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Exploring the use of alternative media to facilitate the instruction of motor movement for special athletes – an athletics case study

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Abstract

Nowadays, interactive technology is becoming more embedded in the world of sports. Whereas much is available for the regular athlete, little is tailored specially to the needs of athletes with intellectual disabilities. This is unfortunate for this user group since they can profit a lot from the benefits of interactive technology, such as improving motor skills, social skills, and self-esteem. Via literature research, interviews, and observations, it has been shown that special athletes experience difficulties with verbally explained exercises. Many of them experience some sort of language comprehension, memory deficit, short attention span, impulsive behavior, and/or hearing deficit, which makes it hard for them to comprehend verbal information. This causes the children to not understand and not be engaged in the exercise and the training. Therefore, the aim of this study is to explore the use of alternative media to facilitate the instruction of motor movement for special athletes.

The creative technology design process is used as a base to address this gap in research, which consists of the ideation, specification, realization, and evaluation phase. This has eventually led to a prototype, which is an add-on instruction system for athletics equipment, that will guide athletes with intellectual disabilities through exercises. This prototype has come forth out of (non-)functional system requirements and is afterward tested with three user tests. In these tests, it became clear that with the prototype; fewer mistakes are made, exercises are completed faster, less time is needed for verbal explanation and more children understand the exercises at once. The special athletes express their preference for the system and the trainer reveals positive feelings towards the prototype. The prototype has achieved its goal, which is to improve understanding and engagement in exercises for children with intellectual disabilities. Certain limitations, such as the number of test participants and the number of obstacles have to be further researched before a general claim for all special athletes can be made.

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Abbreviations and symbols / Glossary

ID = intellectual disability
ASD = Autism spectrum Disorder
ADHD = Attention deficit hyperactivity disorder
DS = Down Syndrome
PA = Physical Activity
AT = assistive technology

CHAPTER 1: Introduction

In this introductory chapter of the thesis, multiple topics will be discussed. First, an introduction is given to the problem identification, accompanied by the necessity thereof within a broad societal perspective. Then, the causes of the problem are given, alongside the current state of research on this topic. In the second section, the research questions are discussed, followed by the methodology of the study and an outline of the thesis in the final section.

1.1 Problem statement

In the Netherlands, between 62 and 74 thousand children have an intellectual disability (2015), which is about 2% of the children between 0 and 17 years old [1]. Children with intellectual disabilities (ID) have difficulties in both intellectual functioning and adaptive behavior, which makes it harder for them to function in daily life as well as to participate in sports. Sports participation rates among children with an intellectual disability are low [2], which consequently makes them miss out on positive health benefits that sports participation provides. Sport provides social interaction with peers, self-efficacy, and motoric skills [3], and it can boost performance, engagement and promotes learning. Additionally, it provides a platform of voice and a way of letting go of intense emotions [4]. Therefore, it is important to engage children with intellectual disabilities in sports.

Children with mental disabilities experience a number of barriers that relate to the low rate of sports participation. One of the difficulties children experience during sports is verbally explained exercises during training. This is difficult due to a combination of language comprehension deficit, memory deficit, short attention span, impulsive behavior, and hearing deficit. Since all types of disabilities differ from each other, the main focus will be on the most common intellectual disabilities, such as Autism Spectrum Disorder (ASD), Attention Deficit Hyperactivity Disorder (ADHD), and Down Syndrome (DS). All causes will be shortly described.

First of all, various groups of intellectual disabilities have difficulties with language comprehension. This is important in sports since it makes it hard for them to comprehend and process the verbal/written information that is given, such as explanations of sports exercises. Individuals with mental retardation show significant impairment across different components of language comprehension [5], one being a weakness in understanding and using vocabulary [6]. It has been shown that children with ADHD ask for clarification more often, use more tangible and unrelated information when it comes to procedural spoken text [7], and have difficulties with the speed of language comprehension [8]. Similar results were found in individuals with ASD, where specific "atypical responses on the auditory word comprehension task and functional brain differences" [9] were found. Finally, it has been established that boys with down syndrome show lower language comprehension than boys that are typically developing [10].

Besides difficulties in language comprehension, people with intellectual disabilities also experience memory problems. This can be very difficult during a practice or game when they need to remember instructions, rules, or exercises. It has been proven that semantic memory plays the biggest role in language comprehension [11], which means that language comprehension and memory are intertwined. This can be seen in figure 1.1, indicated with the double-sided arrow. Furthermore, it has been illustrated that people with ID show relative preservation of implicit memory [12]. For instance, an experiment showed that people with ASD were less able to recall recent activities than their normally developing peers [13]. Athletes with an intellectual disability need more practice/experience with the material before they demonstrate the same as their peers, or instructions should be cut into pieces.

Some individuals with intellectual disabilities experience a short attention span and impulsive behavior. This is difficult in sports since children have to be able to focus on the explanation of an exercise instead of doing other things. Research has shown that children with ASD and ADHD score poorly on motor skills, with an underlying factor inattention [14]. Children with ADHD experience behavioral problems (e.g., hyperactivity, impulsiveness, and attention problems), grounding the need to focus on strategies to control impulsive behavior and improve attention to tasks [15].

Finally, a hearing deficit has been discovered in people with intellectual disabilities. It has been shown that hearing problems are a barrier to physical activity (PA) engagement for children with down syndrome [16]. Since it takes more energy for some children to hear the exercises properly, explaining exercises to them verbally might not be the best medium of instruction.

The five aspects that contribute to difficulties in the instruction of exercises are illustrated in figure 1.1 below. As was discovered in research, language comprehension and memory deficit are intertwined [11], as well as short attention span and impulsive behavior [15]. One can argue that the lack of attention span contributes to not understanding instructions, while it can also be argued that improving the instruction type of exercises contributes to a bigger attention span.

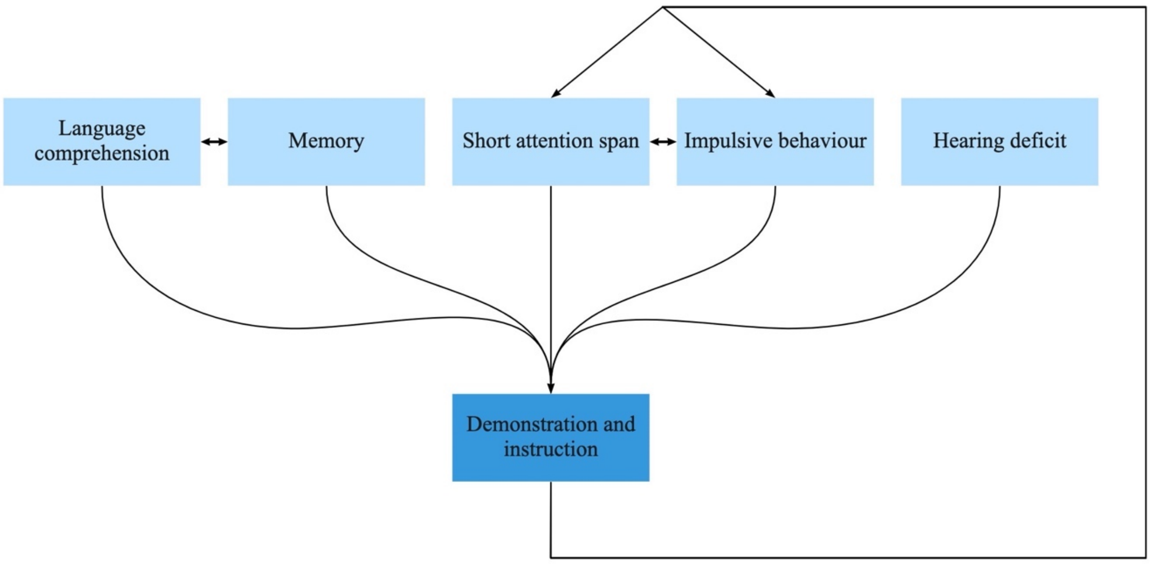


Figure 1.1: the relationship between the main problem and its causes (subproblems)

Alternative modes of instruction and demonstration can be done via interactive technology. However, interactive technology has not been developed for special athletes to the same extent that it has for regular athletes [17]. While there are many sports installations that provide alternative ways of instructions for regular athletes, little is specifically tailored to the needs of athletes with intellectual disabilities. Some rare examples can be found, such as the futureGym [18], which is an interactive floor projection for people with cognitive impairments. The installation consists of visual cues projected on the floor, that facilitate group running and game exercises. Nevertheless, this installation focuses on the interaction between the children, rather than improving the type of instruction and therefore engagement in sports.

All in all, special athletes experience some form of language comprehension deficit, memory deficit, hearing deficit, short attention span, and impulsive behavior. Demonstration and (verbal) instruction of exercises are all reliant on these barriers, and therefore an illustrative case to explore and improve. Demonstration and instruction are crucial to sports participation and thereby positive health benefits as described earlier. Therefore, this thesis aims to investigate alternative modes of instruction through technology.

1.2 Research questions and contribution

To get a more detailed description of problems and difficulties, an athletics sports team has been assigned to this project. The special athletes team of the sports association MPM Hengelo has provided a trainer and special athletes that helped carry out the research. The group consists of children with various types of intellectual disabilities, including the ones discussed above (ASD, ADHD, DS).

To facilitate the coaches and trainers in providing easy instruction and demonstration to children with intellectual disabilities, other ways of instruction are investigated (visual, auditive, haptic). By this means, it becomes easier for the children to participate, as well as lowering the barriers to teaching. A research question has been constructed, which is as follows:

How to support the trainer in instruction and demonstration of physical exercises through alternative media for children with intellectual disabilities?

To help answer this research question, the question is supported by various sub-questions:

SQ1: What discipline in athletics would benefit from support in instruction?

SQ2: What are the opportunities and challenges of the discipline of athletics defined in sub-question 1?

SQ3: What are related systems for instruction/demonstration in sports interaction technology for (special) athletes, using alternative media?

SQ4: How can the already available athletics equipment be used/changed to support the demonstration/instruction of exercises?

SQ5: How do children with intellectual disabilities respond to instruction/demonstration systems that use alternative media?

There are several contributions a paper can give in the area of human-computer-interaction [19]. The goal of this thesis is an artifact contribution, by prototyping a system that consists of interactive technology facilitating the instruction and demonstration of sport. Besides that, it also contains a survey contribution, by addressing this gap in research. The aim of the thesis is to provide an analysis of a system that provides instruction on exercises for special athletes, by delivering a proof of concept (prototype) accompanied by multiple analyses.

1.3 Report structure

In the previous sections, it has become clear that this thesis aims to support the demonstration of exercises for special athletes in sports. Before discovering this gap in research, literature research, interviews and observations have been done. This can be found at the beginning of chapter 2, state-of-the-art. Since improving demonstration and instruction for athletics is a broad term, it is necessary to narrow it down to a specific discipline within athletics. This answers RQ1: “*What discipline in athletics would benefit from support in instruction?*” and RQ2: *What are the opportunities and challenges of the discipline of athletics defined in research requestion 1?*” and can be found in section 2.3. Finally, section 2 looks at related systems that provide demonstration via alternative media, which answers RQ3: *“What are related systems for instruction/demonstration in sports interaction technology for (special) athletes, using alternative media?”.*

In the third chapter, the methods and techniques that have been used to conduct this thesis have been described, as this thesis is conducted according to the ‘creative technology design process. In chapter 4, ideation, stakeholders and their needs are identified and an initial product idea is developed. This chapter aims to answer the fourth research question: "*How can the already available athletics equipment be used/changed to support the demonstration/instruction of exercises?*”.

In chapter 5, specification, the concept is further specified by doing various analyses, such as component analysis, user analysis, and a low fidelity user test. System requirements are made and translated into components choices. In chapter 6, realization, software and hardware are put together into a working prototype, and interaction possibilities are mapped out. In chapter 7, the prototype is evaluated via various user tests, whereafter the results are analyzed. This chapter aims to answer the fifth research question: "*How do children with intellectual disabilities respond to instruction/feedback systems that use alternative media?”.*

In chapter 8, the conclusion, the results are discussed and the initial research questions are touched upon. Finally, in chapter 9 (discussion), limitations and further research are discussed, as well as ethical considerations of the project.

CHAPTER 2: State-of-the-art

2.1 Introduction

This thesis aims to support the instruction/demonstration of physical exercise through alternative media, since this has not been addressed in research yet and is shown to be a barrier for children to participate in sports. Before having discovered this gap in research, literature research, interviews and observations have been done. This can be found in section 2.2, ending with a preliminary conclusion confirming this gap.

To be able to approach this broad research question, the field of research needs to be narrowed down to a single discipline within athletics. This is done via observations and expert interviews with the trainer of the MPM athletics team, Aiko Staudt. This process is described in section 2.3, accompanied by possibilities and challenges of the chosen discipline.

Finally, in the third part of this chapter, related systems that also include alternative media have been discussed. This can be divided into two parts, where the first part looks at systems that facilitate instruction and demonstration via alternative media for regular athletes, and the second part systems that focus on special athletes. It is both included since the second part is very scarce.

In the conclusion, the first three research questions are answered. **After reading this section**, it is clear how this barrier to sports for special athletes has been discovered, which discipline within athletics is chosen and which related systems that use alternative media are relevant to the project.

2.2 Background research

As stated before, literature research has been done to discover the difficulties and barriers to participating in sports for special athletes. The literature research, interviews, and observations serve as a base for the rest of the thesis. **After reading this section,** it has become clear how the gap in research has been discovered, accompanied by chosen research directions.

2.2.1 Literature review

Nowadays, technology is indispensable in the world of sports. Many people use it for the purpose of entertainment, safety, education, assessment, management, or training [20]. However, even though there is much available for the regular athlete, technology for psychosocial disabilities has been understudied [17]. It has been proven that people with mental health disabilities or with most types of cognitive impairments are also less likely to use technology than others [21]. This is really unfortunate, especially for this user group, since it can help them enhance their social and motor skills. For example, people with DS have a desire for more procedures, communication, and external motivation, which can be solved with the help of technology [22].

In order to develop an interactive tool and help these children, it is important to understand the problems that special athletes experience. Therefore, this literature review aims to get an overview of the problems and barriers athletes with intellectual disabilities experience during sports, that can be solved with technology.

This literature research consists of four parts. The first and second part are dedicated to finding barriers and motivators special athletes have <u>before</u> participating in sports. The third part aims to find problems these athletes experience <u>while</u> they are performing the sport. Finally, existing (sports) technology for special users is evaluated in order to find what problems have not been addressed yet. To offer a more targeted overview, researched papers are purposely more focused on children, since this is the experiment group later in the design phase.

Motivators for participating in sports for special athletes
There are three main motivators for participating in sports for athletes with an intellectual disability (ID). The first motivator that is mentioned a couple of times in the reviewed literature is social interaction. Bowers et al. [23] show evidence that participating in sports has an impact on athletes as well as on the family. The athletes feel socially connected and they get a sense of belonging. Everett et al. [4] support these findings for social interaction as a motivator and add that it gives the athletes a platform of voice and a way for them to show intense emotions. Similar results were found by Yu et al. [3], who mapped facilitators and barriers of physical activity participation among children and adolescents with intellectual disabilities. They reported social interaction with peers as one of the most commonly reported facilitators, next to self-efficacy, enjoyment, parental support, and adapted physical activity (PA) programs.

A second motivator that has been found is positive family influence. Yu et al. [3] claim that sufficient parental support is a significant facilitator in participating in sports for special athletes. Sufficient parental support consists of a positive role model of the parents, parental company, and logistic support. Additionally, a positive role of siblings was also identified as a facilitator of participating in PA among children and adolescents with ID. Similar results were found by Memari et al. [24], who discovered that family income and household structure are associated with PA participation. High-income and co-parent families lead to higher participation, potentially due to more access to recreational services, transportation ways, and solutions to health problems.

The last important motivator which is documented by various research is "cognitive and psychological factors", particularly self-efficacy. Self-efficacy can be described as "a person's belief in his or her capability to successfully perform a particular task" [25]. Yu et al. [3] claim that self-efficacy, enjoyment of PA, and personality traits are facilitators of participating in PA. The more the athletes train, the more confidence they gain, which in term contributes to the physical skills and motivation to participate. Everett et al. [4] also address this matter, saying that competing successfully supports the athletes' decision to continue with the sport. Additionally, they state that negative emotions can be managed during the training.

Barriers to participating in sports for special athletes

Besides the three main motivators, there are also three main groups of barriers to participating in PA among people with an intellectual disability. Family influence, previously indicated as the main facilitator, can additionally be identified as one of the main barriers to participating in PA. Yu et al. [3] have found that lack of parental support is of influence, which includes lack of parents' company, financial support, and lack of transport support. Additionally, parents who do not know how to conduct home-based activities, overprotect their children, and are vigilant, are considered constraints for participating. Botelho [26] reported a lack of financial support also as a barrier. Special athletes often need a lot of support, which is expensive to find, get and maintain over time. Moreover, children grow, so adjustments and replacements are needed on a regular basis. Bowers et al. [23] similarly point out financial constraints, reporting on participation costs for special athletes being a financial burden on some families, resulting in some athletes not being able to take part.

The second group of barriers to participating in PA that is mentioned a lot are environmental barriers. Often, there is a special program for people with an intellectual disability, but this is far away from where a person might live. Lack of available community transport was found to be a barrier by Bowers et al. [23]. Njelesani et al. [27] recognize this by putting inadequate or inaccessible facilities as a social-environmental barrier to PA participation. A third and final important barrier that has been reported frequently, is the lack of appropriate programs. Yu et al. [3] examined teacher and classroom-related factors and it was found that lesson contexts organized by PE teachers and teaching behaviors were not suitable for people with ID and therefore identified as a barrier. Similarly, Shields et al. [28] recognize suitable programs as a barrier, specifying the need for someone to exercise with. This provides social interaction and makes exercising meaningful.

All in all, the three main motivators for participating in sports are social interaction, family influence and self-efficacy. The three main barriers to participating in sports are environmental barriers, family influences, and a lack of suitable programs. It has to be noted that not all papers deal with the same kind of intellectual disability. Similarly, not all papers focus on the same user group, since some are focused mainly on children and others on adolescents. Further research could exclude adolescents *entirely* from the research to make it more practical for the actual design.

Problems while performing sports for special athletes

Getting a person with an intellectual disability to participate in sports is the first step, but there are also four main problems that arise when the athletes execute the sport itself. First of all, the athletes experience a delay in gross motor skills and performance when executing the movements. Quinzi et al. [29] assessed motor competence for individuals with down syndrome (IDS) while kicking and discovered a lower motor competence and lower angular velocities. Similarly, Pan et al. [14] compared the movement skills of children with autism spectrum disorders (ASD) and attention deficit hyperactivity disorder (ADHD) with children that do not have these intellectual disabilities. They distinguished locomotor skills (e.g., run, gallop, hop and leap) and object control skills (e.g., catch, kick and dribble) and discovered significant statistical differences between the two groups. Even though not all children diagnosed with ASD or ADHD had motor difficulties, statistical difference has been found to state that children with ASD or ADHD have more difficulties in motor skills compared to typically developing children. Moreover, a study performed by Liu et al. [30], has matching results in showing delays in gross motor skill performance in children in the autism spectrum compared to regular children. The children across the autism spectrum showed significant delays in gross motor skill performance when looking at locomotion and object control skills.

Furthermore, inattention and impulsive behavior during training have been reported frequently as a problem while performing sports. Pila-Nemutandani et al. [15] demonstrate in their study that there are motor difficulties related to ADHD but instead of focusing on this, one should look at strategies to control impulsive behavior and improve attention to tasks. Instead of addressing the physical problem, address the behavioral problem that children with ADHD experience, namely problems with sustained attention, impulsiveness, and hyperactivity. This has also been observed by Pan et al. [14], who argues about the possible explanations on a neurological level of ADHD and ASD, namely inattention and hyperactivity.

Next to distraction and impulsive behaviour, a lot of research discovered social problems during practice. Pila-Nemutandani et al. [15] state that special athletes experience low self-esteem, higher levels of anxiety, and poor social functioning, which relates to poor motor performance. Additionally, Maher & Haegele [31] argue that disabled children often get inappropriate support and instruction, and receive restricted access to activities by getting passive, unimportant, or tokenistic roles in games. One might argue that there is a correlation between these two, namely low self-esteem being further developed when getting unimportant roles in games.

Finally, there has also been research on verbal instruction being a problem for people with intellectual disabilities in sports. Bittner et al. [32] indicate that it is difficult for people with Autism Spectrum Disorder to get instruction during physical activity which relies on verbal communication and social interaction. They argue that more effective instructional methods have to be developed to retain the attention of the children.

In short, the four main problems that arise for people with intellectual disabilities in sport are; motor competence problems, distraction and impulsive behavior, social problems (e.g., low self-esteem and anxiety), and the medium through which instruction is given. Again, it has to be noted that the reviewed studies do not all relate in the type of intellectual disability (e.g., ADHD, DS, etc), and the user group is not everywhere similar (adolescents compared to children). With this knowledge, the current state of the art in technological interventions needs to be researched in order to discover the gaps.

Sports technology for special athletes

The (sports) technology that already exists for athletes with an intellectual disability can be divided into two categories. The first category is inventions that are specifically made for people with an intellectual disability which include little technology. In this case, an intervention with little technology is defined as a service or set of guidelines, rather than a tangible product. Mobile phone applications, shared screens, and games are examples of this category. Ryan et al. [33] show an example of this by designing a mobile app for bipolar disorder. This application is a self-management intervention that helps individuals with BD, by aligning coping strategies with personal goals. Additionally, Bittner et al. [32] demonstrate an example of mobile phone applications with their exercise buddy application, a visual exercise system to tackle the problem of verbal instruction. Besides applications, Andriolo et al. [22] establish guidelines on how to change the method in exercise programs to optimize training for individuals with an intellectual disability. They stress the importance of external motivation offered by instructors, and familiarization with the environment and procedures.

The second category can be defined as technological inventions specific for special athletes. As an example, Takahashi et al. [18] tackled the problem of interpersonal interaction in sports education for children with special needs, by creating a ‘futuregym’. This is an interactive floor projection, that allows group running and a group exercise game to support the development of social interaction. Visual aids to help the children to be aware of social cues are important in this process. Additionally, an example that uses visuals is described by Hanrahan [34], who stresses the importance of imagery and communication with working with athletes with intellectual disabilities. Imagery has been shown to enhance performance in cognitive tasks and motor tasks, and audio recordings might come in handy to convey messages. Furthermore, Takashani et al. [18] describe other forms of tangible interventions, such as robotics, virtual reality, tabletops, tablets, speech output, and computer-mediated communications. Even though there are some examples, they are rare to find and mostly only focussed on interpersonal interaction.

Conclusion and discussion

The goal of this literature review was to get an overview of the problems and barriers athletes with intellectual disabilities experience during sports, that can be solved with technology. From research, it is shown that motor competence problems (category of physical problems) are already well tackled and intervened. However, mental problems like distraction, impulsive behavior, social problems, and the channel of instruction have not been tackled to a similar extent. Studies like the futuregym [18], have looked at visual aids to solve social problems, whereas other research looked at other forms of communication. However, these interventions were mainly focused on supporting interpersonal interaction, and not on making sure the instruction is conveyed properly. By creating a new way of conveying the instruction of the training, indirect distraction and impulsive behaviour are tackled as well. Therefore, it can be concluded that insufficient instruction and demonstration is a problem for athletes with an intellectual disability, which has not been assessed by technology or any intervention yet.

A limitation to this literature review, as briefly mentioned, is the variability of mental disabilities and age ranges. Not all research focuses on the same type of mental disability. For example, individuals with Down Syndrome cannot be compared to individuals with Autism Spectrum Disorder that easily. Additionally, some papers focus on children (between 7 and 15, which is the aim of the research), but others also take adolescents into account. Besides variability, the amount of reviewed material can be extended, and the search range could be put to these last five years to only include up-to-date interventions. Alongside, there are some limitations to the topic itself as well. For example, Ryan et al. [33] rightfully mention that it has to be considered that technological solutions are not applicable to everyone. Technological interventions are most applicable to individuals who are more technology-oriented and motivated, so it is important that discrimination bias is avoided. Additionally, some problems mentioned like distraction and impulsive behavior cannot be directly credited to be a problem specifically in sport, but more of a general problem. The athletes experience this in their daily life, and therefore it is too broad to tackle in sports interaction technology.

An interesting future research direction is looking into different ways of communicating instructions for intellectually disabled athletes. Narrowing down to the factors that determine good instruction for this user group can lead to more targeted and successful information transfer. When knowing the specific factors that lead to successful information transfer, it can be combined with research on various communication channels to find the most effective one.

2.2.2 Interviews

The result of the literature research was to investigate other ways of instruction and demonstration, since this is a problem the athletes experience while performing in sports and had not been acted upon yet.

For a more specific approach, the trainer of the special athletes children team MPM Hengelo has been interviewed, as well as one of the legal guardians. The purpose was to discover difficulties and problems children experience during the training and around the sport. Additionally, the previously found problems in the literature review were presented to the trainer and legal guardian and they were asked to what extent they agree/recognize them. The interview can be found in **appendices A and B.** The results are summarized in the section below.

Trainer: Aiko Staudt

Aiko Staudt is the trainer of the special athletes' children's athletic team in Hengelo. Aiko has been a trainer for four years of this team and has no specific background or experience in training this special user group. He has been a discus thrower himself, studied sports management in Zwolle, and from there started to give training in discus throwing in the area.

The **problems Aiko recognizes on the playing field** are mainly getting the children to focus and listen. Sometimes it is more important to get them to focus than other times, for example with 'dangerous' sports like discus throwing. The trainer cannot just offer anything he likes, because the discus is quite heavy (3kg), and if this lands on the neck of the children in the wrong way it can cause serious injuries. Additionally, losing attention is also one of the biggest problems. He feels like he needs personal contact to get attention, which is almost impossible if there are ten children to pay attention to. Other things he notices are; copying of bad behavior of others, playfully fighting between family members, overstimulation of senses, needing clear boundaries, and getting mad over little things.

Based on the literature review, Aiko was asked to what extent he recognized/agrees with the previously found problems.

There were various **problems Aiko did agree with**, which were; problems with motivation to finish an exercise, problems with verbal instruction, problems with communication, impulsive behavior, and short attention span. In his opinion, having practices with less structure keeps the motivation higher. He also argued that emotions are closely related to being able to express themselves during training. The children can say what they want, but sometimes you have to pull relevant information out of them. Finally, he feels that a short attention span is the result of the way training is given and that it is intertwined with impulsive behaviour.

Issues he did **not completely agree with were**: motivation to show up, having not enough information during a training, personalized training, and unstructured training. If the children need more information, then the activity is too difficult for this user group. The goal of the training should be to play, not to think about difficult aspects of a game. He also indicated that the need for personalized training was more present in the beginning since everyone wanted to do something else. Now they have a structure that all aspects come across every once in a while, and all children are fine with that. It is important to keep in mind that the children have to release energy and have fun, so this is contradictory to explaining them something detailed (this is already done in PE lessons at school). Aiko is sure the children come to train mainly to play, not to improve themselves.

Legal guardian

Besides the interview with Aiko, an interview is held with a legal guardian, the mother of two players on the team. She was asked almost the same questions as the trainer, with the goal to discover problems the children might have on/around the playing field. Her oldest son has the intellectual disability of mental retardation, meaning he is 15 years old but behaves like a child between 4 and 7 years old. Her youngest son has Autism Spectrum Disorder (ASD) and epilepsy.

The main issue that she recognized is distraction during the training. She explained that the trainer would explain exercises, while the children would already be playing with each other. However, once the trainer called them out, they would listen afterward. During practice, her two children interact a lot with each other (usually friendly fighting), which can distract other kids as well.

Similar to Aiko, several issues out of literature research are presented and asked to what extent she recognizes this in her children.

Issues she agrees with are short attention span and distraction. Especially at the beginning of a practice, the children need external stimulation to stay focused. She **partly recognizes** difficulties with verbal explanation and difficulties expressing themselves. She stated that she thinks if they would not understand or like the exercise, they would just ask it. Additionally, when the children do not like something, they will let Aiko know or walk away. **She does not recognize** low motivation to go to training (they really enjoy it), insufficient information for an exercise, or communication problems. Furthermore, the way the training is structured does not matter in her opinion. However, she does notice that Aiko must have hard and specific rules to keep the children in line, otherwise, it will become a mess.

It is important to keep in mind that the interview is conducted with one of the parents of the children, thus making it potentially biased. Additionally, she is talking about her children who have a specific type of disability, so this might not be generalizable for the whole group.

The trainer and the legal guardian have been asked to rank the found problems from literature to the extent they recognize them, on a Likert scale from 1 to 10. Respectively, this goes from not recognizing it at all, to fully recognizing the issue. The result can be seen in figure 2.1.

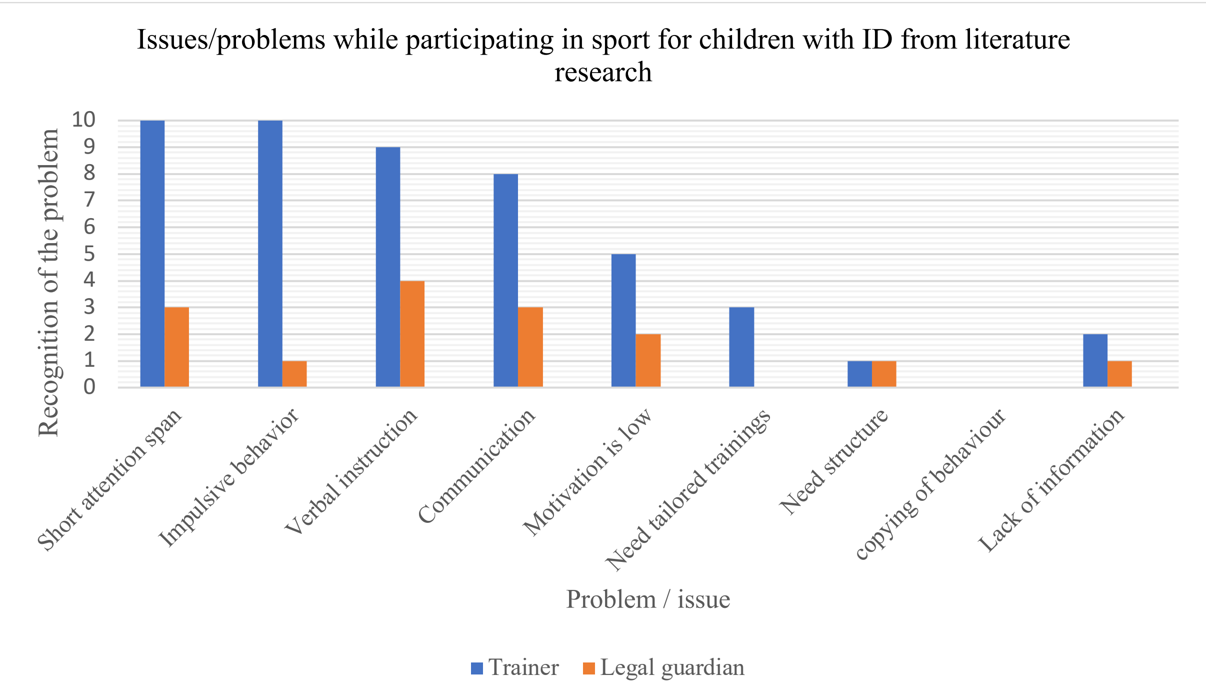


Figure 2.1: Recognized challenges for children with ID by trainer/legal guardian in relation to problems found in literature research

2.2.3 Observations

Finally, after literature research and interviews, observations have been made to discover first-hand experience on challenges special athletes might experience during training. A general training has been attended, which lasts from 18:30 till 19:30 on Tuesday evenings. The observed challenges can be seen in table 2.1.

Table 2.1: observed challenges special athletes have while participating in sports

Challenge	Observation	Likert scale extend (1-10)
Fast distraction / short attention span	From the beginning on, the trainer had to scream for attention. However, once he did this, the children listened instantly. During the exercises, the children do other things with the material than supposed to. If the children do the same exercise for a too long time, they get distracted.	9
Impulsive behaviour	Some children randomly scream, possibly to let the energy go. Some children randomly sit down. One child had a small anger attack when he saw another child sitting down, potentially because he felt injustice.	7
Lack of motivation	For the warming up, the children had to run with small weights in their hands around the field. Some children already stopped after 10 meters because they thought they could not do it anymore, possibly too heavy weights or cold hands. At the final exercise, the children were losing motivation and were asking “when are we done”?	5
Copying of behaviour	One of the children did not want to run the full circle, but when he saw someone run past him, it motivated him again. He ran past the person that just passed him, which in turn made that person go faster again.	7
Lack of self-efficacy	One of the children got mad at herself because she could not throw the discuss that far. The said frustrated: “why did my arm get less strong?.	
Tailored trainings	Not all children understand an exercise the same way. Some needed an additional explanation, while others didn’t.	7
Verbal instruction	One of the children didn’t understand that he had to push the ball, and therefore the trainer used an analogy (he took his fist instead of a ball), which resulted in the child putting his hand around the ball and push. With this analogy, he was able to understand it.	7
Communication	One of the children didn’t do the movement correctly (he knocked over the hurdle), which resulted in him being slightly mad and distracted. In turn, he took the hurdle and started throwing with this. All the children really like to talk, either to no one or to each other.	5

2.2.4 Pre-liminary conclusion

Based on the literature research, interviews and observations, a decision has been made on what to focus on in this thesis. The problems from the literature research have been mapped out, presented to the trainer and legal guardian, at put next to each other. Additionally, observations have been made and ranked in the same way. The result can be seen in figure 2.2, where the intensity of the problems decreases from left to right. Figure 2.2 is an extension of figure 2.1, where now the observations are added as well. It has to be noted that the results are objective, as they are two interviews and one observation, subjectively graded. However, the discussed topics come from literature research, and the relatively graded issues are graded by the test/user group, therefore still valuable for this research.

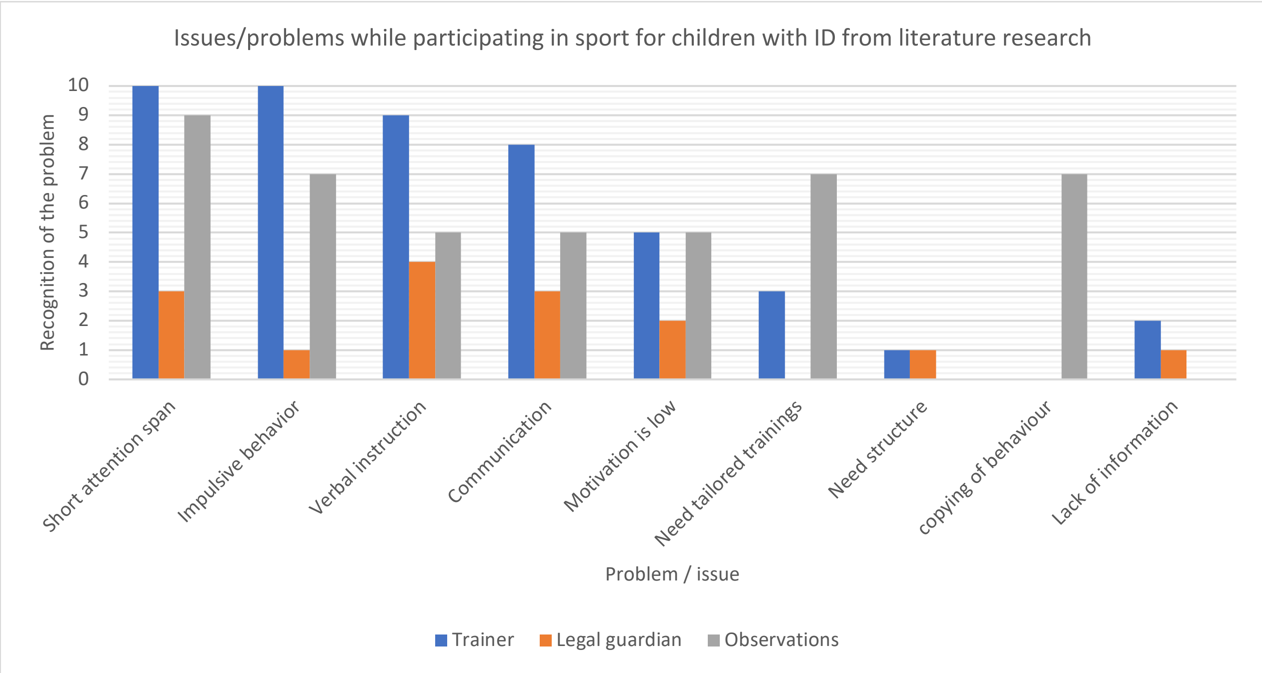


Figure 2.2: issues while participating in sports for children with an intellectual disability

Based on these results, it can be seen that short attention span, impulsive behavior, and verbal instruction are the main three problems athletes experience during sport. As discussed in the introduction, this thesis focuses on facilitating instruction and demonstration of exercises. It is known that people with intellectual disabilities have language comprehension problems, memory deficit problems, hearing deficits, short attention span, and impulsive behavior. Taking all of this together, there is a need for another form of instruction, which makes this thesis direction relevant for our user group.

Additionally, the focus of instruction/demonstration of exercises is chosen because it is a visible relevant problem and feasible enough to tackle with the knowledge of creative technology. It is a narrowed down and tangible problem, as observations of the trainer and field research can be done once the prototype is created. Furthermore, this direction has been chosen since it is linked with a lot of other things, such as language comprehension, memory, attention, attention span, and hearing problems.

Even though this is already a narrowed-down problem, it needs to be narrowed down even more to a single discipline within athletics. This is further discussed in section 2.3: instruction and demonstration in PA.

2.3 Specification of discipline within athletics

In this section, a specific discipline of athletics is chosen to further examine. The aim of this thesis is to work towards a better understanding of how difficulties in instruction and demonstration of exercises can be addressed through alternative and interactive media. The focus is not on solving the problem but on getting a way of better understanding the problem via a specific example. This is done by observations, where current practices are analyzed on structure and execution (section 2.2.1). Additionally, an interview is held with the trainer to ask for his opinion (section 2.2.2). After choosing a discipline, the opportunities and challenges of this discipline are mapped out in section 2.2.3. **After reading this section,** it has become clear what discipline of athletics is chosen to focus on.

2.3.1 Common practices

To be able to focus on a single discipline within athletics, it is important to know how instruction and demonstration are done right now, specifically within this children's athletics team of MPM Hengelo. Every practice has the same structure: children start with warming up, do the first aspect of athletics, have a break, do the second aspect of athletics, and then finish. This way, in every training 2 elements of athletics are executed.

There are three main categories/elements of athletics: sprint, jumping, and throwing. From the expert interview with Aiko (trainer), it became known that there are several aspects within these three elements that they train for, as shown in figure 2.4.

Sprint	Throwing	Jumping
•Technique •Starting block •Relay	•Shot put •Javeling throwing •Discus throwing •Discus swing	•High jump •Long jump •Hurdle jumping

Figure 2.3: the three categories within athletics

Throughout the season the three elements are rotated, and in every training one aspect of two categories will be executed. This way, they try to ensure that every aspect of athletics occurs equally. However, training never builds onto each other, like extended training. According to the trainer and legal guardians, children come for fun and not to improve themselves and need a variety of exercises to stay motivated. Nevertheless, the trainer does think it could be beneficial to include extended training sessions but needs time and effort to implement this in a good way.

At the moment, most attributes that are used are non-technological. Think about lighter balls for throwing, rubber rings for the discus swing, soft javelins for throwing, and low hurdles to jump over. However, there is one technological installation on the track, which is a series of lights all around the track (WaveLigh). This can be set at a certain pace, and the children (anyone on the field) can run along with this light to run a certain pace. Unfortunately, it has been proven that this does not really work for these children. The children will run one round with the light but then get distracted and stop running along. The trainer thinks this is because the light is not interactive enough and the attention span/motivation to follow the light is not high enough for this user group. Additionally, MPM Hengelo has a speed meter that can measure how fast someone is going. They do use this sometimes in training and it is perceived as really fun, but not really valuable or necessary for anything.

2.3.2 Interview and chosen discipline within athletics

By interviewing the trainer, input can be gathered on what discipline of athletics needs the most guidance. This interview can be found in **appendix C.** According to the trainer, the sprint category exercises are the easiest to teach. After the children understand how to start, the exercise mostly runs smoothly. On the other hand, throwing and jumping need a lot more explanation and adjustments.

Athletics is a sport where athletes often have to wait until they can execute a movement. An example of this is a long jump, where the children stand in a line waiting to jump one by one. To avoid long waiting times, the trainer puts down an obstacle course for the children so they can still make a lot of jumps in the meantime. However, since the trainer is busy guiding the other children who are actually doing the long jump, he cannot focus on the obstacle course. Some children will stop doing the circuit training once they forget what to do, fail in doing it or see other people stop (copying behavior). The trainer indicates that extra management in this would be an added value to the practice.

The situation where children have to wait for a long time occurs a lot of times in a lot of situations since athletics is simply a sport where you cannot all participate at the same time. Therefore, he claims that obstacle parkours are used a lot of times. Additionally, he uses these same obstacles in a circuit practice, where the children have to do a certain exercise at one spot, then another exercise at another spot. Since this is used a lot of time and specifically indicated by the trainer as valuable, the focus of this thesis is **on guiding the explanation of the obstacle course and keeping the children engaged.**

Al in all, the chosen case study for this thesis is obstacle courses/circuit form training. This can, as described above, be used to guide jumping over things for the purpose of long/high jumps. It can also be in the form of little stations. An example of this would be three stations with different exercises that all contribute to some discipline (e.g., shot put). The design/installation should help them guide through the exercises when a trainer has to divide attention. Additionally, the proposed design direction might also be valuable for other teams outside the special athletes.

2.3.3 Opportunities and challenges of the discipline

The discipline of athletics that is focused on is obstacle course running and using the obstacles in additional circuits. The idea is that participants follow a track through the exercises, either at a certain time at each station or through all stations as fast as possible (more obstacle course-wise). Obstacle courses are often used to train or assess certain qualities. For example, there is an obstacle course (with 12 tasks) created to assess the functional balance and mobility of elderly [35]. Other functions of obstacle courses are to improve fitness, agility, and confidence, and to supplement other types of training. While many obstacle courses focus mainly on improving muscular condition, circulatory and respiratory responses [36], the focus of this thesis is on experience improvement (mental practice), in an attempt to get the children more involved in the sport.

There are several opportunities and challenges that come with making an obstacle course/circuit training. Mullins [37] discusses what effective training should entail and what characterizes well-designed obstacle courses for regular athletes. He states that obstacle courses are highly effective, in the sense that you train multiple fitness components and skills. It is an opportunity to have a variety of traditional training that engages participants. In our case, it is an opportunity to let the children play with something else than the traditional (long waiting time) exercises. Additionally, it is shown that circuit training reduces the time devoted to traditional strength training, allowing a training volume to be achieved.

When it comes to challenges, psychological challenges and design challenges can be divided. Psychological challenges are self-discipline, perseverance, courage, resourcefulness, and self-reliance. Design challenges come in creating a suitable obstacle course for the user group. Mullins describes that it is important to think carefully about the obstacles and order in the course. For instance, obstacles in a row should not all attack the same muscle group after each other, and the last few obstacles should not be the highest or most difficult.

There are several aspects an effective circuit training/obstacle run should entail. To start off, the obstacles in a course/circuit should be in line with the main exercise (in our case of the athletics children). For example, if the main exercise is a long jump, the circuit training should entail exercises that build up to this. Secondly, the training should be a mixture of random and variable training. As described by Mullins, there are 4 types of practice: blocked practice (long time one skill, then long time the next), random practice (rotating), constant practice (one skill), and varied practice (different versions of the same skill). In the case of obstacle courses/circuit training, random and varied schedules work the best since they promote learning and retention in the motor stage of learning. This should be applied in our circuit training as well.

Other ways that instruction and demonstration can be implemented in circuit form/obstacle form, are manners of pedagogy. In the taxonomy provided by Postma et al [20], it is stated that there are several ways of pedagogy and didactics. Model-based practices such as teaching games for understanding (TGfU), sports education, and student-designed games can be of interest to this thesis. These techniques have a student-centered pedagogical model, which is useful in the case of the special athletes. An example of TGfU is digital video tagging. In this game, player behavior is recorded, and small sides games are interacted with in real-time. Using games in this obstacle course/circuit training is valuable since this thesis deals with children who are more engaged when gamification is applied, which was also mentioned by the trainer. According to him, adding a game element will highly increase the engagement and motivation of the children. Other things to consider are practical pedagogical questions, such as when, why, who, where, and what. These questions should be answered as an analysis of the students' learning phase. Learning is done through three stages of sports teaching and learning [38]. The movement learning stages go from the cognitive stage (new material is presented to the brain) to the association stage (first movements are produced) to the autonomous stage (no need of thinking about an exercise anymore). It is important to know at which stage the children are when teaching them exercises. Finally, there are multiple ways of modelling/giving feedback, such as self-modelling, peer-modelling, and expert modelling. However, these are mostly focused on improving the technique of the players, while our user group comes to practice for fun, not to improve themselves. The instruction/demonstration of circuit training here has the goal of engagement and attention, hence modelling types are not included in this thesis.

Concluding, it is important to realize a system with short waiting times in line with opportunities of obstacle courses. When looking at challenges, a system should be made that has a random and varied schedule of obstacles. Additionally, the theories described above, such as manners of pedagogy and state of learning, can be implemented in the design.

2.4 Related systems

In this section, related systems that include alternative media for the purpose of explanation and demonstration are discussed. It is divided into three parts, where the first part focuses on installations for regular athletes, the second part focuses on installations specifically for athletes with intellectual disabilities, and the third part analyses these systems. **After reading this section,** it is clear what other installations are already existing and how this installation is going to differ from that.

2.4.1 Systems in facilitating movement instruction for the regular athlete

The first category consists of systems facilitating instruction for the regular athlete, so not been narrowed down to special athletes yet. Eight systems were found, divided into different types of instruction/feedback. Most systems focus on visual feedback, these are the first five systems that are discussed. Additionally, there is one system that uses audio instruction and finally, there are two systems that use haptic instruction.

Visual instruction

ClimbVis [39]

Demonstration and instruction in climbing can be difficult due to the time between the instruction of the trainer and the execution of the trainee. It can be hard for a trainee to remember detailed movements and the next steps of the climb, and he/she cannot mimic the movements of the experienced climber as it cannot be done at the same time. As a solution, climbVis provides a video recording of the experienced climber and displays this on the wall in-situ. There are 2 presentations, one is a third-person view of the climber, and the other one is a life-sized projection. It has been found that a life-sized projection is easier to follow. This installation is shown in figure 2.4 on the next page.

Super mirror [40] [41]

In ballet, there are already systems that show a step-by-step illustration of movements. However, it is hard to know if an athlete is doing the movement right. There are already a lot of studio mirrors in ballet rooms that can solve this problem. Super mirror combines these studio mirrors with prescriptive images to give real-time instructional feedback. They show the ballet movements, capture the live motion of the athlete, and show the difference. A Kinect system is used, which is visible in figure 2.4 as well.

Lightguide [42]

When executing movements that require a certain accuracy or a proper technique, it is necessary to provide a type of feedback or instruction that does not hinder the person's body. For instance, when doing physical therapy or exercises that have a great deal of technique. An instructor can provide this feedback, but when instruction is not there, another type of guidance is necessary. Therefore, lightGuide projects guidance hints directly on a user's body, to steer these into the desired motion. This alternative approach to movement guidance can be done in for example following a spot, changing colors, showing an arrow, or showing the path ahead. The installation is visible in figure 2.4.

Slackliner [43]**:**

The correct way of training can prevent injuries and can lead to a faster build-up of skills. Therefore, real-time feedback is been provided in this system, the slackliner. Participants see themselves in front of a projected display, and a Kinect system tracks the user movements. Real-time feedback will guide the trainee during the exercises. Important things to mention here are that participants felt motivated due to the gamified approach and that the training has a significantly improving effect. However, a trainer is more helpful when giving specific advice on aspects which the Kinect could not detect.

IGym [44]**:**

In this final example of visual instruction and demonstration, a gym is developed where people with and without physical disabilities can play together. This co-located play is in the form of a ping-pong game, made possible via visual targets on the floor. The system contains both circle interaction and adjustable game mechanics. This is shown in figure 2.4 below.

Figure 2.4: Installations with visual instructions, with on the left top corner ClimbVis, right top corner IGym, left bottom corner Lightguide and left right bottom Super Mirror

Audio instruction
Urban musical game [45]**:**
Besides visual instruction and feedback, there are also forms of audio instruction and feedback in the sport. In this example, augmented sports balls to create an interactive music environment are used. Based on several motions (e.g., roll, spin, shake, tribble, throw, hit), several types of audio feedback (music) are given. This way, the participants can focus on the relationship between movements and sound.

Haptic Instruction
Haptic directional instruction system [46]**:**
While visual and audio feedback can be useful in some cases, it is not always possible. Indicating which direction you need to run is often done by voice, but in some cases, the athlete cannot watch or listen to the instructor or simply does not understand it. In that case, the haptic directional instructed system is developed. This consist of a joystick for the controller and a unit around the waist with vibrations on it. The instructor can in this way provide the player with instructed directions.

Tactile motion instructions in snowboarding [47]**:**
While it is not always possible to rely on auditive/visual feedback and demonstration, it is sometimes also not practical. In this experiment, they provided the athlete with a set of full-body vibrotactile patterns, that were used to correct the wrong posture during physical activity. It has been shown that users respond quicker to vibrotactile instructions than to auditive instructions.

2.4.2 Systems facilitating instruction for special athletes
While there are many examples of systems that use alternative media for regular athletes, little is found for special athletes when applying the same search strategies. it is difficult to find systems facilitating instruction for special athletes, which indicates the gap in research on this topic. However, four systems have been found that can be divided into the same categories as above, namely two visual systems, one audio, and one haptic instruction system.

Visual:

FutureGym [18]**:**
Individuals with ASD or ID often have difficulties creating interpersonal interactions with other children, which is highly valuable for the inclusion of these children in the group. To increase opportunities for interpersonal interactions, the future gym is providing a large-scale interactive floor projection. Visual aids help the children to be aware of social cues, and exercises like group running or group games can be executed here. It has been found that visual instruction is easier than verbal, and a large screen is more effective than a small screen. Additionally, animated cues are better than static visual aids. It has to be noted that the main focus of this project is the interaction between children, whereas this thesis aims to look at facilitating instruction and demonstration.

SpaceHunters [18] [48]**:**
Another example of visual demonstration and instruction is the SpaceHunters installation. This installation is an interactive floor that provides an exergame for the children with a visual explanation of the exercise. An exergame is a game in which exercise is promoted, in this case, a role-play tutorial on astronauts in space. The system is made with a Kinect sensor. The goal is to promote eye-foot coordination for children with ASD.

Audio:

Location-based audio messages [49]**:**
Individuals with visual and mental impairments (VMI) usually do physical activity with the assistance of caretakers. However, since these caretakers might limited time, long waiting queues arise which results in demotivation of the athletes. Therefore, a prototype is developed which provides location-based audio messages. The prototype consists of Bluetooth beacons and speakers, which detect if a smartphone comes close and starts playing an audio instruction of the exercise. it is important to take into account that this user group often needs a longer time to understand a message or needs to hear it multiple times.

Haptic:

Bendable sound [50]**:**
Children with autism spectrum disorder have problems with sensorimotor movements. Music therapy is available for them that combines music and rhythm, where the idea is to keep the beat of the music in rhythm with the movements. The bendable sound system is a system that enables children to tap and touch a fabric, thereby playing rhythmical sounds. It goes in three stages: first letting them explore it, secondly letting them discover rhythmical sounds, and finally letting them react to instructions given by an astronaut to play a certain song. With this system, sensorimotor movements are supported for children with ASD.

Figure 2.5: Instruction systems for special athletes, with at the top left corner futureGym, top right corner SpaceHunters, bottom left corner audio messages, and bottom right corner bendable sound

2.4.5 Interpretation and analysis

What can be learned by looking at all of these systems and what categories can be uncovered? To start, by looking at related systems that use alternative media for regular athletes, it became clear that the instruction type can be divided into three big categories, namely visual instruction, audio instruction, and haptic instruction. This can guide as an inspiration and starting point for the design solution of this thesis problem.

Additionally, when looking at specific installations, much can be used as inspiration and points of attention. Visual instruction systems have shown multiple ways of providing visual instruction, such as in-situ wall projection, body projections, floor projections, or using the Microsoft Kinect. The ClimbVis installation has shown that a life-sized project is easier to follow, and the super mirror has shown the need for step-by-step movement instruction. Lightguide showed alternative ways of instruction not to hinder a person's body, whereas the slackliner shows the need for a gamified approach to enhance motivation. IGym shows interaction possibilities, and the haptic systems show vibration possibilities when visual or audio instruction is not possible. All in all, these installations guide as inspiration and attention points, as these systems do not specifically address special athletes but only regular athletes.

As described above, there are four installations found that are specifically made for special athletes. However, all of these systems are not aligned with the goal of this thesis, and therefore not sufficient for solving the problem. The futureGym focuses on interpersonal interaction, the spacehunters installation on eye-foot coordination (motoric movements), the location-based audio messages on making children more autonomous, and the bendable sound focuses on sensorimotor movements. These installations are not touching the goal of this project, which is improving the medium of instruction and thereby information comprehension and engagement in sports. Nevertheless, inspiration and guidelines can be taken out of these installations, such as the futureGym showing that visual instruction is easier than verbal instruction. Additionally, they show that animated visualizations are better than static visualizations.

To conclude, installations for regular athletes are very applicable and can be used as inspiration and attention points. However, since they don't apply to the right user group and thereby don't specifically address the needs of these children, they don't suffice for solving the problem. When looking at systems specifically for special athletes, none of the systems is in line with the goal of this research.

2.5 Conclusion

To conclude the state-of-the-art, the previously stated research question and the sub-research questions are analyzed. The aim of this section was to answer the first three sub-research questions. The research question and sub-questions were as follows:

*RQ: How **to support** the trainer in **instruction and demonstration** of physical exercises through **alternative media** for children with **intellectual disabilities?***

SQ1: What discipline in athletics would benefit from support in instruction?

SQ2: What are the opportunities and challenges of the discipline of athletics defined in research requestion 1?

SQ3: What are related systems for instruction/demonstration in sports interaction technology for (special) athletes, using alternative media?

The first research question has been answered by investigating the current way instruction and demonstration are done in athletics, in particular in the children's athlete team of MPM Hengelo. It has been done by interviewing the trainer as well as observing the training, which led to insightful considerations and opinions. Based on this, it became clear that (unguided) obstacle courses- and circuit practices would benefit from alternative instruction. A lot of problems arise with this, such as long waiting times, lack of internal motivation, misunderstanding of exercises, and copying wrong behavior.

Opportunities and challenges of the obstacle courses/circuit practices are mapped out in section 2.2.3, which answers research question 2. It became clear that it is important to look at opportunities and challenges when designing the prototype. Examples of this are making sure the system does not have long waiting times, has a varied schedule of obstacles, and applies different stages of learning.

Finally, related systems that contain different types instruction and demonstration of exercises have been looked at, for regular athletes as well as for special athletes. It can be concluded that there are already quite some systems for the regular athlete, but not much tailored for special athletes. Existing systems can be used as inspiration and tailored to the needs of athletes with intellectual disabilities. Besides this being a gap in research, this is also necessary to tackle since this user group has a lot of benefits from playing sports. It improves their motor competence, social skills, and confidence levels, as all described above.

In the next section, the method of how to develop such a system or prototype that can help these children will be described. To close this chapter, a design statement is made, which will form a base for the next chapters. The design statement goes as follows:

*"Designing **interactive technology** that provides **engaging instructions** to **support the trainer** in the **explanation of obstacle course**/circuit training for **children with an intellectual disability**"*

Chapter 3: Methodology

To address the research question, the creative technology design process is used [51], as illustrated in figure 3.1 below. The design process consists of an ideation phase, specification phase, realization phase, and finally an evaluation phase.

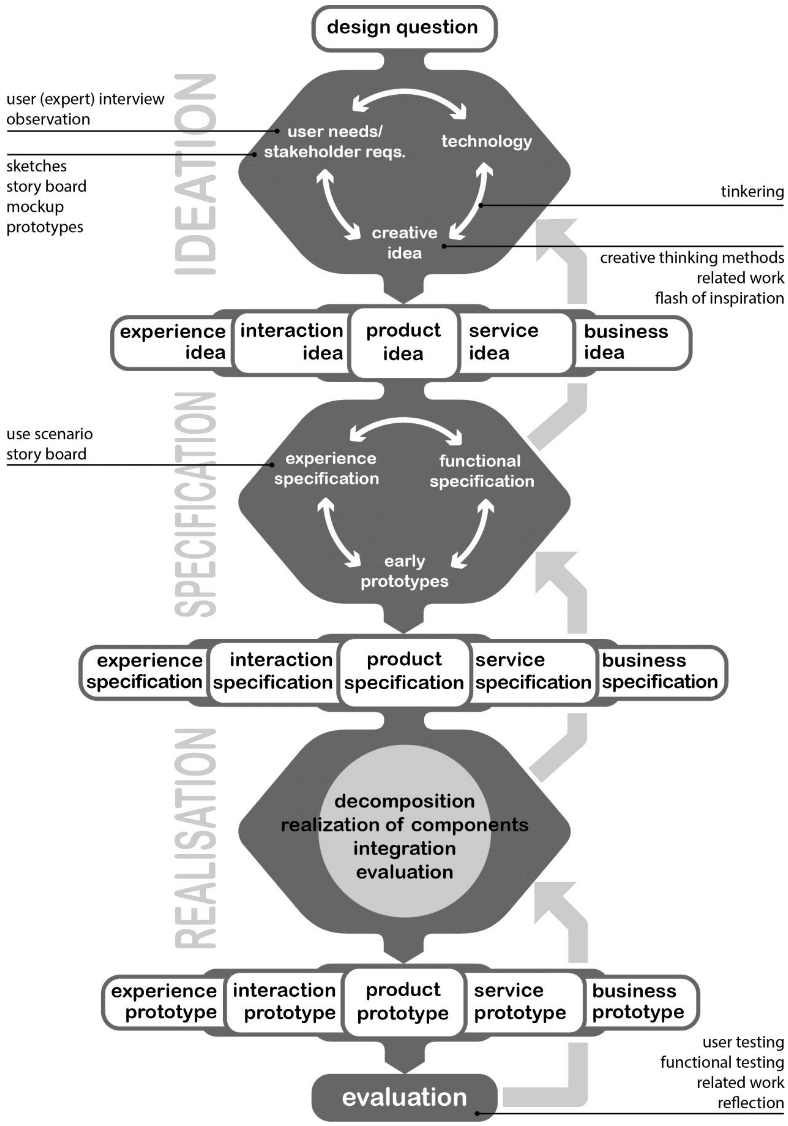


Figure 3.1: The creative technology design process

The ideation phase, as visible in the illustration above, starts with a design question. This question is derived from the design statement given at the end of the previous chapter, which is: "*How to design an interactive technology that provides engaging instructions for the explanation of obstacle training for children with an intellectual disability*".

According to the creative technology design process, the design question can be further explored by looking at user needs and stakeholder requirements, looking at existing technology, and coming up with creative ideas. Several options for identifying the user and stakeholder needs are given (interviews, observations, sketches, etc.), as well as options for coming up with creative ideas, such as creative thinking methods and related work. In the ideation phase of this thesis, a part of the above-mentioned techniques are used. To identify stakeholders and user needs, the 'CEHRES' [52] toolkit and the PACA analysis [53] are used, guided by interviews and observations. Thereafter, a creative concept has been developed by using creative thinking methods such as a mindmap, tinkering, scenarios, and a co-design session. The related work from the previous section has been used as inspiration for the generation of product ideas. At the end of the ideation phase, a product idea has been developed.

The next phase of the creative technology design process is the specification phase and starts with product-, interaction-, experience-, service- or business idea, as can be seen in figure 3.1. In the case of this thesis, this phase starts with a product idea, which can be further specified via an experience specification, functional specification, or early prototype testing. This specification chapter consists of a few analyses that lead to (non-)functional system specification, as well as low fidelity early prototype testing. System requirements are made, which are translated into component choices for the hardware of the system. Similarly, user requirements define the software applications of the system. This phase leads to a product specification.

In the realization phase, the earlier specified components and requirements are realized and integrated into each other. Hardware is divided into sub-systems and the software is developed based on system user requirements. User interactions of the system are mapped out, in order to fully develop the prototype. At the end of this phase, a product prototype has been developed.

Once the prototype has been finished it is ready for evaluation, as can be seen in figure 3.1 above. In the evaluation phase, user testing, functional testing, and reflection can be done in order to see if the prototype has achieved its goal. In this thesis, three user tests and reflections are done to evaluate the prototype. This led to insights and discussions, which will be described in detail at the end of this thesis. It has to be noted that this is an iterative design process, so changing back and forth between the stages has occurred several times.

Chapter 4: Ideation

4.1 Introduction

In this chapter, a product concept is generated via the application of the design process for creative technology, as described in the previous chapter. This process starts with a design statement that guides the process. The design statement is as follows:

*“Designing **interactive technology** that provides **engaging instructions** to **support the trainer** in the **explanation of obstacle course**/circuit training for **children with an intellectual disability**”*

It is important to note that the initial problem states the difficulty of verbal explanation for athletes with intellectual disabilities. However, it has become clear in practice that attention and motivation to participate are equally as big of a problem. The trainer has emphasized multiple times that designing a system with alternative media has to be engaging in a certain way. Therefore, the focus has shifted from only instruction to instruction and engagement. Hence, the design statement calls for ‘engaging instructions’. This is visualized in figure 4.1, where information, comprehension, and engagement stack as building blocks onto each other. The first step is providing information, which will hopefully lead to comprehension of the exercise. When an exercise is correctly understood, motivation to participate might follow and thereby improve engagement.

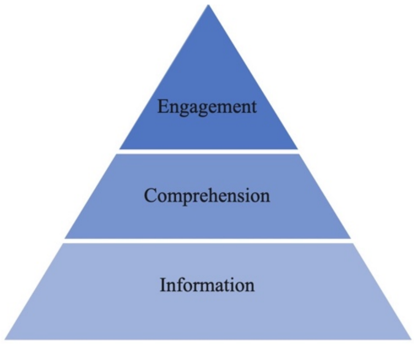


Figure 4.1: The three goal dimensions of the prototype stacked on top of each other

To be able to design a useful product, it is necessary to understand the user and its needs. This is done by carrying out a stakeholder analysis. Based on the user’s needs, creative methods are used to generate broad concepts, from which an initial concept idea has arisen. **After reading this chapter**, it becomes clear what the various needs and desires of stakeholders are, how this has led to several design solution methods, and how this has led to an initial idea.

4.2 Stakeholder identification and analysis

In this first part of the ideation, the stakeholders are identified and analyzed. Based on their needs and values, the preliminary requirements for the interactive product are defined. The stakeholder identification is done via the CeHRes Roadmap toolkit [52], which guides the design process by phases. The phases implemented in this thesis are contextual inquiry and value specification, in which the user and the context are analyzed and the different stakeholder values are determined. To apply a user-centered design, an additional PACA analysis is done in order in order to reveal more stakeholders and needs. Finally, the results of the CeHReS phases and the PACA analysis are summarized and ranked upon importance via the MoSCow design principles. **After reading this section,** stakeholders and values are mapped out, accompanied by system requirements ranked on importance.

4.2.1 CEHRES Roadmap Toolkit

The CeHRes Roadmap toolkit, as described above, is a toolkit that helps design, implement, and evaluate prototypes. There are five stages, which are contextual inquiry, value specification, design, operationalization, and evaluation. Only the first two are used for the ideation phase of this thesis since they specifically deal with stakeholders and needs. After completing these phases, the creative technology design process will be further followed instead of the CeHRes toolkit, as the project is following that processs.

In the contextual inquiry, stakeholder identification and analysis and the current situation are being looked at. To indicate the relevant stakeholders, it is important to discover who is affected by the potential technology and how. The special athletes are affected since they will be using the system, and the trainer is affected since he is using the system as guidance in his exercise explanations. The parents are affected since they are in direct contact with their children (and their emotions) and want the best for their children. Additionally, they make the end decision in putting their child into some sports association. Finally, the sports association is affected by having fewer/more children in their special athletics team. The affected parties are shown in figure 4.2.

Special Athletes	Trainer	Parents	Sports association
• System can change their training routine: more guidance of exercise and engagement via gamification • Task: follow the new instructions	• System will possibly guide the practice (partly), so the trainer has more time to focus on personalized theoretical feedback • Task: use the system set up exercises, guide exercises	• System will improve the information comprehension and engagement of their child in sports • Parents possibly can use the system at home as well (since there is a lack of home based activities)	• Want to create optimal conditions for special athletes to participate in sport teams of their association

Figure 4.2: The relevant stakeholders - who are affected by the technology and how?

The aim of this research is mainly to help the athletes, therefore the stakeholders differ in importance. In figure 4.2, the importance of stakeholders is already visualized, ranking from very important (on the left) to least important (on the right). This decision is based on who will use and need the system the most (urgency), and basic human rights such as safety and privacy (legitimacy).

Part of the contextual inquiry is assessing the current situation. The goal is to look at the problem being addressed, causes, effects, behavioral changes, rules/regulations, and weak/strong points of the current situation. A detailed description of the current problem has been provided in chapter two. A summary is shown in figure 4.3.

Problem:
- (Verbal) instruction / demonstration is perceived as difficult by the athletes

Problem cause:
- Trainer explaining exercises verbally
- Underlying causes: language comprehension, memeory deficit, short attenion span, impulsive behavior, hearing deficit

Problem experience:
- Children lose attention, get mad, lose motivation

Strong points current situation:
- Personal touch by the trainer
- Peace held by trainer
- Respect for autonomy
- Children having fun
- Easy, no constraints or waiting time due to technology

Weak points current situation
- Exercises are not always clear
- Can be messy
- Distraction by a lot of factors
- Division of time by trainer (explaining difficult instructions against little waiting time
- Children refusing to participate (trainer can not give personal attention to everyone)

Rules/regulations:
- Be carefull with too much stimuli
- No discimination of different groups of intellectual dissabilities

Interface:
- Outside, so something tangible, as well as sufficiently visible

Figure 4.3: Current situation including problem, cause, experience, strong/weak points, rules, and interface

Once the current situation has been mapped out in combination with stakeholder identification, value specification can be performed. In this second phase, the added value of the technology for the current situation is investigated. What exactly should be improved/supported by this system that is to be created? This can be anything from economic, social, behavioral, or healthcare value, and is done per stakeholder. The results are shown in figure 4.4.

Special Athletes	Trainer	Parents	Sports association
• Want to have fun • Want to have social connection • Want to be able to have more attention / focus on an exercise	• Want to gain extra time to personally help athletes • Want to keep order and structure in a training • Care that the athletes feel good and have fun	• Want their child to feel good and have fun, socialize with others • Want their child to learn to listen, have disclipline of the sport • Possibly want a way to practice at home	• Want children to participate in sport • Possibly want help by examining • Want measurable variables, such as speed, distance, error detection, etc for the purpose of competition

Figure 4.4: The relevant stakeholders and their values and desires

It must be noted that some values are more important than others, (for example fun being more important than learning techniques during practice), as already described in previous chapters.

Now the contextual inquiry and value specification have been done, they can be used to make specific requirements for the system. According to the CeHReS toolkit, the requirements can be divided into five categories, namely context requirements, usability and user experience requirements, functional and modality requirements, service requirements, and organizational requirements. The values of the stakeholders are translated into the requirements of the system. For example, the special athletes want to have fun as well as understand the exercises, therefore this should be a requirement of the system. All the requirements can be seen in figure 4.5 below. Note that ‘the system’, ‘the prototype’, and ‘the product’ are all implying the same.

Context requirements

- The system has to show a way of demonstration of the exercises (visual, audio, haptic), while simultaneously providing fun for the children.

Usability and user experience requirements

- Interface of the system should not be too difficult, so it can be used by the trainer as well as the parents.
- The system should be easy in use, language, and as clear as possible.

Functional and modality requirements

- The system should run via an application, or via touch on the object itself.

Service requirements

- There should be a help desk book / service (possibly only website, or pdf describing it)

Organizational requirements

- The system should have an easy way of setting it up / configuration
  - If the trianer does not have time for this, there should be a way to have pre-settings/save/download practices (potentially some online community of sharing)

Figure 4.5: requirements based on the contextual inquiry and value specification

4.2.2 PACA Analysis

In the previous section, stakeholder analysis and value specification have become clear. To make this list complete, PACA analysis is used to reveal more needs and desires of stakeholders. PACA analysis is used since it is focused on human-centered design, therefore valuable for this research. The characteristics of People, Activities, Context, and Artifacts are considered and indicated (ir)relevant for the new product/system. The results of the PACA analysis can be found in figure 4.6.

People

- Physical abilities
  - Less motor competence
- Mental capabilities
  - Less motivation, fast distracted, language comprehension, memory problems, hearing deficit
- Needs
  - Different ways for instructoin to keep them engaged, informed and motivated
- Motivation
  - For them to make fun, to make friends
- Expectations
  - That they can play a lot, have fun, release energy
- Experience
  - Long waiting times, difficulties in explaining them somethign that is harder (for example, the game 3 in a row)
- Frustrations
  - When something is not going their way, not liking the exercise, not understanding it (it can not be too comlicated)
- Social influence
  - Family has an influence in getting to practice, support (however, this is before coming to practice, not during)

Activities

- Frequency
  - Every tuesday 19:00-20:00.
- Time
  - Only 1 hour. Do not pay that much focus and attention on technique during the practice, the children come there to play.
- Safety-critical
  - Pay attention when throwing heaving things
- Type of activities
  - Three categories (running, jumping, throwin)
  - Easy to do: running exercies.
  - Harder to do: throwing and jumping.
- Cooperation
  - Relay running

Context

- Physical situation
  - Outdoor, at the athletics track in Hengelo
- Social context
  - Private training, only members of the g-team can participate (other children with intellectual dissabilities)
- Organizational context
  - Voluntary, they can join and leave whenever they want
- Physical context
  - Nothing is digital

Artifacts

- Non-technical
  - There are several attributes the trainer uses during a practice: soft spears, lighter throwing balls (1 kilo), small hurdles to jump over
  - Opportunities: lighter, more suitable for smaller children
  - Downsides: not the real weights for competing
- Technical
  - Running lights around the track which you can follow at a certain pace

Figure 4.6: PACA analysis of the situation

Out of the PACA analysis, (use) requirements and relevant criteria can be retrieved. For example, since children (topic people) experience long waiting times, it is important to design a product that prevents this from happening. it is necessary to keep the requirements in mind when designing. A list of criteria is made up based on the PACA analysis, which can be found in Table 4.1 below.

Table 4.1: set of criteria determined out of the user-centered PACA analysis

Criteria
The interface of the product cannot be complicated for the children
The Interface should be easy to use by the trainer
The product has to improve experience (no long waiting times, not too difficult)
The product has to be able to work outside
The product has to provide collaboration and working together with other people with mental disabilities
The interacting with the product has to be voluntary and safe
The product should be fun for the children

4.2.3 MoSCoW Method

In the previous sections, stakeholders are indicated, and their values are discovered. CEHRES toolkit is used for contextual analysis, while PACA uses a more human-centered approach. The results are sets of criteria, that need to be implemented into the design.

However, it is now important to order these, since not all desires can be implemented due to the time constrictions of this thesis. The MoSCoW method is a good time-management tool to figure out what to implement first with the highest priority, and what could be implemented later if there is time and space for that. What the product should entail is divided into what it must have, what it should have, what it could have, and what it would have. This is based on the bare MVP (minimum viable product), and nice extra features for a final prototype. The requirements come from figure 4.5 and table 4.1, based on the CEHRES and PACA methods. Some requirements are overlapping, such as the requirement of an easy interface for children and trainers. This categorization is based on the importance of the stakeholders, as mentioned in figure 4.4. The results are shown in figure 4.7.

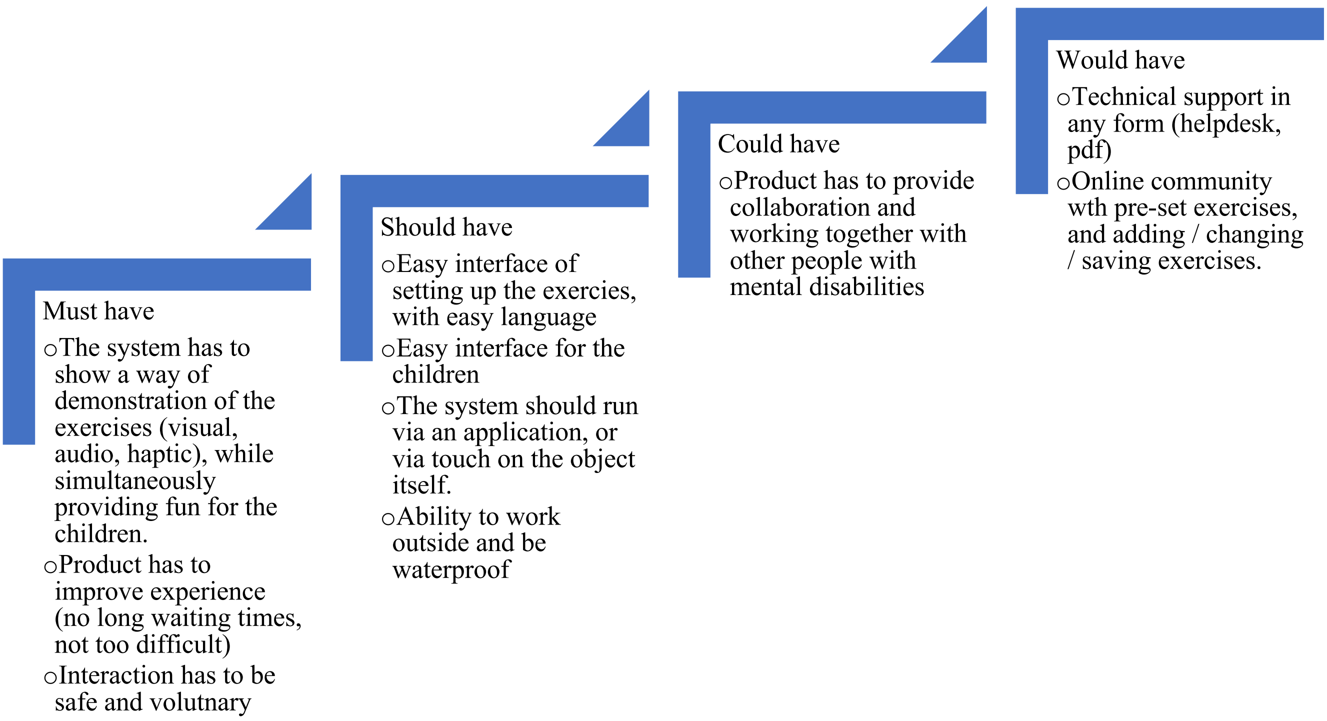


Figure 4.7: MoSCoW method for implementing time management in the design

4.2 Creative Thinking methods

Now the stakeholder's values and thereby preliminary system requirements have become clear, they can be used as a base to generate solutions to the problem. This is done via creative thinking methods, such as making a mind-map, tinkering, co-design, and developing scenarios. **After reading this section,** you are aware of the techniques used for the concept generation of the final design.

4.2.1 Mindmap

To start the creative brainstorming, a mindmap with various aspects of the problem, interaction, and possible solutions is carried out. In the middle of the mindmap, the context (problem) is given, namely 'instruction & demonstration of circuit training/parkour'. From there on, various aspects are drawn, such as input sources, output sources, game elements, and safety. These aspects have relations to options/solutions that can be carried out. This way, the mindmap **serves as an overview of what aspects to take into account when designing the system**. The mindmap can be seen in figure 4.8.

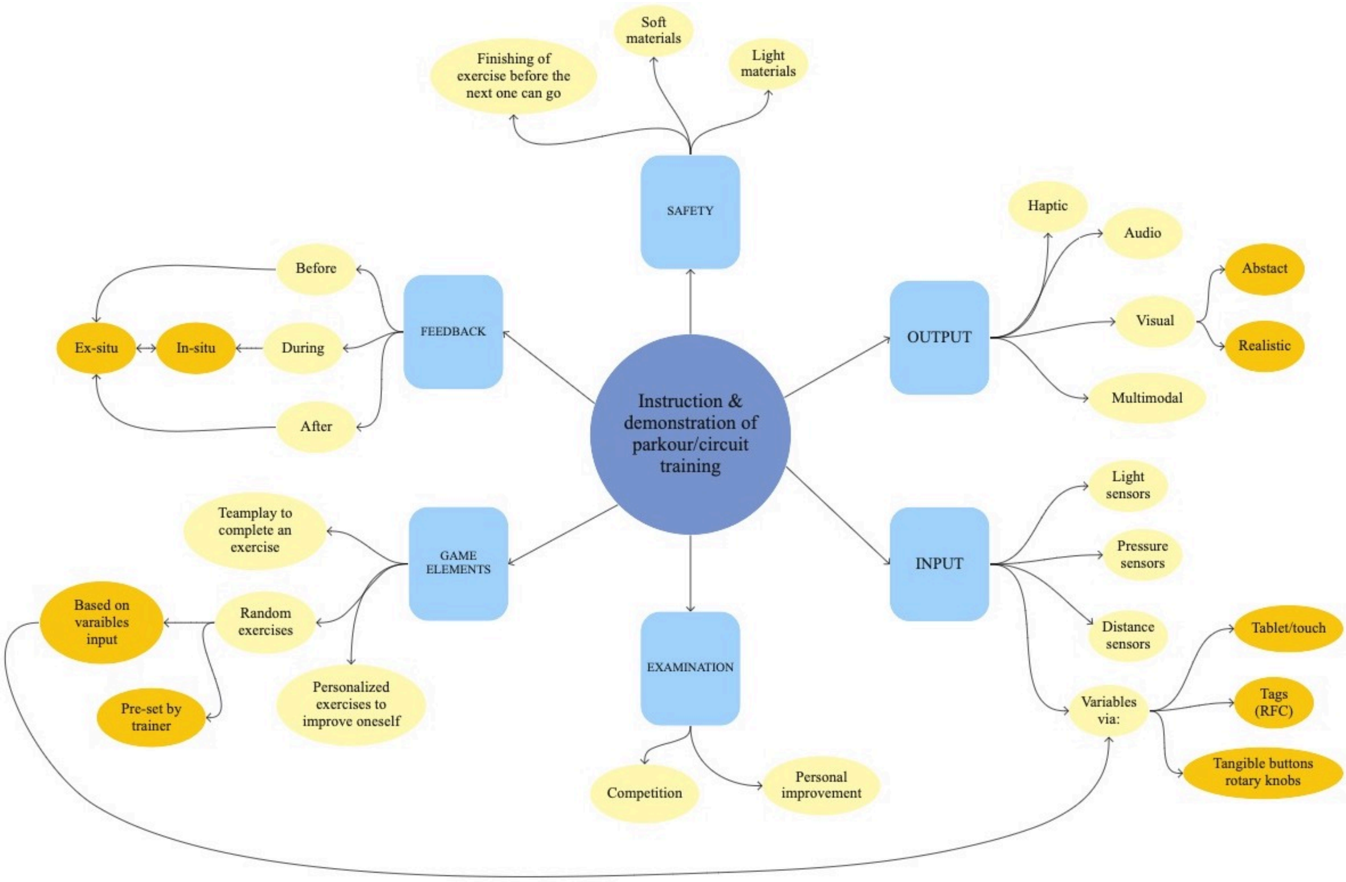


Figure 4.8: Mindmap showing various aspects with options that need to be considered in the design

4.2.2 Tinkering

Tinkering is a way of gaining solutions to a problem in a creative way. For this section, two methods are executed, namely the 'getting 50 ideas in 30 minutes and the 'negative brainstorm'.

The purpose of the '50 ideas in 30 minutes' [54], is to generate as many ideas as possible, in order to generate quantity above quality. These ideas can later be used as inspiration or be combined together. To help generate ideas, certain directions can be used as guidelines. With the design statement in mind, designing a product that provides engaging instructions for the explanation of obstacle course/circuit training, the following suggestions were helpful in generating solutions:

- What if there are no constraints in knowledge?
- What if there is an unlimited budget?
- What if it has to work without people?
- What if it has to work totally offline?
- How would superman/Winnie the Pooh solve the problem?
- What if it has to be something illegal/forbidden?
- How would it work as a game?

As a result of the brainstorming, 57 ideas were generated, which can be found in appendix D. The main result of this exercise was to **include personalized circuits/exercises**, which can possibly be guided by small tags on the body of an athlete. One idea was to let the children wear wristbands, which they could scan at an exercise or at the beginning of the parkour. Other implementable ideas were pressure pads on the ground for interactive instruction and haptic instruction pylons.

Another exercise that goes along with this brainstorm is the negative brainstorm [55], also called reverse problem. How can you make the problem worse? How will it definitely not be solved? The answer to this is having a lot of obstacles/exercises cluttered together, without clear guidance on what to do and when to do it. Not having a single clear line but having things all over the place, and no explanation whatsoever at any station. Another important element is repeating instructions, not just telling them once. Children of this user group often need to hear instructions multiple times, so when just telling them once without further explanation they will very likely not be able to proceed in the exercise. Finally, no starting point, long waiting times, no guidance whatsoever, and very difficult exercises would make it worse. As Aiko also mentioned beforehand, the exercises need to be easy, otherwise, the children will drop out as well.

4.2.3 Co-design

A co-design session was conducted with Aiko Staudt (previously mentioned trainer of MPM Hengelo), in order to find a solution for instructing circuit-based /obstacle training.

The main contribution Aiko made to the design, is that he stated that everything **should contain game-elements**. When traditional athletics are put into a competition/collaboration form, the dual effect of keeping their attention span as well as instructing the children will be reached. However, it is important to note that games are usually avoided in traditional athletics since they reduce the technical aspects of a practice, but for this user group, fun is the most important factor for learning.

Additionally, Aiko pointed out that circuit-based/parkour training is very useful since it can be used in a lot of different forms. it is used a lot as a side-exercise to keep the children busy and avoid waiting times, while he is explaining the main exercise to a small group of athletes. There are two examples that came forth in particular, namely long jump and shot put. In the long jump, a small parkour of hurdles is set at the side to keep the children busy and jumping when it is not their turn to do a long jump. While the children do not have too much difficulty remembering the sequence of the straight line of hurdles, they do lose motivation and interest, which creates chaos in the group.

Another possible application would be shot put. In this case, he envisions the athletes doing different exercises at each station of the circuit training, all contributing to the final movement of shot-put. For example, throwing a ball as high as possible, doing 5 push-ups, and throwing the ball behind your back. All these exercises contribute to the movement and power needed in shot put. This can be made more fun when competing in teams, having challenges, and adding game elements as such. However, games can be hard to explain (he tried this with 3-in-a-row), therefore visual guidance would be necessary.

Finally, he points out that athletics is a 'slow game', meaning athletes have to train for a long time to get better. Additionally, athletes need the courage to participate in matches, which can be very confronting. A way of solving this is translating the goal of traditional athletics into a measurable game. The focus therefore won't be on something abstract (e.g., distance, height), but on getting points in the game.

4.2.3 Scenarios

In the co-design session, two concrete context examples were given where an instruction system for obstacles would be beneficial, namely as a side exercise next to the main exercise and in shot-put exercises. Both situations are explored further to guide as inspiration for the initial product idea, in the form of a scenario below.

Scenario 1:
On a Tuesday evening, the children of the special athletics team of MPM Hengelo have their practice. On this particular day, the children are practicing long jumps. The trainer, Aiko, has set out an obstacle parkour of hurdles next to the long jumping area, in order to keep the children busy with jumping when they are not taking part in the long jump. He needs to pay attention to the children that are doing the long jump, both for safety reasons and giving technical feedback. Therefore, he cannot pay attention to the hurdles parkour the whole time. At the beginning of the training, the children are motivated and try out the course, but as soon as some time passes, they forget that they have to do it, forget the order that they have to do it, or get demotivated when they fail to do a jump. They copy the behavior of each other, so when one person stops and sits down, others will join next to him. How to help them remember the exercise and keep them motivated? This scenario is visualized in figure 4.9.

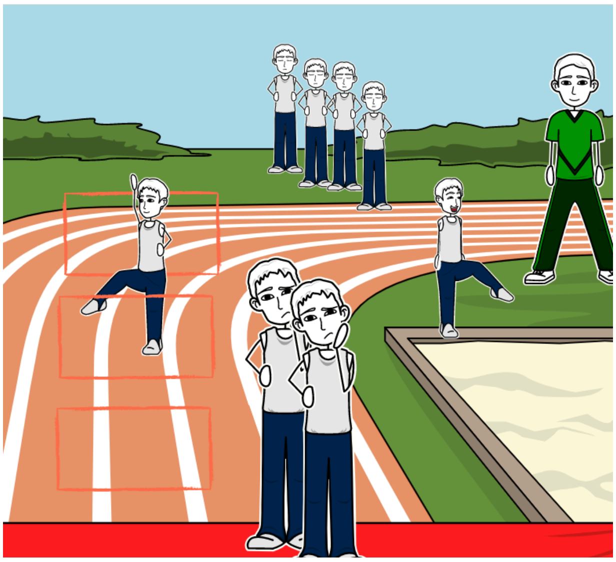


Figure 4.9: visualization of scenario 1

Scenario 2:
On a Tuesday evening, the children of the special athletics team of MPM Hengelo have their practice. On this particular day, the children are trying to learn shot-put. Shot put is a discipline within athletics where they have to push a metal ball as far as possible. This is a hard game to explain to the special athletes, due to a few factors. First of all, it is technically difficult. They have to push the ball instead of throwing it, which is hard to explain. Secondly, it needs a lot of attention from the trainer due to safety reasons. Serious injuries might originate when a child gets the ball in his/her neck of a few kilos. Finally, due to these safety measures, the explanation of the exercises goes slow and controlled, which distracts the children. To teach the shot-put movement step by step, 3 stations are set up with different exercises. At the first station, they have to throw the ball as high as possible. At the second

station, they have to do five push-ups (power training). At the last station, they have to throw the ball behind them. All these exercises contribute to the final movement of the shot-put, but explaining this takes a lot of time, and by the time they started, they have forgotten what to do at each station. How to support the trainer in explaining exercises for these children?

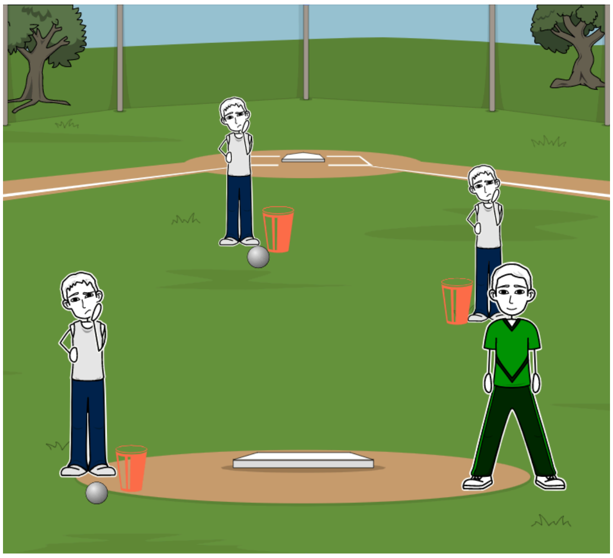


Figure 4.10: visualization of scenario 2

4.3 Initial Product Idea

In the previous section, a mindmap with design space has been made, and the need for a personalized, gamified system has become clear (based on the brainstorming and interview). By trying to solve the presented problems in the scenarios described in the previous section, an initial design idea is constructed.

Since the aim is to support the demonstration of exercises through alternative media (research question), it is important to look at ways to incorporate already available athletics equipment that a trainer already uses. Therefore, the product/prototype that will be designed is an **add-on instruction system for athletics equipment, that will guide athletes with intellectual disabilities through exercises**. The system aims to instruct the athlete by 'just-in-time' instruction, as well as motivate and thereby engage the athlete.

The system consists of an LED strip that can be clicked onto athletics material via straps. Depending on the size of the object, the LED strip can be shorter or longer. For example, an LED strip can be strapped onto a hurdle, pylon, or hula hoop, as illustrated in figure 4.11 below.

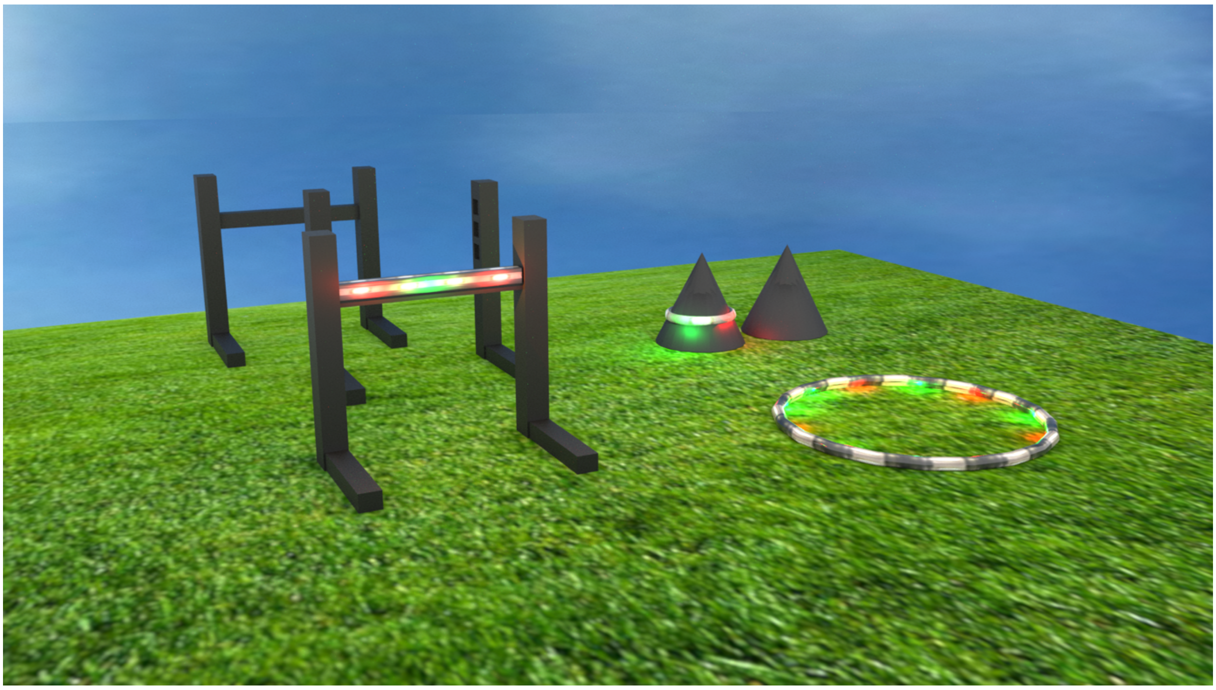


Figure 4.11: Initial idea visualization of the add-on for guiding exercises visually

Additionally, the toolkit/add-on module consists of sensors to measure if someone jumped over/in the obstacle, easily removable straps, and a power module. The add-on module will be almost the same for every obstacle (except for the LED strip length), so it can be easily used for multiple different types of equipment. The system has a 'master-set' which contains the control of all the obstacles, and a big start/stop button to smash on. Optionally, the system can have wristbands with small, personalized chips on them, so parkour difficulties can be changed to the abilities of specific children.

The idea is that the lights can be configured in multiple ways possible, therefore creating a whole scale of activities. Connecting this to **scenario 1** of the previous section, a solution has been found to forgetting the order of obstacles and possibly demotivation from participating. As an example, the trainer can show the sequence of obstacles once, after which the system will remember and display the lights in a 'just-in-time' strategy. When also adding game elements, such as certain points in time or achieving levels, the children can become more engaged in participating in the movements. In chapter five, the design space and possibilities of the system will be elaborated.

This initial idea takes into account the previously mentioned preliminary system requirements which were based on the stakeholder's needs. The preliminary system requirements are summarized in figure 4.6 and table 4.1, and put together in table 4.2. While not all requirements can be judged yet, some are already discussed in table 4.2.

Table 4.2: preliminary system requirements compared to the initial product idea

Preliminary system requirements of figure 4.6 and table 4.1	Initial product idea aspect
The system has to show a way of demonstrating of the exercises.	Visual explanation via LED strips.
System has to provide instructions as well as engagement.	The system has various modes. For example, the system can be a simple show & repeat mechanism, or a full game including points and levels.
Interface should not be too difficult, and easy in use (language, clear, etc.). Not be too complicated either for the children or trainer.	Cannot be assessed yet. However, the add-on consists of simple components, generalizable for different athletics equipment.
The system should run via an application, or via touch on the object itself.	Tangible 'master-node' which controls the whole system.
There should be a help desk book / service (possibly only website, or pdf describing it).	Can be provided.
Organizational: trainings should be able to be saved/added/changed.	Optional to have an online community, where training and modes are shared with others.
Product has to improve experience (no long waiting times, not too difficult).	Has to be made within the software.
Product has to be able to work outside and be waterproof.	Will be user tested.
Interaction has to be safe and voluntary	Will be user tested and the children can stop at any time
Product has to provide collaboration and working together with other people with mental disabilities.	Optional to have game modes of the system where the children have to work together in exercises.

4.4 Conclusion

In this chapter, it has become clear what stakeholders are present in this project and what their accompanying needs and values are. Based on that, preliminary system requirements are made to form a basis for the ideation and brainstorming of ideas. These ideas were evaluated and combined together into the initial product idea, which is:

***an add-on instruction system for athletics equipment, that will guide athletes with intellectual disabilities through exercises**.*

Finally, this idea has been compared against the preliminary system requirements to see if it addresses the stakeholder's needs.

The end product/contribution of this thesis is therefore a little bit changed in regard to the introduction. In the introduction, the research question was stated as: “How to support the trainer in instruction and demonstration of physical exercises through alternative media for children with an intellectual disability “. This question has been narrowed down to a smaller research area, by the decision to make an add-on instruction system that provides visual cues. The new research direction will be an **analysis of what will be a good add-on for providing visual instruction for children with intellectual disabilities**.

It will consist of (1) analyzing the already existing equipment and what sport practices the system can facilitate, (2) analyzing the user group and how this influences the design, and (3) analyzing which sensors can be used for sensing if someone stepped on/into an object. In the end, this thesis will be a **proof of concept** accompanied by an **analysis if the ‘just-in-time’ feedback system works for instructing and engaging** the special athletes. These three analyses can be found in the next chapter, specification.

Chapter 5: specification

In this chapter, the broadly formulated preliminary requirements of the ideation phase are specified into functional and non-functional requirements of the product. To achieve this set of requirements, an in-depth detailed analysis is done of our user group and their surroundings. This includes an analysis of equipment in order to see what equipment the children of MPM Hengelo already use in the athletics training, and how this prototype can add value to that (1). Additionally, an analysis of the children in the athletics team is done to envision how the children might benefit or respond to the prototype (2). Finally, rapid prototype is done, and a low fidelity prototype is presented in a user test to one of the children (3). From this low fidelity prototype, feedback is collected and used to further specify the requirements.

Based on the requirements, suitable hardware components for the final design are chosen. The requirements are also used to map out the interaction possibilities (design space) and to get a clear overview and specification of the product possibilities. **After reading this section**, you have an overview of several analyses leading to product requirements, leading to hardware components and interaction possibilities. In the next section (realization), these hardware and software components come together into a real prototype. Additionally, the fourth research question can be answered:

> SQ4: How can the already available athletics equipment be used/changed to support the demonstration/instruction of exercises?

5.1 Detailed analysis of context

For the design of the add-on of athletics equipment, it is important to know what equipment is already available and used by the children in the training. Additionally, it is necessary to know how different children interact with this equipment, for example, if they all use the same equipment or if they need personalized training based on their abilities. This information is gathered via observation and an interview with the trainer, Aiko Staudt. Finally, a low fidelity user test is done to gather valuable information.

5.1.1 Equipment analysis

An overview of material is necessary to clarify the prototype's specifications: an add-on for already existing athletics equipment. A visit to the MPM Hengelo (figure 5.1) where it was possible to look into the materials room and interview the trainer (Aiko Staudt), led to all the necessary information that was needed.

Figure 5.1: materials room of MPM Hengelo

In **appendix E,** the inventory list of all equipment that was available (33 different materials) can be found. A small part of this list is shown in table 5.1 to get an indication of the dimensions. Additionally, based on the interview with Aiko, it became clear what equipment is used often, what equipment is not used, and what equipment is used for multiple exercises.

Table 5.1: inventory of materials, complete table can be found in appendix E

	Product	Amount	Length	weight	Material
1.	**Product**	**Amount**	**Length**	**weight**	**Material**
2.	**Small pylon**	48	Lower square = 16cm, middle cone diameter = 10cm, top cone diameter= 4/4.5cm	Light	Plastic hard
3.	**Big pylon**	6	Lower square = 24 cm, middle cone diameter = 16cm, top cone diameter = 5cm	Light	Plastic hard
4.	**Cones**	450	Bottom diameter 18 /18.5 cm, Top diameter = 5.5 cm	Super light	Plastic hard
5.	**Shot put + rope**	13	Rope = 96cm, ball = 11 cm	Super light	Plastic hard + rope

According to Aiko, equipment that is being used a lot in the training are small hurdles, soft javelins, light short-put balls, small rubber rings, and high jump blocks. Material that is not used (often) is material that is too hard, high, or heavy. When the materials are too hard and the children make mistakes and fall on them, they will experience pain, which is not good for the learning curve. Similarly, too high hurdles or heavy balls won't add to positive experiences, next to that it is often not safe when the children are not fully focused. Finally, there are materials such as a pole vault or sling bullet that are not used often, since they come with long waiting times for participants. Based on this, the add-on prototype cannot be for equipment that is too high, heavy, or hard material (should only lead to positive experiences) and has to be for equipment where children do not experience long waiting times

One of the goals of designing a multi-functional add-on is to find equipment that is broadly used. To figure out if some equipment has multiple purposes, a cross-impact matrix is made [56], which can be seen in table 5.2. Based on this, it can be concluded that there are not a lot of materials that are used for different purposes. Medicine balls are used for the greatest number of different exercises (5 different ones), but most others are only used for 2 different exercises. If these are categorized, it is visible that these exercises also fall into the same category (jumping, throwing, or running), which does not make it particularly interesting for this prototype (of which the goal is to use broadly). Only hula hoops are used for 'jumping' exercises as well as 'throwing' things into them. Therefore, hula-hoops are chosen for the first prototype.

Table 5.2: cross-impact matrix of equipment used for multiple purposes

-	Throwing	Throwing behind	Abs	Pushing out	Jumping	Ritm jumping	Throwing in	Relay
Medicine balls	x	x	x	x			x	
Hurdles					x			
cones					x	x		
Pylons					x	x		
ladder					x	x		
Hula hoops/tires					x		x	
Soft rings	x						x	
javelin		x					x	
Relay batons								x

Based on the information above and the interview, suitable equipment for this add-on (in obstacle running) are; **pylons, cones, hurdles** (just the small kids' ones), **speed ladders, hula hoops, bikes tires, soft javelins, relay batons, and soft rings**. According to the sizes of these various pieces of equipment (which can be seen in the table in **appendix E**), it can be stated that the length of the LED strip should be between 60 cm and 300 cm, since these are the smallest and biggest materials of the list. Due to the time restrictions, only two types of equipment are used for the prototype and testing, namely the hurdles (jumping over) and the hula-hoops (jumping in).

Figure 5.2: materials that will be used for the design of the prototype add-on

Finally, something should be said about the software. Even though the prototype only consists of a limited number of obstacles to test, the system should be easily expanded to a bigger set. This means that the software on each obstacle should be nearly the same (just a few parameters can differ) as well as the hardware.

Concluding, the prototype of the add-on will consist of hurdles and hula-hoops (figure 33), since they are used a lot, used for the right purpose, multiple purposes, and have the right material. Potentially, the prototype can also be add-on the list given above. In the next section, various users and their interaction types are being looked at.

Requirements based on this analysis:

- The add-on prototype cannot be for equipment that is too high, heavy, or hard material (should only lead to positive experiences)
- It has to be for equipment where children do not experience long waiting times
- The LED strip of the system should be between 60cm and 300cm
- Each obstacle should have nearly the same hardware and software, so it can be easily expanded to a bigger set.

5.1.2 Test group analysis

To get an overview of the group that is working along with this thesis, each child of the Hengelo MPM athletics team is analyzed and described with a few characteristics. An example can be seen in figure 5.3, where participant 1, a boy with Down Syndrome, is characterized by his physical and mental abilities. A complete overview can be found in Appendix **F.**

Participant 1

- Down syndrome
  - People with DS have less motoric skills, which makes them have less power pressure
- Physically not able to jump over high exercises
- Not very big/tall
- Difficulties with coordination
- Copying of behaviour
  - When somene stops running, he will stop as well
- Cannot run 2 rounds as warm-up, does either not have the stamina or motivatoin for it

Figure 5.3: Example of one of the children in the MPM Hengelo team and his characteristics

There are a few things that can be said when analyzing these different characteristics. Mainly, it can be concluded that all the children are so different, that ideally, exercises have to be personalized in order to serve everyone to their fullest potential. This goes for physical abilities (e.g., not everyone can jump the same height), but also mental capabilities (e.g., fast understanding of the exercise or not). Things the group does have in common are impatience and lack of focus.

Requirements based on this analysis:

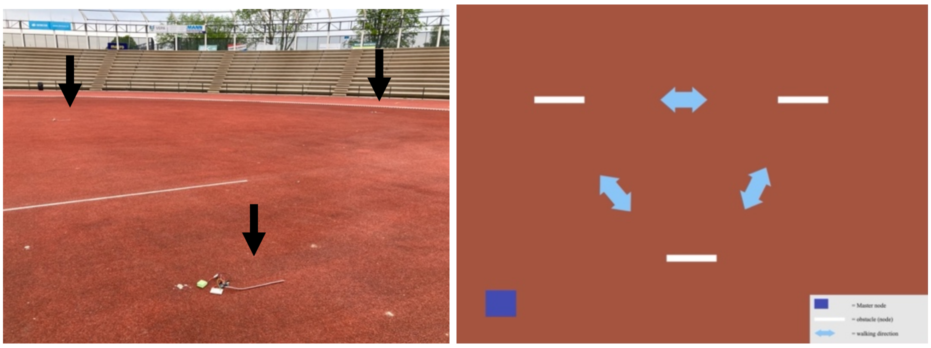
- The system should have a function of differentiation/personalization of exercises.

5.1.3 Low fidelity user test analysis

A rapid prototype has been made to explore the idea of 'just-in-time' instruction. The rapid prototype consisted of 3 LED strips, controllable with buttons that had connections via a wireless network. Three of these modules were placed on the athletics track, and the participant was asked to jump over the led strip as soon as the unit would light up. They were asked to do as many as possible in 30 seconds. The goal was to see how the participant responded to 'just-in-time' instruction, if he could see the LEDs clearly and how he felt during the execution. The setup of the experiment can be found in figure 5.5. In this stage, this system does not work with any sensors yet, but the idea of lights turning on/off when you jump over it is simulated with a wizard of Oz technique, namely pressing buttons on a control panel (figure 5.4).

(a) (b) (c)

Figure 5.4: (a) the master node (wizard of Oz), (b) the 3 light nodes, (c) the light nodes in action



(a) (b)

Figure 5.5: (a) setup of the low fidelity user testing experiment, (b) schematic of the setup where dark blue is the master node, white the lights, and blue the walking direction

The user test is done with 3 participants, and it was observed that the participants got 4 lights on average in 30 seconds. One participant started very fast and motivated, but at some point, one light did not properly go on and he did not know where to go next anymore. At that point, he lost motivation and his pace decreased. In the interview afterward, he pointed out that he did not really get the purpose of it and found it rather boring. It became clear that the system should have some kind of competition against others or yourself (e.g., with levels). However, he said the lights are clearly visible and it was clear where he had to go next. When closer to the ground, the lights become less visible.

Other things that became clear after this test, were the range of operation and the battery usage. The prototype should be wireless since it should work over the full track of the athletics field. The range of operation in this first test was supposed to be 100 meters (specifications of the manufacturer), but it turned out to be barely 25 meters. This means it cannot be used over the full length and width of the athletics track. This is not a big problem for this stage of the prototype but can be solved by buying another module (specified in the next chapter). Additionally, the batteries died way faster than expected, which should be taken into account when developing the prototype further. Finally, the colors red and green appeared to be the most visible in these surroundings (out of a stream of a lot of different colors).

Finally, something can be said about the 'just-in-time' strategy of providing instructions. After this user test, it became clear that this strategy only works when it is really just in time. If the system is too late (which was the case here), the participant gets distracted and loses motivation. Too early did not seem to matter here.

User requirements based on this analysis:

- The system should have some kind of competition/comparison/levels
- The system should have wireless communication, with a minimal range of 100m
- The batteries have to be strong enough to hold for at least 1 hour and have to be able to be changed easily
- The system should include the colors green and red.

5.2 Requirements

In the previous subsection, the requirements are defined. In this section, they are summarized and a distinction is made between functional requirements (FR) and non-functional requirements (NFR). FR are requirements that describe **what** the product does, while NFR are requirements that describe **how** the product does it. FR are often also described as something the system must do, and NFR as a requirement that describes how the system works (such as delivering a specific function). Additionally, the importance of requirements is specified in this section.

There are a few extra requirements that did not come out of the previous analyses (analysis of equipment, analysis of user group, and user test). These requirements are added based upon earlier sections (chapter 4) in the report, regarding to the goal of the system (instruction and engagement) or setup configuration for the trainer.

5.2.1 Function Requirements

The functional requirements are stated below in table 5.3, where they are ranked upon importance (meaning FR1 is the most important, FR10 the least). The importance of requirements is based upon the importance of the stakeholders, whereas the children and their safety are the most important and the organization, competition, and easy reproduction/expansion (special Olympics) the least.

Table 5.3: Function Requirements ranked in importance

Functional Requirement No.	Function Requirement Description
FR1	The system has to be safe, so it cannot be for equipment that is too high, heavy, or hard material (should only lead to positive experiences)
FR2	LEDs should be sufficiently visible (using green/red)
FR3	The system should have a way to sense if someone jumps over/in something
FR4	The system has to be waterproof
FR5	The system should have wireless communication, with a minimal range of 100m
FR6	The LED strip should be between 60cm and 300cm
FR7	The batteries have to be strong enough to hold for at least 1 hour, and have to be able to be changed easily
FR8	The system should be mounted easily onto different existing materials
FR9	Each obstacle should have nearly the same hardware and software, so it can be easily expanded to a bigger set.
FR10	The system should be able to sense when an obstacle is fallen, so it won't keep sensing

5.2.2 Non-functional requirements

The non-functional requirements of this system are stated in table 3, ranked from top to bottom in importance. The importance is again based on the stakeholders, where the children are the most important (therefore wanting to improve their experience the most) and the trainer/examinator the least important (their experience in how to configure the system).

Table 5.4: Non-Function Requirements ranked on importance

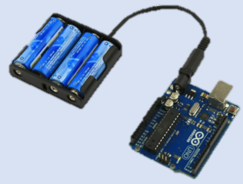
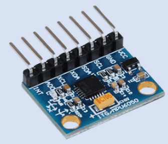
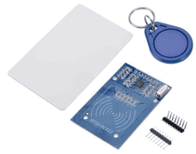
Non-functional Requirement No.	Function Requirement Description
NFR1	The system has to improve user experience: the children understand the exercise better (instruction)
NFR2	The system has to improve experience: the children are more motivated to do the exercise (engagement)
NFR3	The system should provide modes where children do not experience long waiting times
NFR4	Should be able to have different modes (for instruction as well as engagement)
NFR5	The system should have a function of differentiation / personalization of exercises
NFR6	The system should have some kind of competition / comparison / levels
NFR7	The system should be configurated easy, possibly at a distance

5.3 Translation into components

Since the functional requirements are mostly directed to the hardware of the system, they can be translated into component choices. For example, the requirement for wireless communication leads to several possibilities for wireless hardware systems. Possibilities are mapped out and the most suitable hardware component is chosen. The components are possible solutions to fulfill the functional requirements. The result can be seen in table 5.5.

Table 5.5: Requirements translated into usable components

(N)FR	Description	Component and substantiation	Figure
FR2 + FR6	Sufficient visible LED's + between 60cm and 300cm	Since the LED has to be sufficiently visible and changeable in size, the decision has been made to use WS2812B LED strips. These LED strips can be cut of per light (unlike some other LED strips) and since it is a whole row of LED's, it is sufficiently visible.	
FR3	Sense if someone jumps over/in something	A distance sensor can be used to measure activity. There are 4 different types: ultrasonic, infrared, laser distance or time-or-flight sensors. A distance sensor is needed with features for a short range, non-complex objects (just anything over it) and low-cost. Therefore, the Ultrasonic distance sensor (HC-SR04) is the best possible outcome. Infrared is better for complex surfaces; laser distance sensors are better for long distances; and time-or-flight sensors are better for faster readings.	
FR4	The system has to be waterproof	To have a waterproof system, components need to be made waterproof. There is an ultrasonic waterproof distance sensor, namely the LDDS04. Furthermore, plastic coating around the LED and a box around the other components needs to be added.	
FR5 + FR6	Wireless communication with a minimal range of 100m	There are various options for creating a network for Arduino, namely using an Arduino Nano BLE, using an nRF52 module, using the NRF24 modules or using an xBee module. Every option has some advantages and disadvantages, such as price, operation protocol and distance range. The XBee operates over Wi-Fi, which does not make it suitable outside since you are always dependant on Wi-Fi connection. The Arduino nano BLE only operates on a range of 1 meter and the nRF52 is very expensive. This makes the NRF24 a good option, since it has a range of 100 meters.	

FR7	The batteries have to be strong enough to hold for at least 1 hour, and have to be able to be changed easily	To power the Arduino, a re-chargeable battery pack or a power bank can be used. This will have enough energy and can be re-charged.	
FR8	The system should be mounted easily onto different existing materials	To make sure the distance sensor can be mounted onto any material, a 3D case has to be printed and attached to the object with Velcro straps.	
FR10	The system should be able to sense when an obstacle is fallen, so it won't keep sensing	To sense if an object (e.g. hurdle to jump over) has not been fallen, a gyroscope has to be included. This measures the angular accelerators along one axis. A suitable component for this is the GY-521, which contains an accelerometer and a gyroscope.	
NFR5	The system should have a function of differentiation / personalization of exercises	Personalization of components can be done with an RFID reader and NFC tags. This NFC tag can be woven into clothes or bracelets and thereafter scanned onto the reader for a personalized exercise.	

5.4 Interaction specification

The system requirements have been used to specify software and hardware and the same can be done for software and interaction types. As described before, there are many functions/modes possible with this system.

To map out the possibilities of this system, a two-dimensional space with variations has been created. On one axis, inform against engage is mapped out. This axis was chosen due to the initial purpose of this system, informing the children of where to go. They have trouble understanding verbal explanations, and therefore visual cues are helping them to understand. As described in earlier sections, after information (and comprehension), engagement might follow. The secondary (successive) goal of this system is to motivate the children in participating in the exercises.

On the other axis, competition against collaboration is mapped out. This axis starts with no competition/competition against oneself. Then it goes to competition against others, and it ends in collaboration exercises. This axis is chosen because of earlier system requirements of chapter four, where the need for collaboration (social aspect) or competition purpose is explained. Additionally, this was stated in the co-design session together with Aiko. The children either have to compete against themselves, meaning they can get a level and try to improve themselves (these are personalized exercises). They can also compete against each other, or with each other, in both ways making the exercises more engaging, as this was a requirement that came out of the first user test.

In figure 5.6, the axes and seven game possibilities for the system are mapped out.

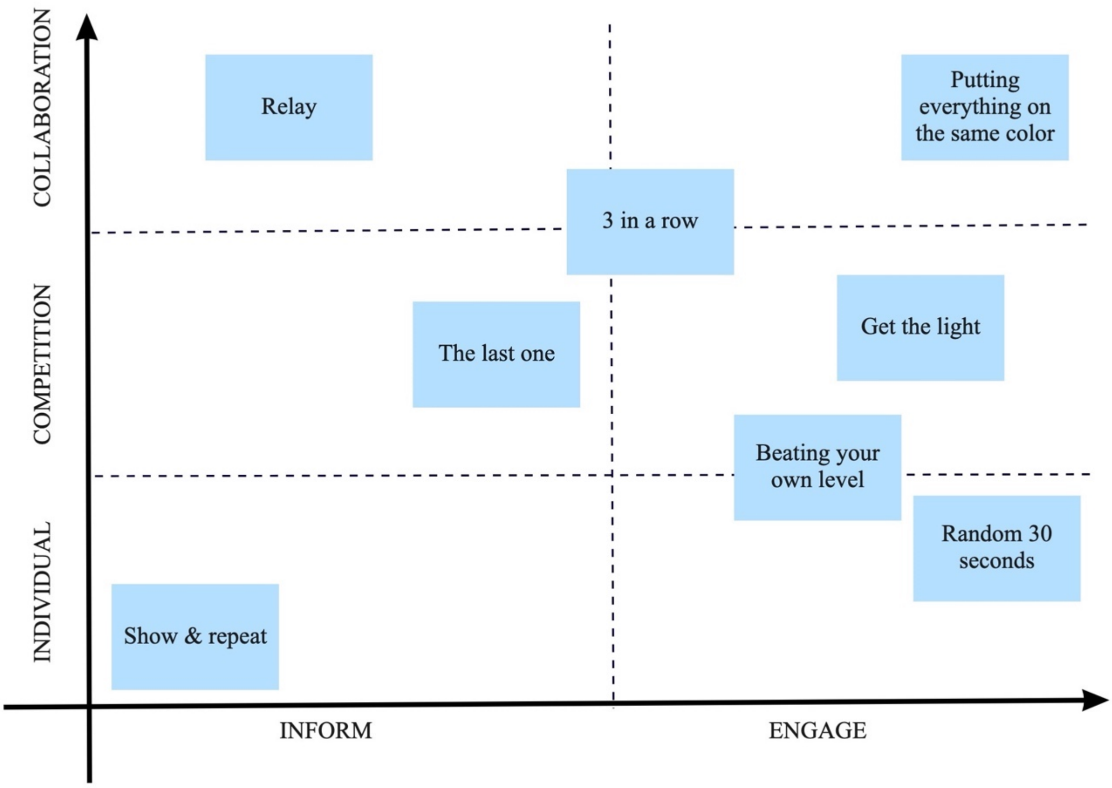


Figure 5.6: two-dimensional design space of the system

The functions of this system are endless, but to demonstrate the abilities seven possibilities are mapped out. The explanation of these possibilities can be found in table 5.7 below.

Table 5.6: Seven possibilities of the system with explanation

Exercise	Explanation	Category
Show & repeat	The trainer shows an exercise, the system will remember it and show it step by step to the athlete ('just-in-time' feedback). The goal is to reproduce the steps of the teacher, so the athletes can do the exercise without guidance of the trainer. This is based on a real situation, where the trainer has to focus on one of the athletes, so he puts out a parkour for the others to keep them busy.	Inform & individual
Random 30 seconds	A random light on an obstacle will go on, the athlete has to go over/in it as quickly as possible. The goal is to get as many as possible in 30 seconds.	Engage & individual
Relay	The trainer shows an exercise, the children all have to copy this example in the form of a relay. The goal is to get the best time possible as a group.	Inform & collaboration
Putting everything on the same colour	The obstacles are spread out over the athletics track. The goal is that each player goes over each obstacle once, then it will turn green. This is based on a real situation, where the athletes have to run one round on the track to warm up but lose motivation for this.	Engage & collaboration
The last one	Instead of the trainer showing an exercise, the children can come up with their own exercises. One person can make it up, and the rest has to copy his exact movements. If an athlete does not manage to do it, they get 1 point. With 3 points they are out of the game.	Inform & competition
Get the light	Every player has his own colour of light. When the game starts, they have to jump over their own colour. The goal is to get as many of their colour as possible.	Engage & competition
3 in a row	The classic 3 in a row game, can be illustrated and explained with lights as well. One person can run to the front, jump in the hula hoop he/she wants, whereafter it is his teammates turn to choose one. Two teams are competing against each other. The goal is to get a row of 3, and to collaborate with your teammates while competing against the other team.	Engage & competition / collaboration
Beating your own level	This exercise incorporates personalization. There is an enormous difference in the level of performance between the children. Therefore, this game allows for personalization, by having its own level with an attached difficulty. The goal is to jump over the obstacles that are specially lit up for them.	Engage & self-competition

For the scope of this research, only three modes will be carried out and tested with the children. To test information transfer, the **show & repeat** mode will be made. To test engagement, the '**putting everything on the same color'** mode will be carried out. Finally, to test if personalization has its desired effect, the '**beating your own level'** mode will be carried out. By making these 3 modes, it is possible to look at collaboration, self-competition, and individualization.

5.5 conclusion

In this chapter, functional and non-functional requirements have been specified, which came forth out of equipment analysis, user analysis, and low fidelity user testing. These requirements were summarized and ranked upon importance, based on stakeholders in the project. The requirements were translated into components of the system, which can be seen in table 5.5, Additionally, the requirements were translated into software/interaction possibilities, which can be seen in table 5.6.

In this chapter, the fourth research question has been answered, which was:

> SQ4: How can the already available athletics equipment be used/changed to support the demonstration/instruction of exercises?

A list of materials has been made on which the add-on prototype can be placed (see previous section), of which hula hoops and hurdles are chosen to actually test the prototype on. The requirements stated in this chapter helped define software and hardware choices, which state in what way this equipment can be used as support for demonstration and instruction (game modes and dimensions).

In the next section, the defined components come together into the hardware of the installation. Additionally, the software implementation and interaction realization will be elaborated upon.

Chapter 6: Realisation

In this chapter, the realization of the prototype is described. The chosen components from the previous chapter are used to develop the hardware of the prototype. Subsequently, the (non)-functional requirements of the previous chapter are used in the development of the software. In the final section, the interaction between hardware and software is described.

After reading this section, it is clear what hardware is used for the prototype, what software (coding, communication protocols, etc.) is used for the prototype, and how the interaction between these systems is mapped.

6.1: hardware

The hardware is divided into sub-systems due to the functional architecture of this prototype. Since it was stated in the previous section that the add-on instruction system should be the same for every kind of athletics equipment, all nodes/units should contain the same elements. Therefore, a master-slave architecture is used, where one master module is responsible for all the computations and signals and sends this to the slave modules. All the slave modules are similar in hardware and software and report back to the master node.

In total, five units have been made in order to evaluate the prototype sufficiently. This consists of one master unit, three slave units, and one slave unit containing an RFID reader (for testing the personalization mode). These three sub-systems will shortly be described. It has to be noted that the reason for choosing these particular components has already been discussed in chapter 5 and will not be discussed here again.

6.1.1: Slave modules

The main goal of the slave module is to receive signals from the master module to set the LED strip on or off, and to send signals back if someone was close and jumped over / stepped into the obstacle. As described in the previous chapter, an HC-SR04 distance sensor has been used for reasons of short-range, non-complex objects, and low cost. Additionally, an LED strip is added to generate visual feedback, varying in size for different equipment. Finally, every module has an NRF24 network module to communicate with the master and a small LED light for testing feedback. The system can be seen in figure 6.1.

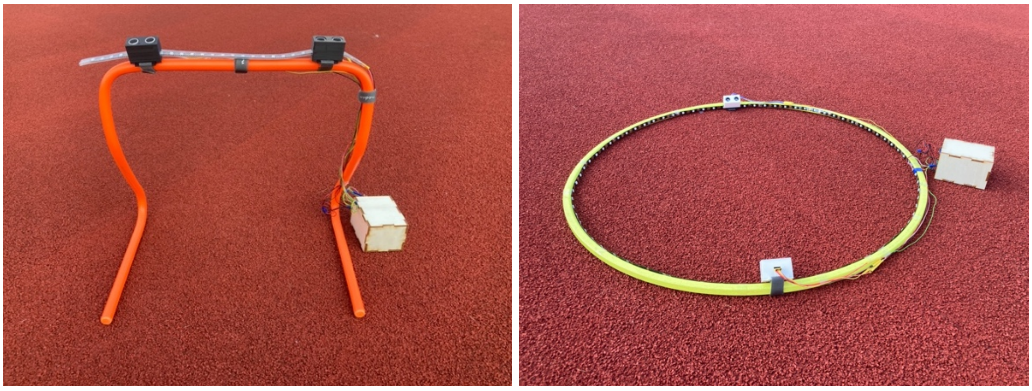


Figure 6.1: Realization of the slave module, consisting of distance sensors and an LED strip

In figure 6.1, it is visible that the LED strip is surrounded by a plastic wrapping, and that all the cables are put into a box. This is both for the safety of the system (children bumping into it), as well as to protect it from rain damage. In figure 6.2, the physical connections between the components can be seen. An extra capacitor (decoupling capacitor) is added between the network module and the power supply to stabilize the signals. The power supply is not visible here, but as described in the previous chapter, a power bank or rechargeable battery unit is used. Depending on this choice, an additional resistor between the power and ground is added, to make sure that the power bank draws enough power to stay on.

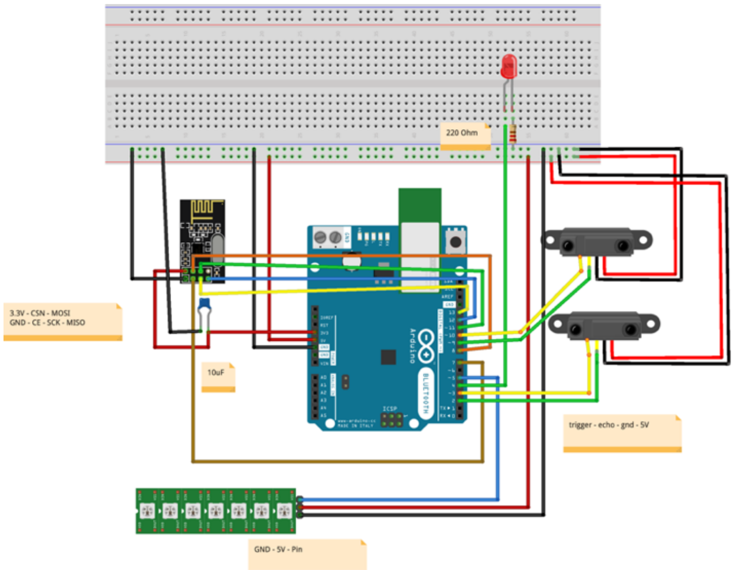


Figure 6.2: schematic of the slave module

Finally, as described in functional requirement 8 of the previous chapter, the system must be mounted easily onto different existing materials. Therefore, a 3D printed case has been developed that holds the sensor as well as the LED strip. The design allows the LED strip to easily move in and out. Additionally, it has holes to put Velcro strips in it to attach it to the equipment. The design is made in Fusion 360, which can be seen in figure 6.3.

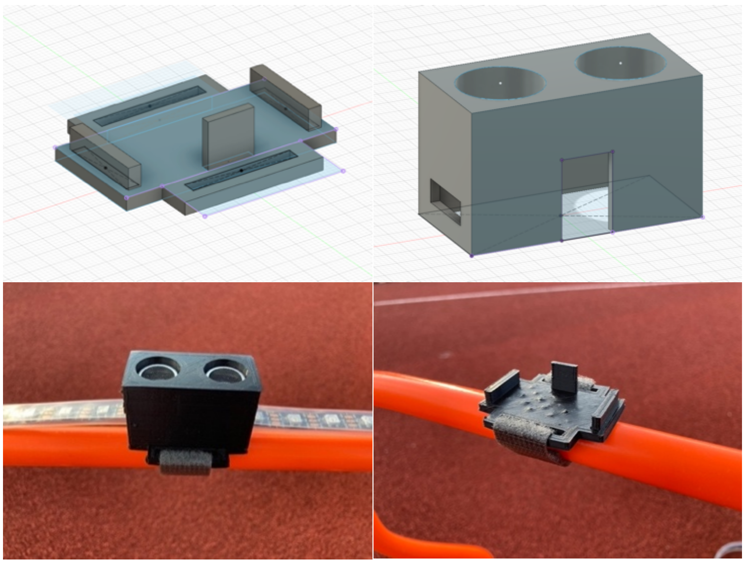
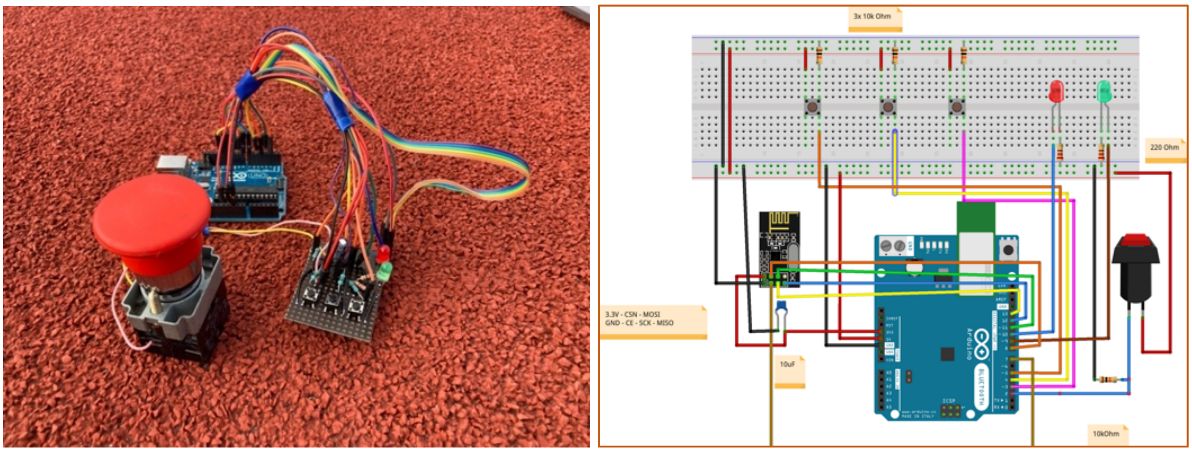


Figure 6.3: attachment of the prototype to athletics equipment

6.1.2: Master module

In the next sub-system (the master module), code can be uploaded so different signals can be sent to the slave modules. This module configures as a single-point control and communication unit for the system. This module is meant for the trainer, where certain training programs can be loaded onto the system by the use of assigned buttons, as well as starting/stopping the system with the big red button. An overview of the realization of the master module can be seen in figure 6.4.

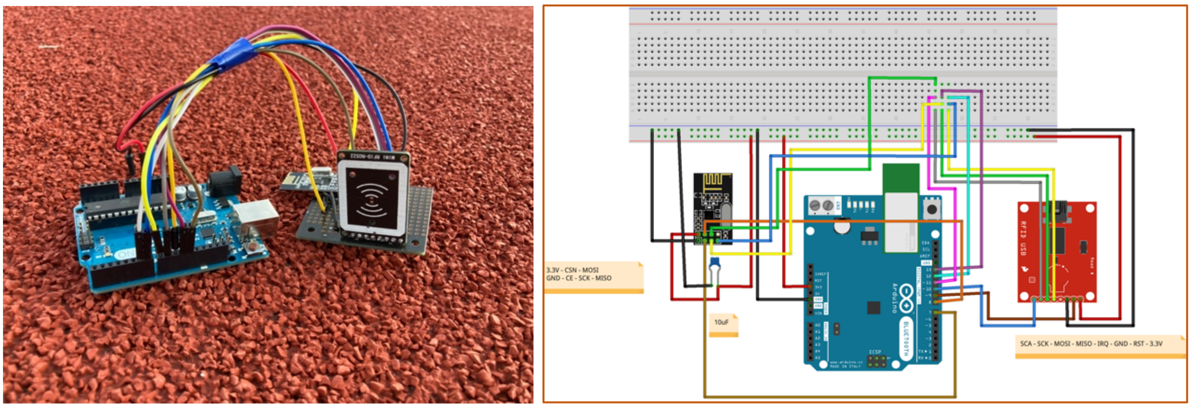


(a) *(b)*

Figure 6.4: The realization (a) and schematics (b) of the master module

6.1.3: RFID module

The final sub-system contains an RFID reader and a network module. This module is responsible for scanning the children's bracelets, hence the reason to separate it from the trainer's control unit. It is not part of an obstacle (slave module) and thus the reason why it is only made once. The children wear bracelets with small NFC tags woven into them, which they can scan on the reader. The realization and schematic can be seen in figure 6.5 below.



(a) *(b)*

Figure 6.5: The realization (a) and schematics (b) of the RFID module

6.2 software

As previously described, the architecture of the prototype is a master-slave architecture. This mainly has to do with the communication protocol of the network. The network is done via a nRF24L01 transceiver module, which uses a 2.4 GHz band with a range up to 100 meters to communicate. A single module is capable of listening up to 6 modules simultaneously. In addition, they can have up to 5 'children' with a maximum depth of 5. This means a network of 3125 (five to the power of five) nodes can be created, which is enough for the system that is needed on the athletics track.

A node is defined with a 15-bit address, which describes the position of the node within the tree. The communication is bi-directional, meaning the master node can send to the slaves and vice versa. In figure 6.5, the tree topology of the network can be seen. If node 01 wants to communicate to node 02, it has to go via the base node 00. The code is different for the slave module and master module, both can be found on GitHub (an online platform to view the code) [57].

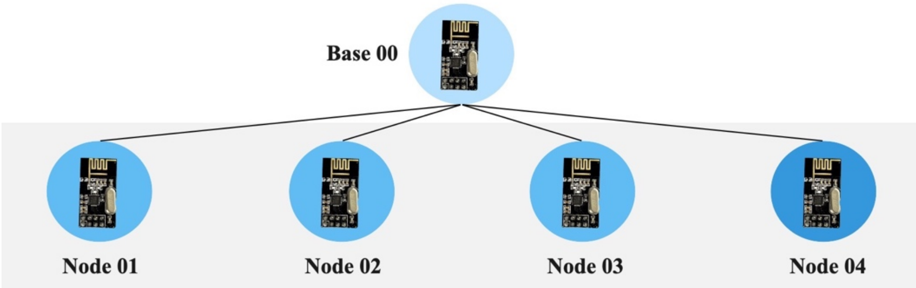


Figure 6.6: Master-slave network tree topology

6.2.1: Slave modules

In the slave modules, the distance to an obstacle is calculated, as well as putting the LED strip on a certain program. No game calculations are done since that is done in the master module, but each slave module calculates its own distance to an object. The software of every slave module is nearly identical, except for the address of the node and the length of the LED strip (number of lights).

In table 6.1, the different functions of the software program are described, as can be found in the GitHub code. The loop() runs through different cases (depending on which game state is on), and the game state determines the color of the lights. The receiving function gets the signals from the master node, which decides if the LED strip is on or not.

Table 6.1: Software structure of the slave node

Function	Description
loop()	Has receiving(), measureDistance(), and a switch between the 3 different modes, which use stopColours(), fillTheLEDs and contdownColor().
stopColours()	Puts all colors on black.
fillTheLEDSs()	Fills the LEDs in the strip and makes them move.
measureDistance()	Reads the distance by using an echo and trigger pin. Then calculates the average distance over the last 4 values. If this is below a certain threshold, it will send a signal to the master node that someone jumped over/in an obstacle.
countdownColor()	Changes between blue color and black color, faster and faster depending on the timer. If the timer is empty, the participant has failed the level.
receiving()	Gets two signals from the master node. It gets the game state that is currently on, together with the state of the LED (on/off).
rdPulseIn()	This method deals with long waiting times for the distance sensor outside. It has a threshold when it should stop looking for a signal.

One important part of this code is the detection of the jump. The distance sensors continuously send out pulse signals and wait for these signals to come back (reflect on an obstacle), which results in a continuous stream of data. It is necessary to take the average over the past values instead of the raw data as trigger for jump detection, since otherwise just walking past an obstacle would then already trigger the system. Additionally, a new method had to be written for the system to be able to work outside. The distance sensor sends a pulse signal and measures the time for this signal to come back, but this will take a very long time outside since there is no obstacle to bounce at (unlike a ceiling inside). Therefore, a method with a threshold had to be written, which simply stops the measuring if it takes too long. This way, the system is way quicker and does not 'miss' anyone from jumping over.

Since the code is nearly identical for every node, it is very easily scalable and can be uploaded without having to change specific code. When a new obstacle is being added, the only parameters that have to be filled in are the address of the node and the length of its LED strip of it. Due to the master-slave architecture, the only code that has to be changed is in the master node, whenever a new game mode has been added.

As can be seen in figure 6.6, the RFID mode is a slave module as well. It does not contain distance sensors or an LED strip, but instead has an RFID scanner. The functionality of the software is simply scanning the NFC tags and sending this to the master node.

6.2.2: Master module

In the master module, code for new games can be uploaded. In table 6.2, the eight different functions of the program are described. Currently, three different games are uploaded on the master module, which are called receivingMode1, receivingMode2, and receivingMode3. Switching between these 3 modes can be done via pressing the button. More modes can be added very easily, by just adding the function.

Table 6.2: Software structure of the master node

Function	Description
loop()	Has runProgram(), sending(), chooseMode() and a switch between receivingMode1(), receivingMode2(), receivingMode3().
chooseMode()	Reads the state of the small buttons and puts the game state to the next game when the button is pressed.
runProgram()	Reads the state of the big button which will start/stop a particular game.
sending()	Sends signals of the LED strips (on/off) and the game mode to the slave nodes.
reset()	Sets all LEDs of the slave nodes off again, as well as resetting the order of exercises, certain variables, etc.
receivingMode1()	When the program is started (button is pressed), the trainer can jump a sequence of obstacles and the system will store this in an array. When the button is pressed again, the LEDs will be put on, one by one.
receivingMode2()	When the program is started, obstacles can be put on 'true', which will change their colour of light.
receivingMode3()	Based on the ability of the child, a more difficult or easier parkour will be shown. Children scan their NFC bracelet to the RFID node.

One important part of this code is the timing of receiving and sending signals over the network. The library of the network module does not allow for sending and receiving at the same time, therefore the system is built in a way that they do not interfere with each other. The slave module will only send a value over the network when someone is jumping over an obstacle, meaning it won't overflow the system. Additionally, sending back the LED values will happen only once every 300 milliseconds, instead of every time while running through the code. This way, sending and receiving can alternate with each other.

6.3 Interaction

To explain the interaction of the prototype, a flow chart is created, where all the possible interactions are explored. The flow chart can be seen in figure 6.7, where it starts on the left side with the master node. The master node has four types of interactions: three button presses and scanning the NFC tag on the bracelet. One button is for changing the game mode, one button is for stopping/starting the game and one button is for resetting the program. Depending on which mode you are in, different values will be sent to the slave modes, containing the information for the LED on/off accompanied with the game state. At the other obstacle (slave) nodes, interaction is triggered when jumping over/in obstacles. This will be sent to the master node, which in turn will then put the next LED on. The NRFC reader will verify a player and send this to the master node when the system is in game mode 3.

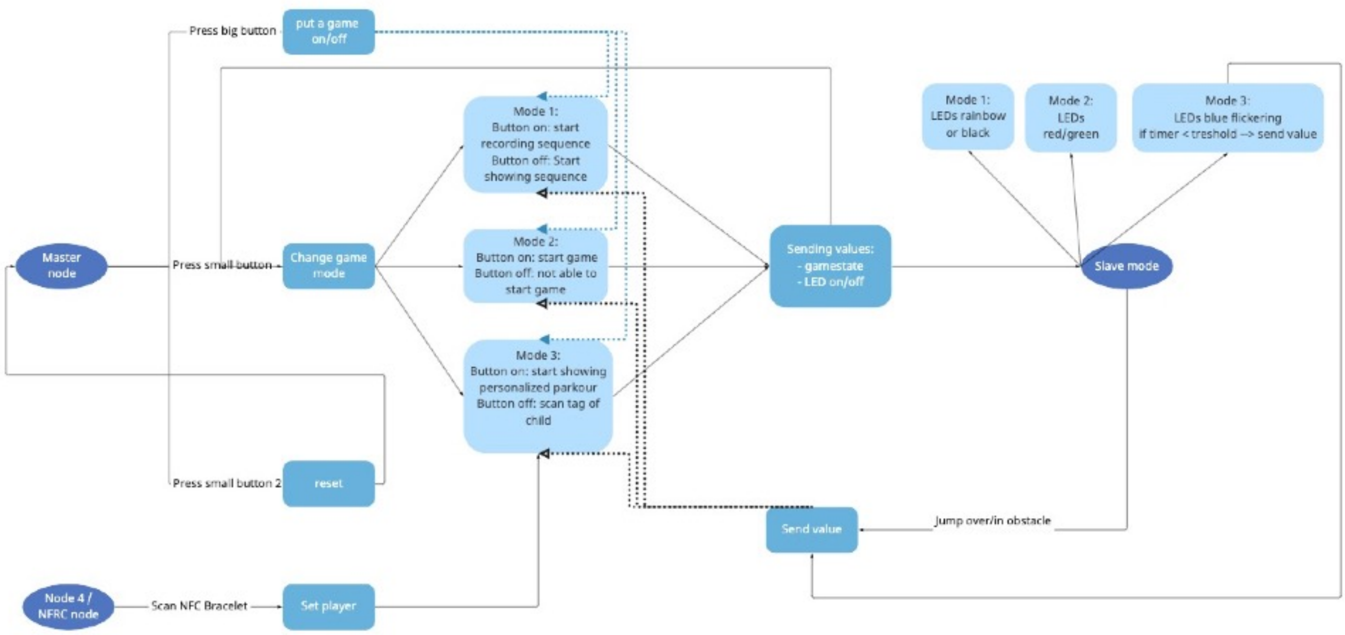


Figure 6.7: Interaction possibilities of the prototype

To summarize, the trainer will first press the button to set a certain mode, after which he can use the big button to stop/start the program. Mode 3 also has the interaction of scanning the RFC tag. The athletes interact with the program by jumping over/in obstacles.

6.4 Conclusion

In this chapter, it has become clear how the chosen components from chapter five are put together, what the software consists of, and how the software and hardware interact. The decisions for certain hardware and software arise from the earlier defined (non-)functional requirements, which can now be examined for completion.

The requirements are examined via points which go as follows: ++ *Requirement is fully met*, + *Requirement is mostly met*, +- *Requirement is partially met*, - *Requirement is mostly not met*, -- *Requirement is not met.* In table 6.3 the assessment of the (non-)functional requirements can be seen. Most functional requirements can be assessed, while most non-functional requirements have to be tested in the next phase.

Table 6.3: Assessment of the (non-)functional requirements

(N)RF No	Function Requirement Description		Conclusion and remarks
FR1	The system has to be safe, so it cannot be for equipment that is too high, heavy, or hard material (should only lead to positive experiences)	+	The prototype is made on hurdles and hoola hoops which meet all these requirements. However, it is an add-on, which in essence can be placed on all types of equipment, including high, heavy, and hard materials.
FR2	LEDs should be sufficiently visible (using green/red)	*N/A*	*Will be tested in the next phase.*
FR3	The system should have a way to sense if someone jumps over/in something	++	Sensing is done via the two distance sensors.
FR4	The system has to be waterproof	+-	Part of the components are waterproof (LED strips, casing), but due to money and time (ordering) restrictions, these are not implemented yet.
FR5	The system should have wireless communication with a minimal range of 100m	++	The nRF24 modules allow for that.
FR6	The LED strip should be between 60cm and 300cm	++	By using a LED strip that does not have LEDs parallel together, the strip can be cut anywhere, which allows easy altering of length.
FR7	The batteries have to be strong enough to hold for at least 1 hour, and have to be able to be changed easily.	++	Using rechargeable power banks or 9V battery units.
FR8	The system should be mounted easily onto different existing materials	+	Even though the system has Velcro straps, the casing is hard plastic and therefore not completely bendable around the material.
FR9	Each obstacle should have nearly the same hardware and software, so it can be easily expanded to a bigger set.	+	All components are completely similar, except for the length of the LED strip (can be easily cut).
FR10	The system should be able to sense when an obstacle is fallen, so it won't keep sensing	--	Not implemented due to time restrictions.
NFR1	The system has to improve user experience: the children understand the exercise better (instruction)	*N/A*	*Will be tested in the next phase.*
NFR2	The system has to improve user experience: the children are more motivated to do the exercise (engagement)	*N/A*	*Will be tested in the next phase.*
NFR3	The system should provide modes where children do not experience long waiting times	*N/A*	*Will be tested in the next phase.*
NFR4	Should be able to have different modes (for instruction as well as engagement)	++	Software is built in such a way that new games can be easily added.
NFR5	The system should have a function of differentiation / personalization of exercises	++	Game 3 allows for a personalized exercises, based on the NFC scan in the bracelet.
NFR6	The system should have some kind of competition / comparison / levels	++	Game 2 is a game where the children work together, whereas in game 3 they beat their own level.
NFR7	The system should be configurated easy, possibly on a distance	++	The games can be changed from a distance, by simply pressing the button.

As can be seen in table 6.3, most functional requirements are met, except for making it completely waterproof, and fall-proof. Most non-functional requirements cannot be assessed yet but will be after the user testing has been done. The non-functional requirements that can be assessed already are considered successful, as can be seen in the table above.

In the next section, the working prototype will be tested in order to see if it has achieved its goal of providing instruction and engagement in athletics for children with intellectual disabilities.

Chapter 7: evaluation

In the previous chapter, the specified (non-)functional requirements have been assessed on realization. However, this does not automatically mean all stakeholders are satisfied, and therefore evaluation with the target user group has to be done. The aim of the evaluation is to assess if the goal of the prototype has been reached, which is providing instruction and engagement in athletics for special athletes.

After reading this chapter, it is clear what methods and techniques have been used to execute the user evaluation, including test parameters and setup. Results are summarized and analyzed and will be used to assess if the goal of the prototype has been reached and answers the last sub-research question:

> SQ5: How do children with intellectual disabilities respond to instruction/feedback systems that use alternative media?

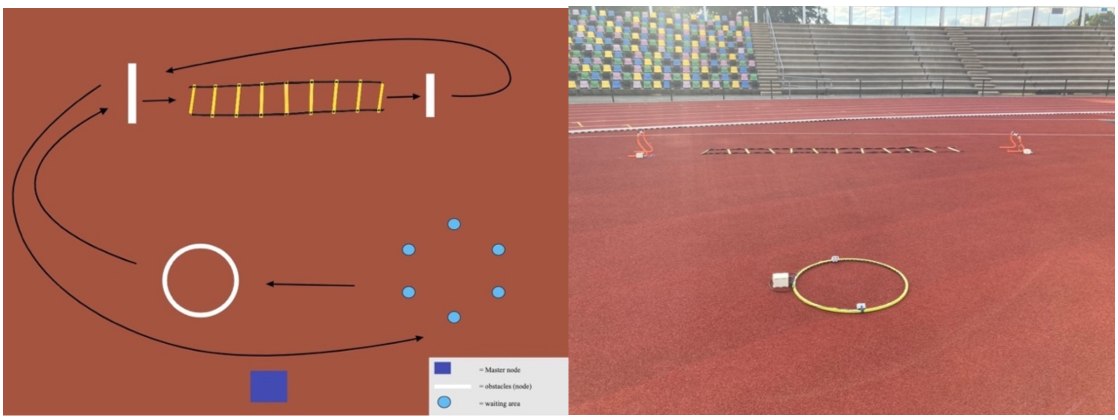
7.1 User test

Based on the design space created in chapter five, three games have been realized for the prototype. This was done in order to test instruction, engagement, and personalization. Similarly, three user tests have been developed in order to test the same things. For evaluating the prototype, two different methods have been used. An A/B testing method has been used to test instruction and engagement and a cognitive walkthrough has been used to test the personalization mode.

7.1.1 Evaluate instruction

To evaluate if the system provides improved instruction for the children, game 1 (show & repeat) has been tested with an A/B test. This means that an exercise will first be executed without the prototype, and afterwards with the prototype. It would be ideal to do a counterbalanced A/B test, meaning that the group will be split into two and they both do one type of test first. However, due to the number of participants (n=10), their abilities, and the structure of the training, this was not possible. The testing is done with a within-subject design, where the same people test both conditions. Two advantages of this are that it requires fewer participants and eliminates individual differences, which is particularly helpful in this group with all different intellectual disabilities. These are the reasons a within-subject approach suits better for this group. A disadvantage of this is that the participants potentially will gain knowledge over time, called carryover effects and progressive errors.

In figure 7.1, the setup of the testing can be seen. In the show & repeat game, the trainer will first show a sequence of obstacles, whereafter the children have to repeat what the trainer does as fast as possible. The exercise is executed in a relay, so all the children start in the circle (light blue) from where they start the obstacle run and come back once completed (whereafter a new person will start).



(a) (b)

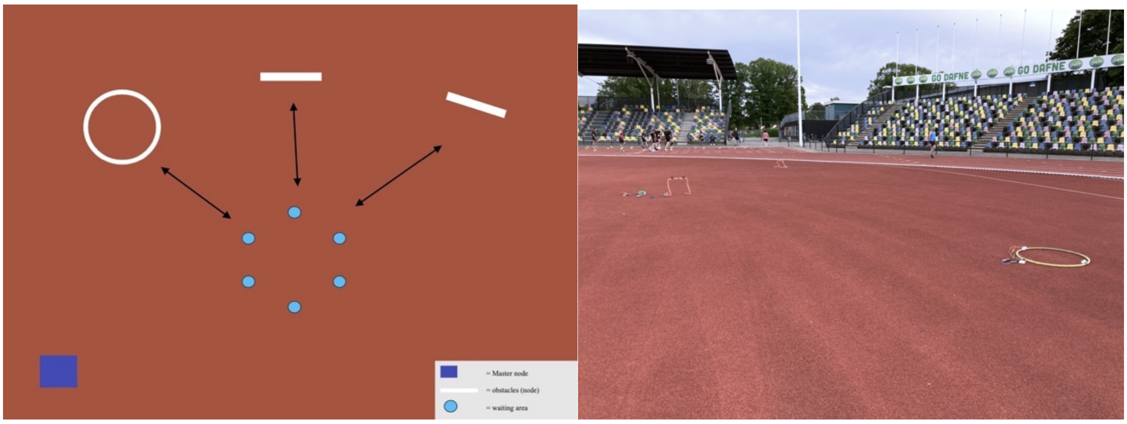
Figure 7.1: (a) schematic and (b) executed test setup of game mode 1 – show & repeat

In test A, the exercise is done without visual guidance of the system, whereas in test B, the system will remember the order of obstacles, and show this ‘just-in-time’, to the participants. The tested order can be seen in figure 7.1a, where the participants first jump in the hula hoop, over the big hurdle, through the speed ladder, over the small hula hoop, and back to the big hurdle. In test A, they have to remember the exercise after the trainer has shown it once, whereas in test B they are guided by the lights. An added advantage of this is that the trainer does not have to pay full attention to this exercise, in case he is explaining another exercise at the same time.

There are a few things that are used for evaluation, which are a recording of the explanation of the exercise, interviews with the participants as well as with the trainer, and observations. The observations and audio recordings are used to gain some measurable variables of the test, such as: how long was the explanation, how many words were used, how many understood it at once, etc. This will be further described in the next section. After the exercises, the children are asked for their opinion.

7.1.2 Evaluate engagement

To evaluate if the system provides improved engagement for the children, game 2 (putting all the lights on the same color) is tested. This is tested in a similar way as mentioned above, which is a within-subject A/B test. The goal of this exercise is collaboration and thereby engagement in the exercise. The children have to work together to complete the exercise, by all jumping once over each obstacle. When they all have jumped over every obstacle, the game is finished. The setup can be seen in figure 7.2. The children start in the blue circle, from where they can run towards an obstacle and back to the circle, whereafter the next athlete can go for a run.



(a) (b)

Figure 7.2: (a) schematic and (b) executed test setup of game mode 2 – collaboration colours

In test A, the athletes and the trainer have to count if everyone has jumped over all obstacles. In test B, the obstacles will light up in red at the beginning, and if everyone has jumped over them (n=10) the obstacles will turn green. This way it provides engaging instructions on where to go next. Evaluation is done via the same methods as described in 7.1.1.

7.1.3 Evaluate personalization

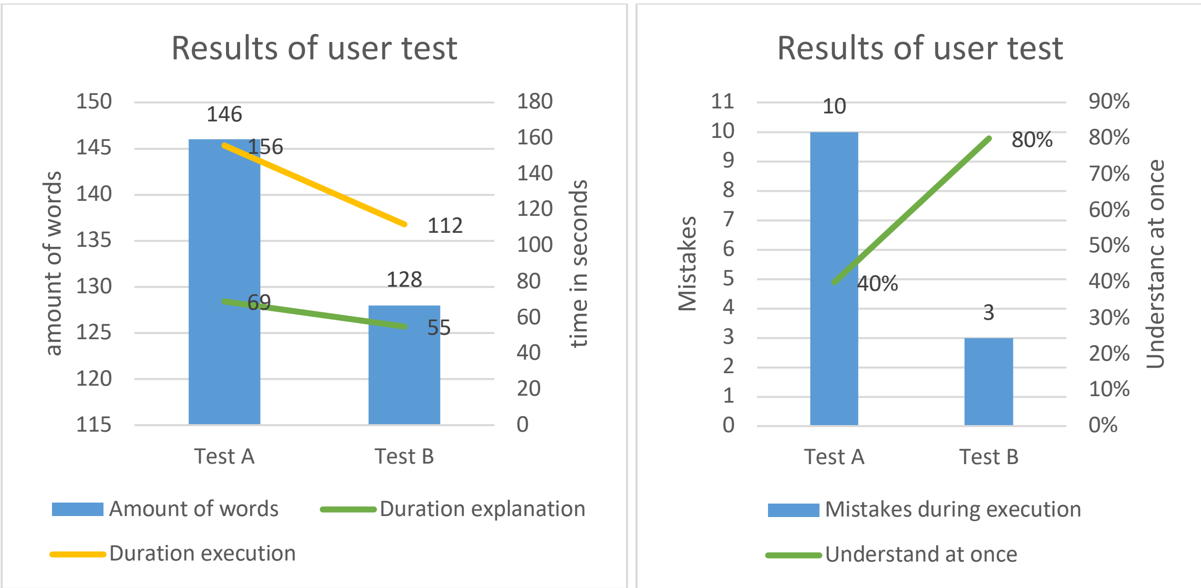
To evaluate if the personalization of exercises is a valuable feature and partly a possible solution to the differences in abilities, game 3 has been tested. This is done via a cognitive walkthrough instead of an A/B test, since this mode is still in an early stage of development. A cognitive walkthrough is an expert review (in this case the trainer), who walks through a series of talks. The trainer has a good understanding of the users, their tasks, exercises, and difficulties, which makes him a suitable person for this test.

The system works as follows: a child will scan their bracelet, which will turn on a specific parkour. This parkour is shorter/longer and has easier/more difficult obstacles, depending on the abilities of the athlete. The goal is that the athlete will finish the parkour in time, so his/her level will go up and the parkour will become more difficult. Timing is shown on the obstacles by blue light that is flickering faster and faster, eventually ending in black if the athlete was not fast enough.

7.2 Results

7.2.1 Metrics

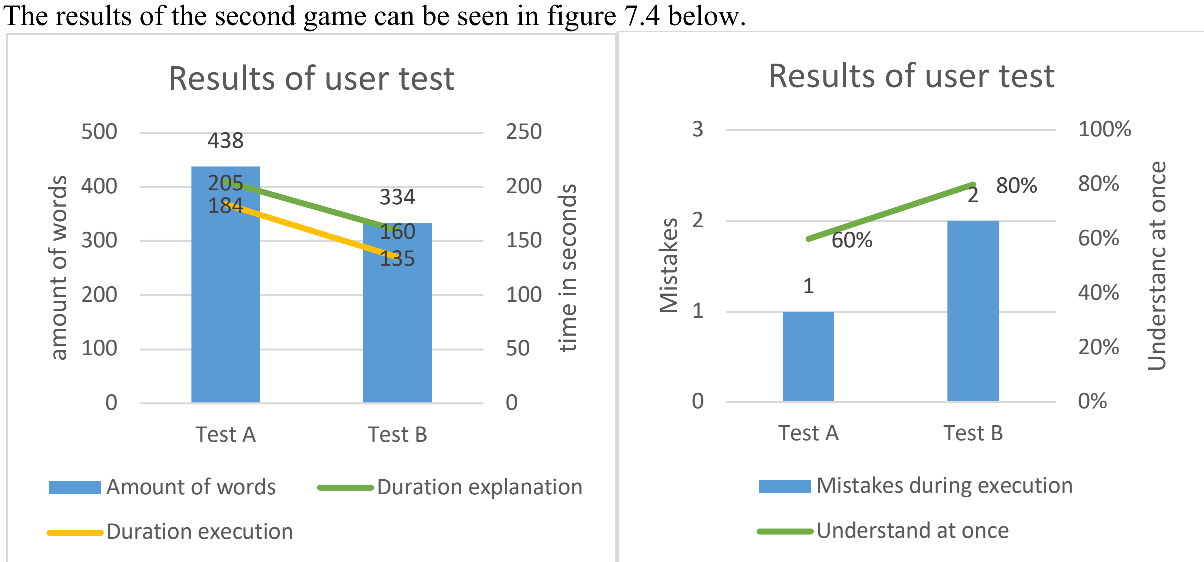
Whereas the first A/B test aims to mainly evaluate instruction and the second a/B test to mainly evaluate engagement, every test can evaluate both aspects of the system. The results of the first game can be seen in figure 7.3 below.



(a) *(b)*

Figure 7.3: (a+b) Results of the A/B user test of game mode 1 (show & repeat)

The results of the second game can be seen in figure 7.4 below.



(a) *(b)*

Figure 7.4: (a+b) Results of the A/B user test of game mode 2 (collaboration colours)

As can be seen in the big bars in figures 7.3a and 7.4a above, the number of words to explain an exercise has greatly decreased from test A to B. Additionally, the time to explain an exercise has decreased in a similar way from test A to B, showing that it took less time to explain the exercise with help of the prototype. These two numbers indicate that there was less verbal explanation and more visual explanation.

Moreover, these two figures also show the time it took to complete the exercise, which went down in both cases. This means the children ran faster and made fewer mistakes to complete the exercise since they did the exact same exercise in less time. Running faster could mean that they are more internally motivated to complete the exercise.

In figures 7.3b and 7.4b, the mistakes made during the test can be seen. It is visible here that the number of mistakes has gone down in the first game, but in the second game it nearly stayed the same. However, when looking at the people understanding it at once (based on their verbal and facial expressions) went up in both cases.

7.2.2 Observations

In test A, it was directly clear that the children had trouble focussing. The trainer had to try different ways of getting them to listen, constantly warning them while they kept running around. Things that were noticeable during the exercise were the enormous differences in abilities (speed and strength to jump), and differences in internal motivation and exercise explanation. Even though not all children understood the exercise at first, watching their peers made it clear for most. This shows visual explanation works better than verbal explanation. Unfortunately, the children also copy the wrong movements, which is in that turn a negative aspect of copying behavior. Mistakes that were often made are jumping twice over the same obstacle, forgetting an obstacle, or going in the wrong direction.

In test B, more children understood the exercise at once, and they even tried to explain it to their peers. The children ran faster, with a purpose, and seemed to have more fun while doing it. However, they were distracted by all the wires and buttons, and some even started slapping the big button. The system did not always work, which would distract them or lead them in the wrong direction (which however does show that they indeed follow the lights).

Overall, they had the most trouble in the exercises at the beginning and at the end, which could be due to a lack of understanding and fatigue. Additionally, they had trouble when the exercise would change (in direction or color), when new incentives arose or when an obstacle has multiple uses (jump in/over hula hoop).

7.2.3 Interviews

In **appendix G,** the questions of the interview can be found.

7.2.3.1: Athletes

There is a big difference in the group in the experience of this exercise. Some athletes indicated that the first test was difficult, and the second one slightly easier, while other athletes found both exercises easy/difficult. However, most did like the second exercise way more, due to the 'disco lights'. They also argued that it was sometimes difficult to know what to do if the system did not work, that it was not always clearly visible, and that they would have liked to move slightly more.

7.2.3.1: Trainer

The trainer is very enthusiastic about the prototype and believes it has a lot of potential for the future if the number of obstacles could be bigger and the distance longer. Additionally, he would like a way to easily add more games to the system. He feels like this would work even better in winter when the lights would be more spectacular. The simplicity of this system is a key success factor, where the children do not need difficult artifacts to use the system.

With a user group like this, every exercise needs to be explained multiple times before they completely understand it, and this will be no different for this prototype. He claims that once they understand the basic concept of jumping over the light and searching for the next, the system can be expanded. Exercises have to be explained slowly, step by step, and this system does that very well.

7.2.4 Cognitive walkthrough

In the cognitive walkthrough, the trainer and athletes are introduced to the system and asked for their opinion. According to the trainer, the idea of having levels and different games based on the children's abilities is great. The lights that slowly start to flicker faster will encourage them to jump faster.

However, the bracelet that is around the arms of the children will only distract them and stop them from focussing on the exercise. It has become clear here that any object attached to their bodies invites them to try it out, which is not the goal of the feature. Nevertheless, the personalization feature of the system is very much appreciated, since the abilities of children differ very much within the team. To still achieve this, basic buttons could be added, where the children can simply press their level for the difficulty according their ability.

7.3 Conclusion

In this chapter, it has become clear what different tests and types of tests were done in order to evaluate the prototype. Results are summarized and interpreted, which has shown that with the prototype; it takes less time and words to explain an exercise (less verbal explanation), children complete the exercise faster while making fewer mistakes, and more children understand the exercise at once. Completing the exercise faster can be connected to running faster, which can be linked to internal motivation.

The interviews have shown that the children have an overall better experience, as they have said to like the prototype more. In observations, it was visible that the children ran faster, had more fun, and had fewer difficulties with executing the exercise. According to the interview with the trainer, this prototype has a lot of potential in contributing to the training if it can be expanded in the number of obstacles and its distance. Finally, the cognitive walkthrough has made clear that bracelets for personalized parkours are not optimal, but personalization without something attached to the body would be very much appreciated.

Overall, the prototype has achieved its goal, which was providing a better understanding and motivation to the special athletes in athletics. The claim of improving information comprehension is based on the metrics above (less verbal explanation, fewer mistakes), and the claim of improving engagement is based on metrics, interviews, and observations (faster completion time, visible fun, acknowledgment of liking).

With this, the final sub-research question can also be answered, which was:

> SQ5: How do children with intellectual disabilities respond to instruction/feedback systems that use alternative media?

It has been shown in the data presented above that the children respond better to instruction systems that use alternative media when looking at understanding and engagement. While the number of mistakes has gone down (or similar in game 2), it shows that the children still make mistakes. This shows that difficulties cannot be eliminated (difficulties with verbal explanation as well as visual explanation), but the advantage of this system is that the information is fed to the children in pieces. Not all instructions are given at the same time, but the obstacles will light up one by one, which is the biggest benefit of the system.

Finally, there are some specified requirements from the previous chapter that could not be evaluated yet, which are shown in table 7.1 below.

Table 7.1: Assessment of the (non-)functional requirements

(N)RF No	Function Requirement Description		Conclusion and remarks
FR2	LEDs should be sufficiently visible (using green/red)	+-	*Lights were said to be partially visible.*
NFR1	The system has to improve user experience: the children understand the exercise better (instruction)	+	*The children showed less mistakes and understood the exercise better at first.*
NFR2	The system has to improve user experience: the children are more motivated to do the exercise (engagement)	+	*The children ran faster and completed the exercise faster, encouraging each other.*
NFR3	The system should provide modes where children do not experience long waiting times	+-	*In the testing mode, only 3 obstacles were realized yet, which still led to long waiting times.*

In table 7.1, it can be seen that the requirements of improving instruction and engagement have been reached, but realizing a complete visible and clear system still needs improvement. Additionally, due to the number of obstacles and short distance range, children still experienced waiting times, which has to be tackled in upcoming versions.

In the next section, the initial research questions and all the sub-questions will be touched upon in order to reach a general conclusion.

Chapter 8: Conclusion

This thesis aimed to tackle the problem of verbal instruction of exercises in athletics for athletes with intellectual disabilities, which had been found to be a gap in research. Special athletes have difficulties with understanding exercises that are verbally explained, due to language comprehension, memory deficit, short attention span, impulsive behavior, and hearing deficit. This results in difficulties in understanding exercises, accompanied by a decline in motivation. A research question has been constructed, which is as follows:

> *RQ - How to support the trainer in instruction and demonstration of physical exercises through alternative media for children with intellectual disabilities?*

Five sub-research questions have been constructed to answer this research question, which are answered throughout the chapters. Chapter two starts with narrowing the design space by looking at a specific discipline within athletics that would benefit from alternative ways of explanation. It answers the first sub-research question:

> SQ1: What discipline in athletics would benefit from support in instruction?

Based on a narrow collaboration with the MPM special athletics team in Hengelo, where interviews and observations were conducted, it became clear that (unguided) obstacle- and circuit practices would benefit the most from alternative instruction. These types of exercises are usually set out as a side exercise to avoid long waiting times (e.g., jumping over obstacles), while the trainer can give one-on-one instruction during the main exercise (e.g., long jump). The trainer cannot divide his attention between both exercises, which will result in the athletes failing to recall the exercise or losing motivation and quitting the exercise. Once this discipline of athletics had been chosen, the second research question could be answered:

> *SQ2:* What are the opportunities and challenges of the discipline of athletics defined in research requestion 1?

It is important to look at opportunities and challenges within obstacle courses to be able to use and process this in the prototype. Research has shown that the obstacle course should be a mixture of random and variable training, be in line with the main exercise, and avoid long waiting times. The exercises should be designed in a way that they cover a variety of muscles, and at the same time attack the appropriate mental challenges, such as perseverance and resourcefulness. Finally, manners of pedagogy and state of learning should be implemented in the design. To complete the state of the art, the third research question is answered, which was:

> SQ3: What are related systems for instruction/demonstration in sports interaction technology for (special) athletes, using alternative media?

By looking at related systems, it has become clear that there are a lot of systems that use alternative media, but they are mostly designed for the regular athlete. These systems do not take the specific needs of the special athletes into account therefore making them not suitable for these athletes. However, inspiration is taken out of these systems, such as the types of instruction (visual, audio, or haptic) and electronics used for these instructions (Microsoft Kinect, beamer projections, vibrations). There are a limited number of examples of systems that are specifically made for children with intellectual disabilities, but all with a different focus than this project. The existing installations focus mainly on the interaction between the children, improving sensorimotor movements and making the children more autonomous, whereas this thesis focuses on improving the medium of instruction and thereby engagement in athletics.

The research is carried out via the creative technology design process, which consists of ideation (chapter four), specification (chapter five), realization (chapter six), and evaluation (chapter seven). To start the ideation phase, a design statement was made that guided the process:

> ***"****Designing* ***interactive technology*** *that provides* ***engaging instructions*** *to* ***support the trainer*** *in the* ***explanation of obstacle course****/circuit training for* ***children with an intellectual disability****"*

As can be read in chapter four, the design statement, stakeholder identification, and value specification were used as the basis for creative thinking methods, which led to the idea of an add-on instruction system for athletics equipment that will guide athletes with intellectual disabilities through exercises. The focus has now shifted to analyzing what would be a good add-on for providing visual instruction for children with intellectual disabilities. With this, the fourth sub-research is answered:

> SQ4: How can the already available athletics equipment be used/changed to support the demonstration/instruction of exercises?

To further answer this question in detail, an analysis of already existing equipment and common practices, an analysis of the users, and low fidelity user testing were done to further specify the prototype. It became clear that hurdles and hula hoops were going to be used for the prototype, due to weight, purpose, and safety. These two are accompanied by a list of other athletic equipment that can also be used for the system, which can be found in chapter five. By making the prototype an add-on device, no new equipment is needed, which makes it easily applicable and usable for athletics associations. It is very simple and easy to use, and at the same time broadly expandable in the number of obstacles as well as the number of games/programs.

Out of the analyses, functional and non-functional requirements have been specified. These requirements were ranked on their importance and translated into hardware components of the system. Additionally, the requirements that led to software and interaction design choices, were specified in the realization. Most functional requirements are met, except for making the system waterproof and fall-proof. To examine the remaining non-functional requirements, user testing has been done. With user-testing, the final sub-research question can also be answered:

> SQ5: How do children with intellectual disabilities respond to instruction/feedback systems that use alternative media?

To answer this final sub-research question, three user tests have to be conducted in order to evaluate the improvement of information comprehension, engagement, and personalized exercises. Interviews and observations are conducted and meaningful variables are measured, such as explaining time, executing time, the number of words used, and the number of mistakes made. This has shown that with the use of the prototype, it takes less time and words to explain an exercise (less verbal explanation), children complete the exercise faster while making fewer mistakes, and more children understand the exercise at once. The faster completion time of the exact same exercise indicates improved internal motivation.

In observing the children interacting with the prototype, it is visible that the children run faster (more motivated), have more fun, and have fewer difficulties with executing the exercises. The children also categorize the prototype as more fun, and the trainer expresses his interest and emphasizes the potential in the prototype when the number of obstacles and distance range can be improved.

When looking back at the initial research question, *how to support the trainer in instruction and demonstration of physical exercises through alternative media for children with intellectual disabilities,* this thesis has developed a possible solution. Implementing an add-on prototype that provides visual cues for athletes with intellectual disabilities, has been shown to improve information comprehension as well as engagement. These claims are made based on the results described above, where improvement of information comprehension is shown by less verbal explanation (shorter explanation, fewer words) accompanied by fewer mistakes, and improvement of engagement by showing a faster completion time accompanied by bigger internal motivation.

This graduation work has a few contributions to the field. First of all, it has discovered a gap in research, namely providing difficulties in instruction for children with intellectual disabilities. While certain installations do use alternative media, only rare examples are specifically made for athletes with an intellectual disability, and none of them have improving instruction and engagement as the main purpose. Additionally, this graduation work has provided a tangible solution, accompanied by an analysis of what would be a good add-on system and an analysis of the 'just-in-time' instruction/feedback system.

It is necessary to pay attention to this problem since participating in a sport for children with intellectual disabilities is of utmost importance. Many health benefits are related to participation in sports, such as improvement in social interaction with peers, self-efficacy, and motor skills. Additionally, it boosts performance, promotes learning, and gives the athletes a platform of voice. This thesis has a larger implication for society, where it can close the gap between regular athletes and special athletes and makes more athletes with intellectual disabilities participate in sports. While the prototype is developed for special athletes, it could in essence be used for all athletes to motivate and inform them.

Even though the prototype has shown good results, a lot of improvements can be made. In the next chapter, limitations to the research, future improvements, and ethical considerations are discussed.

Chapter 9: Discussion

In this chapter, limitations, ethical considerations, and further research are discussed. There are limitations to the prototype, the type of testing discussed in earlier chapters, the results, and the specified system requirements. This user group requires extra care and guidance, therefore some ethical considerations are taken into account. Future research directions are opposed, based upon earlier limitations and time restrictions.

After reading this section, it is clear what implications the test has and how this influenced the result, what limitations the prototype has, and which system requirements are not developed yet. Additionally, it is clear what ethical considerations need to be taken into account and finally, future work directions are given.

9.1 Limitation and discussion

The limitations are divided into four categories: limitations to the test, limitations to the result, limitations to the prototype, and limitations to the system requirements.

First of all, the a/b test that is now conducted is far from ideal. The number of participants is very small since MPM Hengelo only has 1 team of 10 children to work with. Additionally, no counterbalanced test is conducted, meaning that the group would have been split in half, where one part would do the tests in the order a-b, and the other half in the order b-a. This was not possible due to the number of participants and trainers, as well as the attention span of the children. If the children would see that half of the group does something else, they would get distracted. With this way of testing, they might have remembered and learned from the first test and taken this with them to the second test.

The first test (testing game mode 1) is conducted with a sequence of 4 obstacles in a row. It would have been better to try it with a sequence of 3, 6, and 9 obstacles, to measure from which sequence length they would get in trouble. However, this was not possible due to the attention span of the children. Nevertheless, it was found that a substantial number of mistakes were made in the sequence of 4 obstacles, making the results still valuable.

The test was not representative of a typical situation in athletics, due to the number of obstacles that are created. Due to time and money restrictions, only three add-on units have been developed (small hurdle, big hurdle, hula hoop), which is not enough to create a fully similar situation as they are familiar with. Additionally, the hurdles did not have a range of 100 meters (which was written down in the specifications of the hardware), which led to the obstacles being close to each other. Again, this is not representative of the real situation.

Looking at the results of the test, one can argue that the number of mistakes made in the second a/b test is similar to or even higher in the test with the prototype (it went from 1 to 2). Even though there is no clear decline in mistakes, it has to be noted that the children need slightly more time to get used to a new system/way of working. According to the trainer, the children need four to five times to interact with something new before they are familiar with it. Additionally, in the first test the number of mistakes did go down from 10 to 3. The testing of game 2 (test 2), has been conducted before testing game 1 (test 1), which can also explain part of these results. Another discussion point is the interviews with the children. Even though they say the level of difficulty was similar in both tests (with and without the prototype), the measurable results show differently.

Another limitation to the test and results is the functionality of the prototype. Since this is the first version of the prototype, not all signals and sensors worked as well as they were designed. Obstacles did not always send the right signals over the network, which would lead to the wrong obstacles going on/off. This can be due to power source differences, outside noise, distance limitations, or network library mistakes. Additionally, the prototype sometimes experienced some delays, which would result in not sensing a jump if someone jumped over/in the obstacle too fast. Finally, the modules interfere with each other (mostly inside due to signals bouncing on the ceiling), which makes it hard to test inside or close to each other outside. These limitations led to system mistakes also during the testing, which might have influenced the experience of the children.

Finally, not all (non)-functional system requirements have been met, as has been described in earlier chapters. For example, a gyroscope has not been implemented in the prototype. This would measure if the obstacle is still standing and would stop the program if the obstacle has fallen. However, due to time restrictions, only the most important requirements of the system have been realized. A minimum viable product has been developed only including the essential features. This minimal viable product was used for testing. However, it would improve the usability of the prototype very much, and therefore these requirements will be further discussed in section 9.3, future research.

9.2 Ethical considerations

There are a few ethical considerations that come with this project. To start off, it is important to make sure to not discriminate on the type of disability. In the athletics children team are a lot of different kids with different disabilities, take for example ADHD, Autism Spectrum Disorder, or Down Syndrome. They might all experience problems different, and one solution/design might work perfectly for a child with ADHD but works counterproductive for a child with Down Syndrome. This thesis has tried dealing with this disparity by looking at the most common ones within the MPM Hengelo team. By designing for the most common types of intellectual disabilities most people are covered, but there is still a need to be aware of interpersonal differences that might be present. Additionally, this means it is more difficult to expand the thesis to bigger groups of special athletes. It is hard to perfectly take every type of intellectual disability into account, but it is important to be aware of this when researching and designing.

Another ethical consideration is designing something actually for the children's needs. It is important to avoid making something visually/audibly nice for the designer/regular athlete, but overwhelming for the children. Research has to be done in order to understand how the children perceive the signals/instructions, to not get on their senses but to actually reach the goal of engaging instructions. This consideration can be extended to the approach to children, where it is important to be careful not to overstimulate the children by asking questions or observing them. The well-being of children is more important than getting input for the design.

9.3 Future work

Future research can be divided in improving the type of test and testing, improving the hardware of the prototype and improving the software of the prototype.

9.3.1 Testing

As discussed above, there are limitations to the type of test and test results. To improve this, a counterbalanced a/b test should be held with a significant number of children, preferably from different sport associations and different types of intellectual disabilities. To make the testing more representable to a real situation, more modules and a bigger distance range need to be made and added.

9.3.2 Hardware

To improve the distance range, the nRF24 can be swapped with the nRF24 PCB antenna**.** This works via a similar network as the previous one, but the module is slightly more expensive and therefore initially not used for this thesis. Additionally, a gyroscope can be added to avoid the system from crashing when an obstacle falls down. Otherwise, the system would keep sensing and would detect children walking past it. The system should be made completely waterproof, as well as improving the battery life. One option for this would be to use power sources (e.g., power bank) with solar panels on top of it (creating a power source), usefull since the prototype is mainly used outside. Furthermore, the position of the distance sensors has to changed, since they are now on top of the obstacle, which makes the obstacle higher. A possible solution can be found in figure 9.1 below.

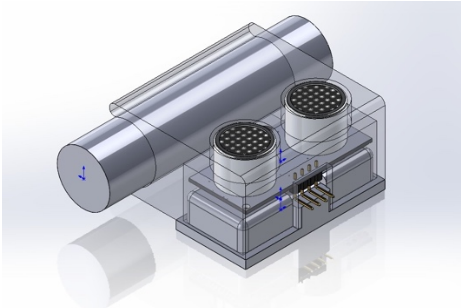


Figure 9.1: Alternative mounting of the sensor onto the obstacles

Continuing on the distance sensor, some obstacles would benefit from more distance sensors than just two. Two distance sensors have been chosen to cover the space above the hurdle, as well as connect it tightly to the equipment. However, in an obstacle such as a hula hoop, space covering is not possible with just two distance sensors. Ideally, you want at least three distance sensors to cover almost all space in a circle. This is illustrated in figure 9.2 below. Nevertheless, it has to be noted that the children usually do not jump at the sides of the hula hoop, so for testing purposes, this did not have a large influence.

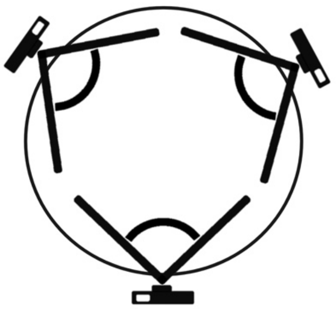


Figure 9.2: improved distance angle on the hula hoop with three distance sensors

Finally, the LED strip on the hurdle is now placed in the direction of the sky, whereas this is probably not the best visible position. This position has been chosen for visibility from both sides of the object, but a better solution would be adding two LED strips at an angle. Additionally, the sun reduces the visibility of the LED strips, which would also be less if the strips are at an angle. More features could be added to improve the experience of the children, such as sound and visual timers. As has been discussed in the evaluation, bracelets for personalized parkours did not work, but pressing big buttons to indicate the difficulty of the exercise would be a better alternative.

9.3.3 Software

At the moment, only three games have been implemented in the system. Even though it is very easy to implement new games for a programmer, this can be difficult for a trainer or for the children. In future research, the design for a user interface or application is required to allow the implementation of additional games by the trainers or athletes. This way more games can be implemented, possibly via some kind of visualization for the trainer and athletes to make their own games and training. Additionally, games could be saved, changed, and shared via a community, where trainers from all over the country can share their training routines. This is particularly helpful since the trainer mentioned that there is not much guidance available on the internet, so trainers from different special athletics teams have to visit each other to gain inspiration. This tool was also mentioned in figure 4.6, but due to time restrictions not realized.

Another thing that should be changed in the software is the code for game mode 3. At the moment, the different levels are always the same, where higher hurdles will be added when the level becomes higher. However, it would be better (not hardcoded) if this is done via an automatic algorithm, that considers the different difficulties of the obstacles. For this purpose, an obstacle should have a certain difficulty level. All obstacles are still the same, but a few variables should be added when an obstacle is configured, such as LED length, address of the obstacle, and now also difficulty level (a number between 0 and 1). Additionally, it should be easier to add children to the system, as now only three NFC chips ('children') are included in the system.

In chapter 2.3.3, opportunities and challenges of the discipline are given. However, due to time restrictions and more important features, these opportunities have not been implemented in the system yet. Take for example stages of learning and manners of pedagogy. It has been shown that children learn the best when their state of learning is analyzed and incorporated into the exercises, as previously described. Features like this can be added to the software for future improvement since it enhances the learning abilities of the children (and therefore engagement).

To finish the software improvement with some details, the distance sensor could be improved with a temperature sensor. The distance sensor measures a distance by sending waves into the air. The speed of these waves depends on air temperature, which makes the measurements unprecise when this is not taken into account. A way of measuring this would be: *velocity = 331.4 + 0.6 * temperature + 0,0124 * relative humidity.* This is slightly beyond the scope of the project but would measure the distance more accurately and therefore improve the prototype and experience of the athletes.

All in all, the prototype has a lot of future research directions and improvements available. Nevertheless, it has already been proven to improve understanding and engagement among special athletes at MPM Hengelo. The system is cheap, can be put on existing materials, and is similar to every obstacle. Even though it is a simple device, it can be expanded to an enormous possibility of modes onto the system. Hopefully, it can help a lot of special athletes in the future.

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Appendices

A. Interview Transcript Trainer

Introduction: see formed consent + information brochure

Information about Aiko:
- For how long have you been a trainer of special athletes?
- What is your experience/background in this area?

Situation:
- What athletic elements do you include in your trainings?
- For what reason do you think athletes come to train?
- How do the athletes interact with each other?
- What problems do you recognize <u>athletes</u> have during the training of athletics?
- What is a problem <u>you</u> experience in training these athletes?

Specific question (per found domain):
How would you rate this problem (from 1 to 10 (1 = not noticeable, 10 = noticeable)
- Motivation for sports is low
- Normal instruction (mainly verbal) is hard to understand
- Lack of information / not enough of assessable information (thinking it will be too hard)
- Hard to show emotion / express / communicate themselves
- Impulsive behavior
- Short attention span
- Difficult to have a training tailored to specific needs of different players?
- Trainings are not structured enough

Connection:
- Do you feel like any of the above-mentioned problems correlate with each other? For example, hard to express themselves leading to a short attention span?

Improvement
- Do you use any kind of special technology/objects now?
- What (technology) do you think is missing and could really benefit the athletes?
- What (technology) is there other athletes could use, but have to be tailored for these special athletes?

Ending:
- Are there any other things you would like to add?

B. Interview Transcript Legal Guardian

Note: the interview was conducted in Dutch, and translated later for the purpose of this thesis

Introduction: see formed consent + information brochure

Information about child:
- Who is your child and why does your child play in this team?
- For what reason do you think your child comes to train/ what motivates them?
- How does your child interact with other children?

Situation (during and outside training)
- What problems do you recognize your child has during the training of athletics?
    - Does your child express any difficulties?
- What difficulties do they have outside playing sports?

Specific question (per found domain):
Do you feel like your child is having any of these problems: (from 1 to 10 (1 = has this a lot, 10 = not noticeable)
- Motivation for sports is low
- Normal instruction (mainly verbal) is hard to understand
- Lack of information / not enough of assessable information (thinking it will be too hard)
- The feeling of being unheard during training / hard to communicate themselves
- Hard to show emotion / express themselves
- Impulsive behavior
- Short attention span
- Trainings are not structured enough

Connection:
- Do you feel like any of the above-mentioned problems correlate with each other? For example, hard to express themselves leading to a short attention span?

Improvement:
- Does your child use any assistive technology already?
- What (technology) do you think is missing and could really benefit your child?

Ending:
- Are there any other things you would like to add?

C. Expert interview state of the art

The following questions were conducted during the interview:
1. Which aspects do you train on in the athletics trainings?
2. What aspects are harder to teach?
3. Is there a specific aspect you think the children will lose attention quickly?
4. Is there a specific aspect you think the children will not understand the exercise easily?
5. Is there a specific aspect where you think the children have more trouble with executing the exercise correctly due to instruction?

D. 100 ideas method

Ideas

1.A toolkit that you can construct before a training
2.All obstacles have lights, go off/on when you go over it
3.Sounds that goes on/off when you jump over it
4.Led strips that guide the way
5.Speed games
6.Buttons they have to press when over something to go to the next, new light will go on
7.Have to throw a ball trough a certain thing, then next will open
8.Holes that open where you have to go next
9.A screen on the side that shows the parkour
10.A game that randomly selects a parkour
11.Randomly creating a parkour based on input (how good someone is)
12.Personalized circuit training
13.Discus throwing over a certain line
14.Measuring how far a ball is thrown
15.Pressure sensors that measure where someone is
16.Spear throwing that measures how straight the throw was
17.Lines in the air they have to hit
18.Balloons in the air they have to hit
19.Obstacles that go higher/lower depending on who is coming
20.Tag of a child (RFID), scan it to the parkour and a different light combination will come up
21.Indivually differing parcours
22.Game based where they have to
23.Run behind the light
24.Video taping the movement of thworing and correcting it via vibrations
25.Video taping the movement of throwing and correcting it via sound
26.Showing the line of the throw visually on the ground, when a camera gets the angle of the arm of the children
27.Showing the line of the spear and where it would land, based on video that measuers how the children are standing
28.Showing on the ground what the diff
29.At each station AR shows what to do
30.Personalized AR at every station
31.Game with multiple elements, circuit form that adds up the scores, in the end you have a winner
32.Pads on the ground that sense pressure and light up where you have to place hands and feet for a pushup
33.A robot that shows the way
34.Little car that drives the way you need to go
35.Car drives a little, stops to see if you are following
36.Game where they have to compete against other stations as a little team
37.Tablet that shows exercises
38.VR that shows exercises
39.Pylons ou can touch and they will tell the exercise
40.Pylons that you can scan and they will show you the exercise
41.Pillons you can scan and material you need will light up
42.Arrows on the ground which can turn directions via motors
43.Random exercise generator depending on a ball
44.Scan a ball and the a parkour will be generator
45.An interface with multiple variables (child, age, skill) that makes a parkour for you
46.Party music when completing a good exercise
47.Time will be measured and a leaderboard will be shown
48.Leaderboard is shown base don colors the atheltes are wearing
49.Athletes have a wristband which show them colors → used for team making, leaderboard showing
50.Projector showing a person in the air/ on a wall doing it
51.Check into a station with your tag, to measure who is where
52.Check into the parkour with your tag
53.Every new time you start doing the parkour, it will be faster / different
54.Press a button, do the thing, press buton again = timer
55.Working together to achieve a station
56.A countdown / lights that cue when you have to throw/do something
57.Vibrations that start vibrating more heavily when it is time to do something

E. Inventory

1. Product	Amount	Length	weight	Material
2. Small pylon	48	Lower square = 16cm, middle cone diameter = 10cm, top cone diameter= 4/4.5cm	Light	Plastic hard
3. Big pylon	6	Lower square = 24 cm, middle cone diameter = 16cm, top cone diameter = 5cm	Light	Plastic hard
4. Cones	450	Bottom diameter 18 /18.5 cm, top diameter = 5.5 cm	Super light	Plastic hard
5. Shot put + rope	13	Rope = 96cm, ball = 11 cm	Super light	Plastic hard + rope
6. Shot put soccer ball + rope	8	-	light	Fabric + air + rope
7. Shot put metal ball + rope	15	-	3kg	Metal + steel
8. Yellow very small hurdles	15	Height: 17cm, width:47cm	Super light	Plastic hard
9. Orange small hurdles	19	Height: 30 cm , width: 48cm	Super light	Plastic hard
10. Orange big hurdles	19	Height: 40cm, width: 48cm	Super light	Plastic hard
11. White small hurdles	5	Height 30cm: Width: 65cm	Light	wood
12. White big hurdles	5	Height: 40cm, Width: 65cm	Light	wood
13. Red small hurdles	4	Height: , width: 102cm	Heavy	Steel + fabric
14. Red big hurdles	4	Height: 87cm, width: 102cm	Heavy	Steel + fabric
15. White adult hurdles small	4	Height: 60cm, width: 117cm	Heavy	Steel + wood
16. White adult hurdles big	6	Height: 70cm, width: 117cm:	Heavy	Steel + wood
17. Steel adult hurdles	20	Height: 70cm, width: 118cm	Super heavy	Steel
18. Medicine balls	20	Diameter 30cm	3kg	Plastic?
19. Ladder	4	Distance between steps = 40 cm, width = 42cm	Super light	Plastic + fabric
20. Balls 1kg soft	9	Diameter= 25cm	1kg	rubber
21. Balls 1k hard	20	-	1kg	Steel
22. Balls 2kg hard	50	-	2kg	steel
23. Hula hoop		Diameter 83cm	Super light	Hard plastic
24. Bicycle tire	12	Diameter 80cm	Super light	rubber
25. Spears (diverse sizes)	65	-	200g-800g	Wood with coating
26. Starting block	25	Length 20cm	heavy	metal
27. Discus soft	80	15cm length	Super light	rubber
28. Discus hard	16	-	Heavy	steel
29. Soft javelin	10	Length: 30cm	Light	rubber
30. Soft ring	12	Diameter 16cm	Super light	Plastic
31. Relay batons kids	13	Length 30cm	light	PVC
32. Relay batons heavy	15	10cm	heavy	metal
33. High jump poles	4	2.5 m high	heavy	metal

F. User analysis

Participant 1

- Down syndrome
  - People with DS have less motoric skills, which makes them have less power pressure
- Physically not able to jump over high exercises
- Not very big/tall
- Difficulties with coordination
- Copying of behaviour (
  - When somene stops running, he will stop as well
- Cannot run 2 rounds as warm-up, does either not have the stamina or motivatoin for it

Participant 2

- Has a problem with balance
- Problem with coordination
- Does not see well (take this into account when making exercises)
- Cannot run 2 rounds as warm-up

Participant 3

- Autism, adhd (never just 1 thing)
- Very strong
- You have to tell him your boundaries, otherwise he will keep trying you
- Strong personlaity

Participant 4

- Strong
- Brother of participant 5, attact each other a lot and playfully fight with each other

Participant 5

- Slow but physically strong
- Jumping needs more time
- Brother of participant 4, attact each other a lot and playfully fight with each other

Participant 6

- Autism, ADHD, etc
- Slow but physically strong
- need to touch the 'on-button' before he actually starts doing something
- Can get slightly (playfully) agressive / mad at training

Participant 7

- Physically strong, is able to do almost everything
- Lacks in motivation, stops then and says he is 'injured'
- More fast than strong
- Bit quiter (has to do with his home situation, dad got sick)

Participant 8

- Motoric slow, is behind
- Understand things slowly
- Hard to indicate how much power he has, at least seems like he cannot use it due to his motoric problem
- Mental and motivation struggle
- quickly distracted, looks around him what he has to do
- needs a lot of attention
- Sometimes acts slightly crazy, possibly because his senses get overstimulated

Participant 9

- ADHD, Autism, dyslexia
- competitive
- hard to concentrate on explanation of exercises
- Losing control

G. User test interviews

Interview of the athletics:

- How did you experience doing these exercises? Did you find it easy or difficult?
- Which test did you find easier to do, the first or second?
- Which test did you like doing more, the first or second?
- Was it clear what you had to do at all times?
- Could you see the lights where you had to go?

Interview with the trainer:

- Do you have the feeling the children are more motivated with the use of the system?
- Do you have the feeling that the children understand the exercises better with the help of the system?
- Does it become easier for you to explain an exercise with the help of the system?