device Index:
                ↪  {device_indices[mic_index]} - Volume:
                ↪  {peak_value:.2f}, Peak Frequency: {peak_freq:.2f} Hz")

                # Prepare data to send over serial
                data_to_send = f"Microphone {mic_index + 1} - Device
                ↪  Index: {device_indices[mic_index]} - Volume:
                ↪  {peak_value:.2f}, Frequency: {peak_freq:.2f} Hz\n"

                # Send data over serial to Arduino
                arduino.write(data_to_send.encode('utf-8'))

            except Exception as e:
                print(f"Error capturing audio from microphone
                ↪  {mic_index+1}: {e}")

# Run the audio capture and update function
capture_audio_and_update()

```

10.4.4 Design cycles

Ethical cycle of van der Poel et al. [2]

10.4.5 Creative technology design cycle of Mader et al. [1]

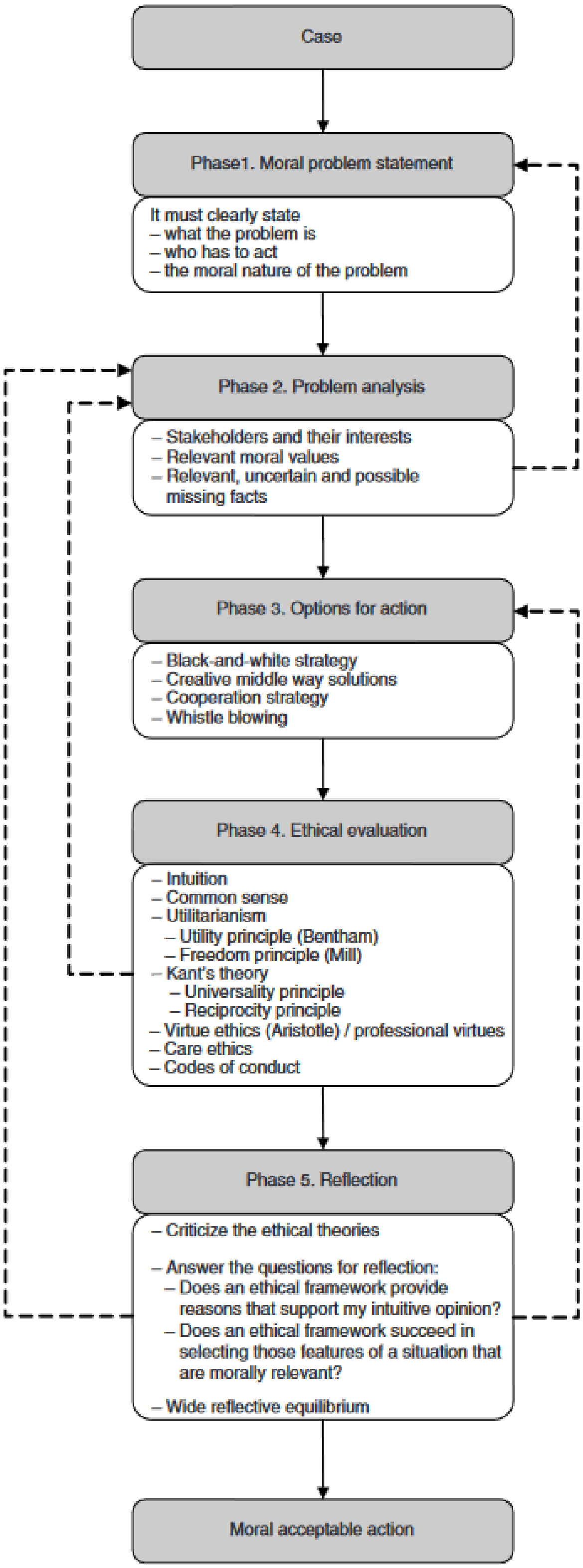

Figure 10.1: Detailed overview of the Ethical Cycle of Van de Poel et al. [2]

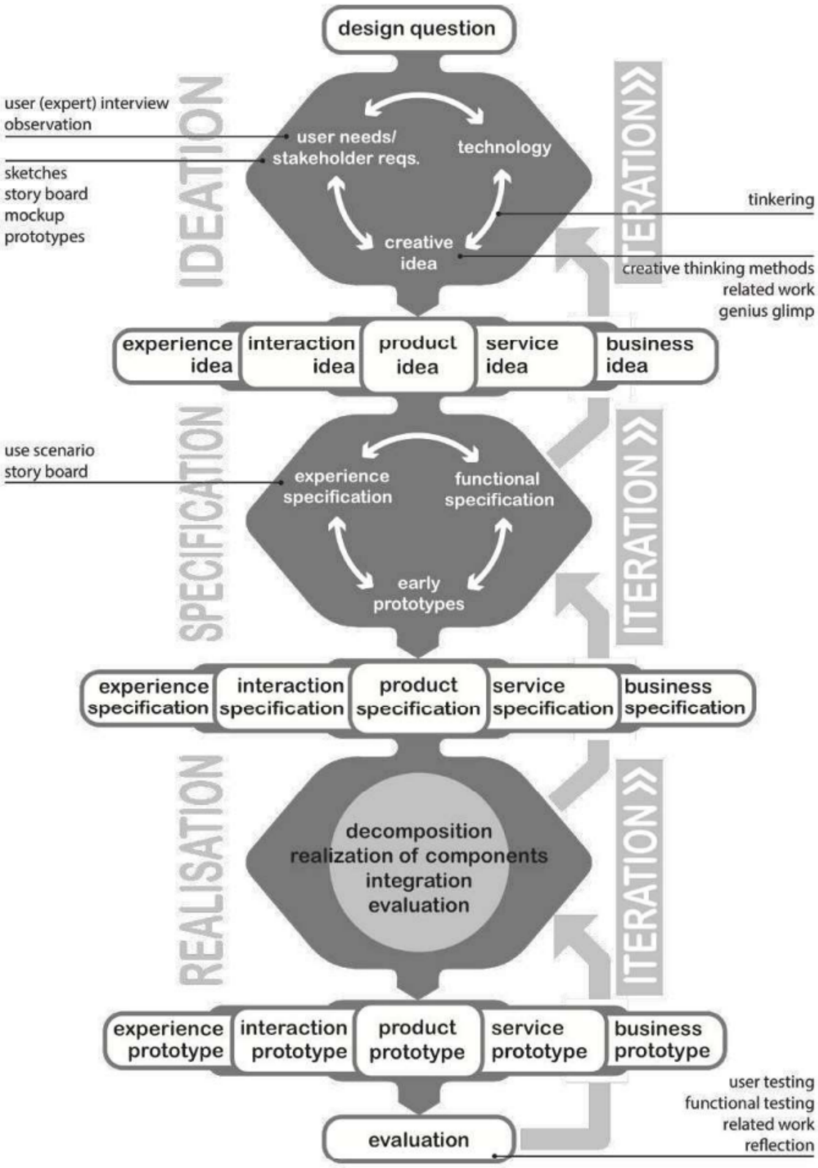

Figure 10.2: The Creative Technology Design Cycle [1]