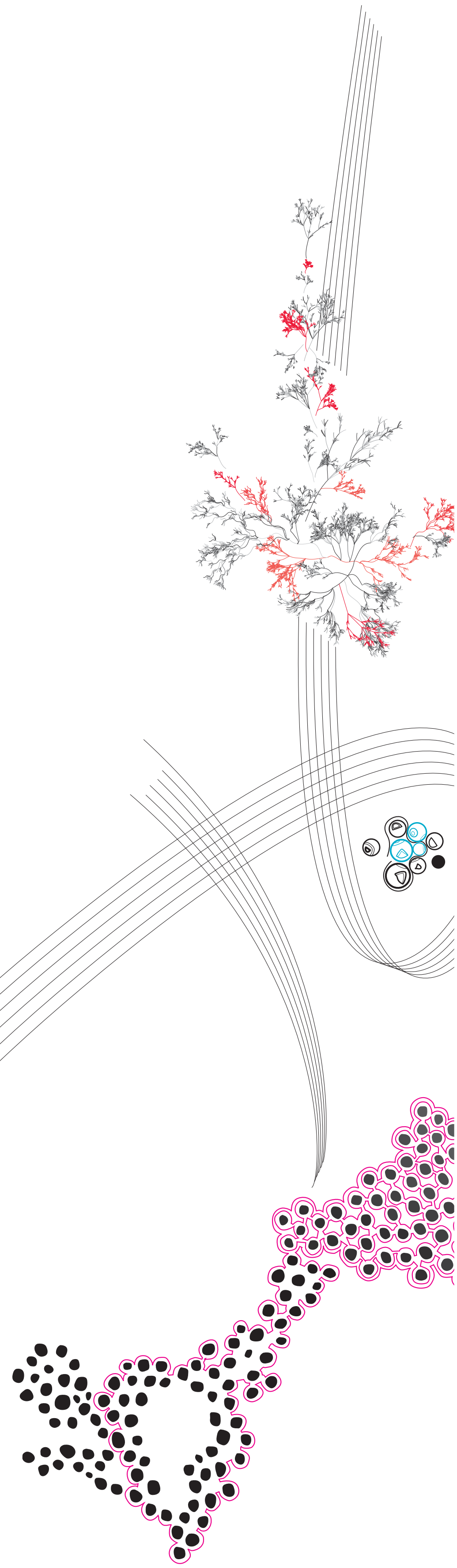

MSc Interaction Technology
Master Thesis

Designing Dynamic Digital Environmental Enrichment for Capuchin Monkeys

Puck Yasemin Kemper

Supervisors:
dr.ir. R.W. van Delden
dr. M. Gerhold
L.M. van den Berg MSc

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Department of Human Media Interaction
Faculty of Electrical Engineering,
Mathematics and Computer Science,
University of Twente

UNIVERSITY OF TWENTE.

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Abstract

Environmental enrichment can have positive effects on the well-being of zoo animals by challenging the animals, accommodating their ethological needs, or providing cognitive stimuli. Animals like capuchin monkeys are highly intelligent, which makes creating new and stimulating enrichment scenarios time-consuming and leaves little room for individuality. Making the enrichment systems digital allows the enrichment to change constantly, making it interesting for longer and offering a different challenge to each animal. The goal of this study is to investigate what the design process of such a dynamic digital environmental enrichment may look like. After reviewing different methods, frameworks, and principles we chose to adopt an animal-centred design method, where the animals are invited to co-design their environmental enrichment. Within the context of Apenheul Primate Park, we build upon previous research with the Capuchin monkeys and digital environmental enrichment. This report presents the theoretical background of environmental enrichment design, welfare, and co-design with animals. Then it covers the design process of multiple prototypes for digital environmental enrichment. To start the design process, observational data and carer experiences were gathered. Based on this information, off-the-shelf products are used as lo-fi prototypes to test the influence of presenting multiple units on the social dynamics of the group. Later, a hi-fi prototype consisting of two wooden boxes with two sensors and a food dispenser is introduced. Based on this research, there was not a conclusive result on the effective targeting of ethological needs. Further testing is needed to see if the prototype was effective in targeting those needs and thus if the process was suitable. Next to the targetted interactions, the Capuchins explored the prototype using unexpected interactions and manipulations. The evaluation of the prototype and the design process shows the importance of open-ended design to allow for expected and unexpected forms of interaction. Concluding, co-design methods can be used for an animal-centred design process for environmental enrichment. When doing this, the dignity of the animals should be safeguarded and anthropomorphisation and habituation should be minimised. Open-ended design can help with these hurdles and offers the animals a choice.

Keywords: animal computer interaction, environment enrichment, Capuchin monkeys, co-design

1. Introduction

Enclosures in zoos have changed drastically over the past decades [14, 73]. The general opinion on animal welfare, together with the attitude towards keeping animals in captivity, has influenced the way zoos operate and present themselves and their animals [17]. Policies and missions of zoos shifted from pure entertainment to conservation and education. This meant changing from concrete enclosures with iron bars in the 1960s to fully immersive and naturalistic enclosures in the 2020s [14]. The well-being of the animals and the learning experience of the visitor are now the main points of attention for zoos [17, 70].

Part of this increased attention to animal welfare also means aiming to decrease any abnormal behaviour, since these behaviours are possible indicators of bad well-being [67]. Examples of this behaviour include pacing up and down the enclosure, obsessive scratching, or hair plucking. Newer frameworks for captive animal welfare ensure that behavioural interactions and mental state get a place alongside nutrition, environment, and health [67, 90]. This leads to the growing importance of allowing animals to display 'natural' behaviour and have control over their environment. Natural behaviour generally means the behaviour which animals can display in their natural environment [9, 11]. Part of these natural behaviours are behaviours that evolved as a reaction to a changing environment and are embedded into their natural behaviour [91]. This means the animals have a strong intrinsic motivation to behave this way and not facilitating this behaviour can be detrimental to their well-being [43, 64]. These needs can be categorised as ethological needs [40].

The mission of Apenheul Primate Park, located in Apeldoorn in the Netherlands, is to give its animals the most naturalistic environment possible. All animals can be outside in an appropriately forest-like environment, and half of all residents can also roam a big part of the park freely. The goal is to allow the animals to display this 'normal' behaviour and to give visitors an insight into how the animals would behave in the wild [8].

Unfortunately, the Dutch weather does not allow all animals to stay outside year-round. Dropping temperatures force the animals to their inside enclosures and even though the park employees work hard to provide environmental enrichment, the inside enclosures can not mimic the dynamic and challenging forest. Efforts are being put into creating cognitive stimuli by giving the animals puzzles or hiding food. The animals often become uninterested in the enrichment after solving them. Frequently coming up with new challenges takes a lot of time and energy from the carers, which is a limiting factor. A fixed enrichment also offers the same challenge to all animals but different animals might need different levels of challenge. In the past decade, digital environmental enrichment has been an up-and-coming research field [39, 84]. Digitalising enrichment ensures less investment of time and energy towards this aspect of care. Furthermore, it can also create an adaptive chal-

This introduction is largely sourced from the Research Topics written for the same study, completed by Puck Kemper in December 2023 lenge and easy individualisation in difficulty per animal [82]. Increasing the reusability in this way can give carers more time for other ways to maintain the well-being of the animals.

Digital or modular enrichment can be tailored to cater to a specific target user group. Environment, species, age, gender, social dynamics, and cognitive abilities can greatly impact the method of designing such enrichment and the final design itself [7]. In literature, many digital enrichment studies have been performed on great apes [30, 50, 72, 93, 94], birds [34, 47, 48], and elephants [25, 26, 100], but relatively few consider smaller primates such as New World Monkeys [23, 36, 70]. Even though the focus is on different animals for each study, the process and principles used can be valuable for the overarching research field. Therefore, any study with any animal can add to the research field. However, researching a certain species can enhance the environmental enrichment design for that species. The contrast between the amount of research on environmental enrichment with New World monkeys and other primates highlights the need for research on New World monkeys. This study will focus on Capuchin Monkeys at Apenheul Primate Park because of the Capuchins' natural curiosity and intelligence. Their intelligence matches that of great apes, but they are not as big as some great apes [78]. Prototypes do not have to be as sturdy for Capuchins as they should be for great apes. Creating multiple prototypes for iterative design is therefore less time and resource-consuming for Capuchins while still having to challenge their intelligence.

For these Capuchins at Apenheul Primate Park, previous research focussing on designing a digital environmental enrichment device has been carried out by Snigdha Guntuka [33]. She created a hi-fi prototype with branches, light sensors, LEDs, and speakers playing typical Capuchin prey sounds like frogs or insects. This previous project serves as a suitable inspiration and basis for this current project and is of great value to the design process.

Designing environmental enrichment can be done by using different methods and picking a fitting method is vital for the well-being of the animals. The field of Animal Computer Interaction (ACI) is rooted in the Human-Computer Interaction (HCI) field, and the same user-centered design principles carry over [54, 87]. In the 2011 ACI manifesto [53], Clara Mancini argues that ACI should value animals as stakeholders just as much as their human carers. Most researches already incorporate an animal-centred approach where the animals take an active role in the design process [23, 25, 26, 34, 36, 47, 63, 93, 94, 100]. Research on enrichment uses a wide range of frameworks, methods, or loosely adapted HCI principles such as user-centred design. Other HCI methods can be used to overcome challenges in ACI. To work around the communication barrier, we can use methods used with other non-verbal users. There is room for more in-depth analysis of which frameworks and methods are favourable for creating effective, well-designed, and ethically responsible digital environmental enrichment.

Gathering the unexplored environmental enrichment opportunities for Capuchin monkeys, we formulate the following research question and sub-questions:

How to design digital environmental enrichment for Capuchin monkeys focused on their ethological needs?

What are the ethological needs of Capuchin monkeys?

How can choice and control be incorporated into the design of digital enrichment?
What does choice and control mean for this context?

What digital and non-digital enrichment methods have already been explored in previous research?

How can the design process be user-centred and involve the animals as co-designers?
How did previous research in ACI include animals in the design process?
Can we adapt methods that include non-verbal users to work for designing with animals?

To what extent does the design of the digital enrichment prototype target the ethological needs of the Capuchin monkeys and incorporate agency, choice, and control?

2. Theoretical Framework

To gain a better understanding of the research field of ACI, we explore previous research on environmental enrichment design, and design methodologies with animals in general.

2.1 Literature research

We have created some boundaries for our literature search so that the sources are relevant and useful. The search consisted of three separate strategies. The first is related to the inspiration research for this project which is described in the paper *"Co-designing with orangutans"* [94]. The two accompanying papers were also used as starting points [14, 93]. Related papers were collected in the first strategy by looking at cited papers or papers that cited these inspiration papers. In searches two and three, we focussed on any sources published on the ACM Digital Library [22]. Search two was aimed at gathering sources on digital environmental enrichment design and co-designing with animals. Within the conferences Tangible and Embedded Interaction (TEI), Animal Computer Interaction (ACI), Designing Interactive Systems (DIS), and Human-Computer Interaction (HCI), we searched with terms related to ACI, enrichment, co-design and user-centred design. For strategy three, we looked into TEI, DIS, HCI, and Interaction Design and Children (IDC) with the terms "co-design" and "non-verbal". The specific search terms and number of sources can be found in Appendix A.

All these sources were then filtered using content-specific criteria. Papers from strategies one and two were removed if they did not have anything to do with ACI, enrichment, welfare, or Capuchin monkeys. Some specific topics were also removed, these included micro-organisms-, fungi-, plant-, and canine-computer interaction. The sources from the third strategy were removed if they were specific for disabilities that do not insinuate that the users are non-verbal, or focussed on strictly social behaviour in children with autism. Then all papers were subjected to some general filters. This meant a source was removed if it was four pages or less and did not include any results of the study, if the source was a duplicate, if it was a book that was not peer-reviewed, and if it was not available to us. This resulted in a total of 114 sources left. These sources were used to create a broad overview of current research on ACI, digital environmental enrichment, and co-design with animals or non-verbal users.

2.2 Welfare

To understand the fundamentals of why enrichment design is so important, we must first understand the welfare principles mentioned in the enrichment design papers. Designing enrichment can be done with a few goals in mind, it is most often providing cognitive

This chapter on the theoretical framework is largely sourced from the Research Topics written for the same study, completed by Puck Kemper in December 2023 stimuli[14, 23, 27, 29, 32, 34, 36, 45, 47, 48, 58, 63, 70, 72, 82, 83, 94, 100] , offering choice and control to the animals[27, 29, 34, 47, 48, 50, 58, 63, 82, 100], and/or welfare monitoring and improvement[23, 36, 45, 58, 82, 83]. These reasons are reflected in the 'Caring for Wildlife' statement from the World Association of Zoos. They state that zoos should introduce enrichment which can provide challenges, choices, and comfort to the animals to be beneficial for their psychological health [5].

2.2.1 Normal behaviour and ethological needs

Some behaviours that animals display have evolved over many years and were important for the survival and fitness of their species. Through this process of natural selection, the animals can be highly stimulated to carry out this behaviour because they get hormonal or neurological rewards from their bodies. The result is that the animals have a high intrinsic motivation to behave in this way: the behaviour is an *ethological need*. This need will still be present even if it is hard or impossible to carry out the behaviour [40].

Being able to fulfil their ethological needs often refers back to the animals being able to perform *normal* or *natural* behaviour. What is the difference between *normal* and *natural* behaviour? In general, both natural and normal refer to behaviour that is part of an animal's biological functioning [9]. However, natural could be seen as *before domestication* or *in the wild*. Not all normal behaviour is based on ethological needs, think of running from predators. However, foraging is normal behaviour and an ethological need.

On the opposite side of normal behaviour is abnormal behaviour, or stereotypical behaviour, which is described as influencing the ability of the animal to function effectively in daily life. This definition comes back to the adaptability of an animal to changes. Changes are part of daily life, and being able to adapt or react to them sufficiently is a sign of good welfare since this adaptability is not hindered by abnormal behaviour such as pacing and scratching [9].

2.2.2 Choice and control

In a study in which pandas could choose between outside and inside enclosures instead of being constrained to just one, the researchers saw the animals were less stressed when they were given this choice [69]. Choice and control have an impact on the mental state of an animal and therefore the on well-being of that animal [62].

Another important aspect of choice is the choice to participate in research. In the ACI manifesto, a section is devoted to ethical principles such as treating each animal as an individual, only working with species if you want to advance knowledge, protecting human and non-human participants from harm, and getting informed consent from all participants [54]. In the same year as the manifesto, the 3 Rs: Replacement, Reduction, and Refinement were introduced. This principle is focused on animal testing with drugs, however, it is also applicable to ACI research. (The Oxford Reference categorises animal testing as tests done on animals for cosmetics, vaccines, and pharmaceutical drugs [75]. The European Commission also refers to the 3 Rs strictly in the context of testing drugs and cosmetics [3].) A revised worksheet focusses on ACI, ethical practice, and consent [56].

Replacement stands for always looking for the possibility to replace your intended species with a less vulnerable species. It should trigger the researcher to consider their impact on the animal and whether there are more ethical candidates for the research.

Reduction means reducing the number of animals that you use in the research. They argue that you should use a minimum number of animals so that your results are still statistically valid. However, other researchers conclude that designing for specific individuals in a specific context is never statistically valid, as in that you cannot draw general conclusions about the whole population [7]. Since this research involves specific individuals at Apenheul, the research does not provide any statistically valid data and therefore should not carry out the research at all. However, the ethical guidelines in the manifesto state that ACI research should only be carried out if it is to advance knowledge and technology and if it is beneficial for the animals who participate. This project aims to improve the well-being of the Capuchins thus falling in this category.

Finally, **Refine** means to design the whole experience of participating in the research in such a way that it causes the least amount of stress to the animals. This includes reducing pain, suffering and distress and understanding cognition and behaviour to interpret the internal experience of the animal.

Together with choice, control is an important part of animal welfare. Control is mentioned in the 4Cs model on welfare, which states that animals should experience Comfort, Companionship, Challenge, and Control [92]. Where choice is about creating different options to choose from and the ability of the animal to make a decision, control means that the animal has the option to manipulate their environment or situation. They should have the opportunity to influence their environment in a meaningful way. Giving animals control over sounds or videos that are played in their environment can result in a positive effect on their well-being [36, 70] and technology is a promising way of providing this control [74, 91].

2.2.3 Cognitive stimuli and challenge

Challenge is another one of the four Cs in the 4Cs model [92]. Challenge can encompass solving puzzles to find food and overcoming great dangers like predators. These challenges can be seen as cognitive stimuli, and when they are applied to enrichment, we call this *cognitive enrichment*. Cognitive enrichment is often employed as enrichment or testing of cognitive skills. In both cases, there have been signs of increased welfare like less abnormal behaviour, signs of emotional satisfaction, and voluntary participation [91].

Challenges are also linked to stress, which is often seen as something negative. On the contrary, challenges are great cognitive stimulants, giving the animals something to do [74]. Then there is also the challenge of challenge. On one hand, overcoming a challenge can be very satisfying and result in a positive emotional effect. On the other hand, if a challenge does not come with a solution the animals can get extremely frustrated, leading to negative effects [61]. There is a balance where the enrichment has to be challenging enough to be interesting but it should always offer a solution so it is not frustrating. For humans, the flow model can help determine whether a challenge can frustrate or bore the user. However, there is not enough evidence to conclude that his model works for animals in the same way because the model is based on self-reported evidence from humans [61].

2.3 Environmental Enrichment Design

Enrichment has undergone as many changes as enclosure design has in the past decades. This is not coincidental, since enrichment is focused on increasing the welfare of animals, as we have seen in the previous section. Enrichment - or environmental enrichment because we aim to enrich the environment to improve the well-being of animals - can be designed in multiple ways. The method of designing depends on how the designers want to improve welfare, for which individual animals, and for what context [74].

In this section, we discuss the three main kinds of digital enrichment: cognitive enrichment, facilitating ethological needs, and human-animal interaction. Note that these kinds can be combined in one enrichment design and are not mutually exclusive. For this project, facilitating ethological needs is the best category to draw inspiration from. However, cognitive stimulation can also be applicable depending on the specific behaviour targeted with the enrichment.

2.3.1 Cognitive stimulation and measuring cognitive skills

Cognitive stimulation ranges from audio or visual stimulation[23, 34, 36, 45, 58, 70, 82, 83], to an interchangeable food-based puzzle for Gorillas[16, 30], to whole interactive systems that blend multiple modalities[14, 27, 29, 32, 47, 48, 63, 72, 94, 100]. Using audio and visual stimulation, White-Faced Kakis were presented with some screens and the option to control what was shown. The researchers aimed to give the animals control over their environment and provide some cognitive stimulation [36]. A mixed modalities example is a study where Orangutans could use objects in their enclosure to trigger different audio stimuli [72].

Some researchers added a cognitive measurement aspect to the setup. A lot of projects that focused on tablets for great apes also focused on cognitive skills measurements of individual animals [23, 36, 45, 58, 82, 83]. These measurements could be used to assess the welfare of an animal. Other options for monitoring are using technology to monitor the weight of animals to assess their welfare [12].

The cognitive stimulation goals also include challenges: from puzzle feeders [16, 30] to understanding a projected interface [13, 94]. Depending on the form of interaction that the challenge requires, the setup can also target ethological needs.

The Gorilla Game Lab (GGL) project [30, 16] tackled the challenge of creating a dynamic cognitive puzzle by creating a grid which can be filled with different puzzle blocks. The goal for the gorillas is to move a nut from the start of the puzzle maze to the end. The nut can be moved and manipulated by small holes in the puzzle blocks using the fingers. The goal was to create a puzzle that would challenge the gorillas' problem-solving skills and dexterity. The blocks are removable so the carers can create different levels based on different skill levels and cater the setup to individual animals. The blocks were also customisable by laser cutting the base for the block and then using any animal-safe material to create their own levels. Even though the design was mainly based on game design theory and not on ethological needs, the study is still an interesting inspiration for this project. The main takeaway is the level of difficulty and therefore challenge can be modular. The challenge can be adjusted so that the interaction with the setup can leave all the animals with a satisfying feeling.

2.3.2 Facilitating ethological needs

Ethological needs can be used in enrichment design by, for example, targeting head bobbing in parrots [48] or designing an interface in such a way that a platypus can use its natural hunting instincts to control a wave generator in its pool [63]. Some papers use the term *normal behaviour* instead of ethological needs, and in some cases, the animals' aesthetic preferences are used to describe their innate preference. This can be a preference for visuals and textures but also for performance aesthetics: how they like to behave [27, 29].

Ethological needs can change per species, group, and individual [74], so there are just as many varying examples of ethological design and design methodologies. Some researchers put ethological needs more in the background [47, 50, 58, 82] and others put a lot of effort into defining the needs and use it as a basis for the whole project [34, 100]. Almost all projects saw positive results regarding welfare from implementing these kinds of environmental enrichments. Some did not have welfare as a main goal but were more focused on creating an intuitive interface for the animals [27]. The main takeaways from all these environmental enrichment design projects are how diverse ethological needs can be, that it can be an important leading principle in your research, and that intuitive interactions can look vastly different for animals than they do for humans.

2.3.3 Human-animal interaction

The last major category found in literature is the goal to foster human-animal interaction. It targets interactions between visitors and animals to either create empathy for the animals or teach visitors about the animals [14, 45, 48, 49, 50, 83, 94]. This topic is less relevant since we do not aim to increase interactions between visitors and the Capuchin monkeys. However, it is noteworthy as part of the enrichment design space.

2.4 Food or no food

Enrichments can be designed using food as a reward to get the attention of the animals, or without food, trying to make the interaction itself interesting enough the animals have intrinsic motivation to engage in the activity. Within the literature, most of the papers gravitated to not using food rewards [14, 27, 29, 32, 34, 36, 47, 48, 63, 70, 72, 82, 83, 94, 100] compared to using food as an incentive to use the enrichment [12, 16, 23, 30, 50, 57] . Eventually, both options are valid options for designing environmental enrichment and it highly depends on the context of the enrichment what the best choice could be. It is important to consider feeding patterns, park and carer preferences, what the animals are already used to, etc.

2.5 Environmental enrichment design methodology

The methods used when designing environmental enrichment can be divided into three tiers. The top tier is the method of research, which is tied to the goal of the research. The second tier is the overarching method of design, which is often user-centred and/or animal-centred design. The final tier contains the methods of creating the designs and prototypes. These can be methods like crafting, rapid prototyping, co-design sessions, or workshops.

2.5.1 Frameworks and Research Methods for Environmental Enrichment

There are multiple frameworks for designing in ACI. These describe the design and evaluation process from beginning to end, also including important values, priorities, and accompanying design methods. There is the Agile with Animals framework, that proposes an interactive and iterative approach to designing and evaluating. It prioritises welfare and value-driven design. It states that including other disciplines like ethology and biology in the design process will yield important insights [88]. Another option is a framework based on competence. Here choice, control, variety, and complexity are central values of the framework. It describes how to introduce the technology to animals to ensure they have control over the introduction and the technology [96]. Then there is the habituation framework, which focuses on the novelty effect in enrichment [38]. It is important to take habituation into account, not only when evaluating your design but also in your design process, development, and deployment. For example, deploying the prototype unpredictably or varying the stimuli when offered can be useful. HCI knowledge of the novelty effect can also be used in this context. The final relevant framework consists of understanding the users, activities, and interactions. By interpreting interaction design principles and identifying relevant usability goals, and finally looking at behavioural measures of animal usability and improving animal user experience. With this framework, designers can overcome the challenge of having different cognitive and physical capabilities than animals. The authors also argue for the importance of looking at species-specific traits as well as individual traits and implications [80].

Being able to use a product intuitively is a big part of human user experience design. For humans, intuitive use is that they can subconsciously interact with a product because they can rely on existing knowledge from previous situations [6]. Tangible user interfaces and knowledge transfers from other domains like biology are the key to intuitive design for animals [27]. Note the importance of observing the ways the animal user interacts with tangible objects and how these objects communicate their affordances to the user. Designers often do this automatically for human users but should consciously make the step when designing for non-human animal users. In other words, think about the aesthetics from the perspective of the animals [29].

Research through Design can be usefully applied within ACI [28]. ACI often focuses on specific cases with specific individuals, making it harder to draw generalised conclusions from big batches of data. Within RtD, this particularity is not a disadvantage but can be used to create a single solution and by doing so generate valuable knowledge. This knowledge is reflected in the different artefacts designed in the process. This process not only reflects the choices made by the researchers but also the preferences of the users and in this case the animals. It is therefore important to present rough physical *sketches* to the animals so they can be included in the design and the generation of knowledge. These *sketches* or artefacts are especially important in the ACI field since they can be used to communicate choices and preferences without using conceptual sketches or words. This form of using artefacts to communicate is the core of embodied interaction [20, 46]. The aesthetics of these objects are also highlighted as important: include all modalities instead of focussing on purely pragmatic solutions.

One of the final stages of creating enrichment is evaluating the final design. The methods used in previous research were either one of the following or a combination of more:

behavioural observations [23, 47, 69, 70], time spent with the enrichment [30, 36, 70, 95], frequency of the interaction [36, 95], motivational tests [59], urine sampling for cortisol [69], blood sampling for cortisol [69], and interviews with carers or experts [14, 82].

Looking at the scope of this project blood and urine sampling is ruled out, however, the other methods are within the resources of this project. The first three methods of behaviour and interaction observations can all be combined into a behavioural analysis. Motivational tests are more elaborate and aim to reveal how much effort an animal will make to reach something. Compared to the effort to reach food or water, the effort they are willing to make to reach the enrichment can be more or less than this baseline.

2.5.2 Animal-Centred Design

Designing environmental enrichment can be challenging. ACI is quite a new field of research, with the first call to action in 2011 by Mancini [53]. Animal-centred design takes inspiration from user-centered design from HCI and especially co-design methods are used quite often in enrichment design processes, all in different ways. We will explore the different animal-centred methods used in the enrichment design process and next to those methods.

There are quite some different design strategies that the different enrichment design projects have used. Some do and some do not include the animals in the design process and only evaluate the system together with the animals and the carers. They all use human carers or experts as interpreters of the animals' preferences but with different degrees of involvement compared to the experience of the animals themselves.

Even though all these studies call themselves animal-centred, they vary vastly in their approach to involving animals in the design process. A position paper from 2023 points out this problem within ACI [87]. The term animal-centred is often used without a clear definition and even in the manifesto from Mancini in 2011 [53] the term is not explained thoroughly enough. The manifesto does not provide any insights into what the implications of moving from user-centred to animal-centred are. Because human-centred and user-centred are different approaches to design, animal-centred and user-centred are also distinct types of design and research. User-centred design focuses on involving the users in the design process to ensure better ergonomics, usability, etc. However, human-centred design (or human-user-centred design) is built around the dignity of people: considering the values, perceptions, and concerns of all stakeholders in the design process.

Taking these definitions, we see that animal-centred design is often used interchangeably with user-centred design: the animals are involved in the design process to some degree. Contrary to human-centred design, we often look at welfare to guide this animal-centred process and ask questions about meeting the basic needs of the animals or their voluntary involvement in the study. What this method fails to do is look at the values, perceptions, and concerns of the animals. These concepts go beyond the basic principles of welfare and are represented by dignity. Looking at different research, losing dignity for animals means being treated in such a way that disregards the animals' status as living beings that should be respected. Following the previous research, the position paper puts forward some ways that animals often lose (part of) their dignity. Objectification or mechanisation portrays the animal as being a mere object or piece of machinery, making fun of the animal or putting it in very unnatural situations, and finally completely losing any

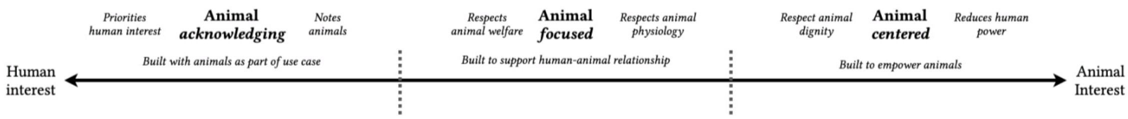

FIGURE 2.1: The spectrum proposed in a position paper from 2023 by Dirk van der Linden [87]. It shows a proposed definition of animal-acknowledging, animal-focused, and animal-centred design and what it means for the goal and values of the design methods.

control over a situation [87].

To further clarify the definitions around animal-centred design, the position paper provides a spectrum of animal involvement in research. From animal acknowledging to animal-focused to animal-centred, what this means can be found in Figure 2.1.

To support any animal-centred research moving forward, the paper points out important questions the researchers have to ask themselves to safeguard animal dignity: *To what extent will this technology fundamentally alter the natural behaviour an animal can and will engage in? To what extent will this technology fundamentally alter the human-animal relationship it normally exists in? To what extent is control over natural behaviour lost or gained, or shifted to additional technological actors? To what extent do the animals (and/or humans naturally co-exist with the animals) become reliant on technology?*

To apply this principle to relevant literature we see that animal-acknowledging research sees animals as part of a use case but gives priority to human interests. We can see this if interactions are designed from a human perspective, without taking into account the experience of the animal [12, 17, 51, 52, 55, 76, 77, 83, 101] and they often target at interactions between animals and humans or only aim to monitor animals. Other studies involve the animals in the process to some degree but the experience and opinions of the humans are held in high regard and is thus animal-focused [10, 23, 30, 32, 35, 36, 37, 42, 44, 45, 47, 48, 58, 70, 79, 82, 93, 94]. Finally, research that minimises the human influence in the design process and safeguards the animals' dignity is animal-centred. Since the position paper on dignity was only published in 2023, the papers do not specifically mention dignity in their method or values. They focus on creating systems that are as close to the desired and natural behaviour of the animals themselves and involve the animals in every step of the process, from idea generation to evaluation. The experience and need of the animals is a top priority [26, 27, 29, 34, 63, 72, 100]. This comes back to the indication of dignity where the animals should never be put in an unnatural situation where they could lose dignity.

2.5.3 Anthropomorphisation in ACI

Another pitfall of designing with or for animals is to anthropomorphise them. Anthropomorphisation, in the context of this study, is defined as attributing human emotions and thought processes to the behaviour of animals. The Cambridge dictionary provides the following definition: *"the showing or treating of animals, gods, and objects as if they are human in appearance, character, or behaviour"* [19]. A dog showing its teeth could be seen as smiling, while in reality, the dog is showing its teeth to warn the other it is angry or scared and is ready to bite.

Many studies mention anthropomorphism and warn of the negative impact on the designs. It can influence every step of the design process: the goal and foundation of the study, misinterpreting the needs of the animals, the chosen technologies like tablets, and the interpretations of the behaviour during co-design sessions. Most papers warn for the impact of anthropomorphism like [74], [68], [23], and [29]. However, in a paper on ethics in ACI, the author mentions critical anthropomorphism [31]. This means thinking critically about when to use anthropomorphism to close any gaps in the methodology and when to be very cautious around it. The author argues that anthropomorphism can have its benefits since humans can interact with the world around them similarly to animals. The empirical data we collect can be helpful in the design process. However, she also states that one should be aware of the differences since animals can process stimuli differently. That is why she advocates for the critical implementation of anthropomorphism.

Anthropomorphism ties into damaging the dignity of the animals, as looking at their behaviour from a human-centred perspective can undermine their dignity. This makes these two values important aspects of animal-centred design: to not design from a human perspective and to safeguard the animals' dignity.

2.5.4 Inspiration from designing with non-verbal users and children

Co-designing with animals can be a challenge because of communication barriers. To get more inspiration we explored the field of co-designing with non-verbal children or people with disabilities that impair their speech. Common methods are: 1. interviews and hands-on sessions where carers or parents were present to interpret behaviour and interactions on behalf of their children [65], 2. interpreting the behaviour of minimally verbal children on the autism spectrum by using an ethnographically inspired observation technique [99], and 3. hands-on methods where researcher and child interact with a prototype together [98]. The first two ways of interpreting the behaviour of the intended users can be used as inspiration in this project. Because the researcher cannot directly interact with the Capuchin monkeys, because of safety reasons, the last method is eliminated.

Co-design for Children Computer Interaction (CCI) and ACI can have quite some similarities [15]. The most important one is the main objective throughout CCI and ACI, which is aimed at empowering groups that normally do not hold a lot of power and does this through co-construction with often rapid prototype-like methods through embodied interaction. They do not have to include dialogue and do not rely on symbols but on actions. Finally, the conclusion is that the objective of co-design is not to understand what it is like to be the target user but to design something that will support the user.

This form of participatory design gives them their voice back and allows them to have some form of control over design processes using dialogue. This dialogue does not necessarily mean with words but often with embodied interaction and symbolism. In the papers' conclusion, the authors stress that participatory design should aim to involve the users in the design process to design technology that is made for them to use and not to create something based on assumptions [15].

2.5.5 Prototyping methods for ACI

Different prototyping and co-design methods can be used to create enrichment or other technologies. These more practical methods are crafting [29], rapid prototyping [16, 30, 44, 88, 100], lo-fi and hi-fi prototypes [96], but also interviews [14, 48, 94, 82] and workshops [94] together with carers, HCI experts and ACI experts. These methods are not mutually exclusive and can be used together.

2.6 Conclusions

What are the ethological needs of Capuchin monkeys?
Ethological needs are expressed in behaviour that animals have to be able to perform since they are so strongly intrinsically motivated to behave in that way. If they do not have the freedom to do it, it can be detrimental to their well-being. These behaviours tie into normal behaviour which is behaviour to support the functioning of the animal. Not all normal behaviour is based on ethological needs as it can also be triggered by external factors.
More species, community and individual-specific research has to be done to create an understanding of the ethological needs of the target users.

How can choice and control be incorporated into the design of digital enrichment?
Choice is an important concept in environmental enrichment design. Not only in the process where animals should have the choice to be involved in the study, but also in the final design of the system. The animals have to be able to avoid the prototypes if they want to and should never be forced to participate. The design and placement of the enrichment should allow the animals to interact with the enrichment when and how they want to.
Together with choice, control can also positively influence well-being. When involved in the design process, the animals can influence the final enrichment design. If their preferences are taken into account, the animals would ultimately have some form of control over their environment. If they show a preference for rain sounds in prototype tests and the final design comes with rain sounds that the animals can trigger, they have control over their environment.

How can the design process be user-centred and involve the animals as co-designers?
Animal-centred design means respecting the animals' dignity and looking at the designs and process from their perspective. The animals and their representatives should be involved in every step of the design process. Ensure to involve important values like well-being, choice, and control. User-centred methods that put the experience of the animals first are fitting. Such methods are participatory design and embodied prototype testing with tangible artefacts, iterative prototyping such as crafting and using multiple prototypes, and interpreting behaviour and interactions using experts. Finally, do not create something based on assumptions.

What digital and non-digital enrichment methods have already been explored in previous research?
Challenge is intertwined with stress and therefore well-being. A satisfying result of a challenge can cause positive feelings in animals. However, not being able to overcome a challenge, or having a problem without a solution, can increase stress and consequently hurt well-being.
Critical anthropomorphism is a helpful tool for designers to interpret the experience of the animals. However, it must be used with care since unchecked anthropomorphisation can harm the animals in the design process and with the final design.
Lastly, habituation is a common pitfall of environmental enrichment design, analogue and digital. Since the goal of this project is to combat habituation, it should be an integral part of the design process.

3. Methodology

The focus of the study is to investigate the process of creating a digital environmental enrichment system for the Capuchin monkeys in Apenheul Primate Park. Since we already answered some questions in the previous chapter, we now look at new subquestions that arise regarding the design process in this context. The main research question has remained the same, however, other questions have been added to guide the design process.

How to design digital environmental enrichment for Capuchin monkeys focussed on their ethological needs?

What are the ethological needs of the Capuchin monkeys at Apenheul?

What methods and resources can be used to fit the context, constraints, and requirements of designing for a non-profit zoological institute like Apenheul?

To what extent does the design of the digital enrichment prototype...
...target ethological needs of the Capuchin monkeys?
...incorporate choice and control?

To what extent is the design process animal-centred?

These subquestions will be answered in three stages: 1. User and context analysis 2. Off-the-shelf prototypes and 3. a Hi-fi prototype. With these three stages, we follow the examples from previous studies. This starts with getting familiar with the users, then ideating, creating prototypes, and iterating. This method is similar to the design thinking methodology, which will thus be used in this study. An overview of the design thinking process and the specific steps of this research can be found in Figure 3.1. This design thinking process is supported by an animal-centred method, putting the values of the animals first, and by a user-design method, putting the experience and perspective of the animals first. Finally, co-design methods like interviews and iterative prototype testing are used to gather information on the experience of the animals.

3.1 User and context analysis

Looking at the design thinking process we start with *empathise*. Here the goal is to gain knowledge of the daily activities of the animals, how they interact with each other and their environment, and what ethological needs they have that are met in their outside enclosure but not in their inside enclosure. During the *define* step of the design process, the goal is to understand what the Capuchin monkeys need and what can best support them. However, it is not the goal to understand what it is like to be a Capuchin monkey. When talking to

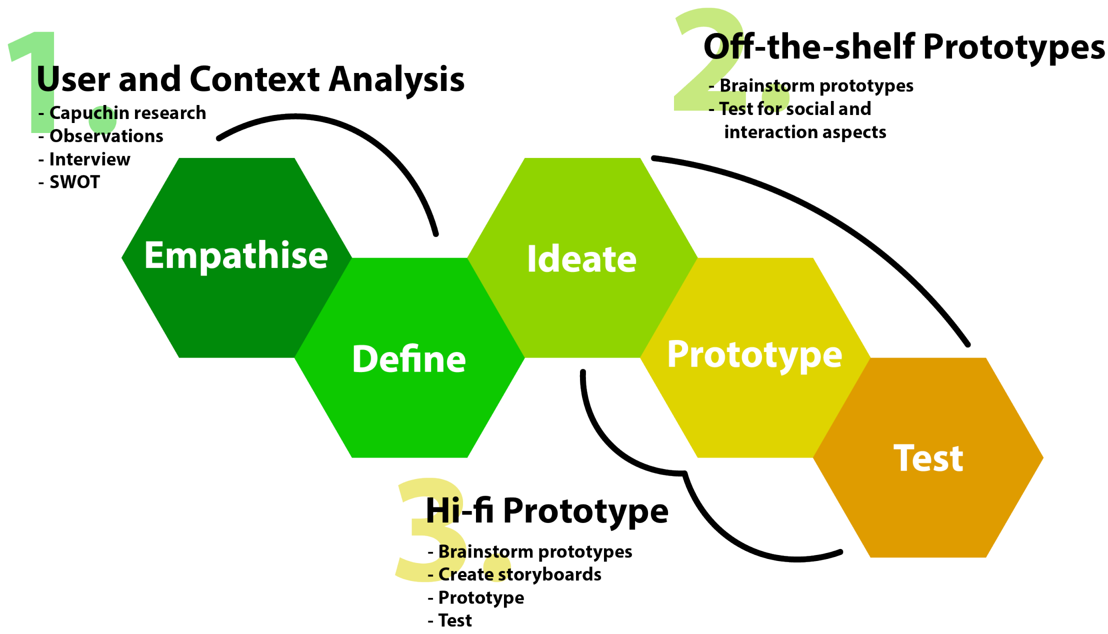

FIGURE 3.1: The five steps of the design thinking method in a graphical representation [71]. This study starts with a problem statement and then further empathises and defines possible subproblems and solutions. Using the ideate and test step an off-the-shelf prototype round will inform the hi-fi prototype stage. The hi-fi prototype goes through ideate, prototype, and test.

carers, the behaviour and needs of the Capuchins are a central point of interest but they will also be asked about any safety and practical requirements for the device. This part of the research is then concluded with a final *define* step. Here the specific direction of this research is chosen so as not to repeat previous research.

3.1.1 Video recordings and scans

Because there is a communication barrier, interviews, surveys, and focus groups are not possible options to gather knowledge on the experience of the Capuchins. Instead, the chosen method to gain this knowledge is to observe the Capuchin monkeys in their outside enclosure at Apenheul Primate Park. There are three groups of Capuchin monkeys: two groups of four Yellow-Breasted Capuchins (YBCs) and one group of seven White-Faced Capuchins (WFC). Each group has their own outside and inside enclosure, which they can almost always access when they want to.

During a three week period, recordings are made of the fifteen animals in their outside enclosures. Each animal is recorded at least twice for a period of 5 minutes, this way each individual is represented in the data. The recordings are then used to make observations on where the animals are, what structures they often sit and move in/on/under, and how they interact with their surroundings.

The book *'gedragsobservatie'* by J.P. van de Sande formed the basis for this these observations. A table containing all the behaviours also called an ethogram, can be found in Table B.3 in Appendix B. These codes will be used to code the videos and scans. This can be done continuously or with an interval. Continuous coding has the advantage that you can record all the behaviour and length of the behaviour but it does take longer to process all the footage. Doing it at an interval decreases the resolution of the results, but is easier and less intensive to do. The goal of these observations is to find out what the animals are roughly spending their time on and what their interactions with the environment look like to inform the design of the prototype. We will continuously code the videos to get an insight into the time budgets of the animals and we will describe any interactions with food or their environment and any behaviour that could be classified as ethological need, in more detail.

Next to the videos, we will also scan their enclosure, writing down where all individual animals are and what they are currently doing. Every three minutes, we create a data point, for about half an hour, so with ten data points in total per scan session. The total amount of scans was four: two for the WFCs and one for each of the groups of YBCs.

3.1.2 Group interview

To get the opinions and insights of the carers, they will be interviewed in a group session. Here the researchers will present the goal of the research, findings in the literature, the outcome of the previous study and some initial ideas for a prototype based on the aforementioned information. The group of carers consists of a welfare expert, a dietitian, two experienced carers for the Capuchin monkeys and one head of one of the main divisions of Apenheul Primate Park. During the meeting, the experts present are asked about their insights into the behaviour, preferences, and safety of the animals. Later in the session, the previous study is discussed, focussing on what was received as promising and what aspects left room for improvement. Finally, some initial ideas are discussed with the group, giving them more freedom to create a more open discussion. These initial ideas are already part of the *ideate* stage of the research. The questions and introduced ideas can be found in Appendix C. The session is recorded using a live transcript using Microsoft Teams with accompanying handwritten notes.

3.1.3 SWOT analysis

To find opportunities for furthering the previous study at Apenheul, a Strengths-Weakness-Opportunities-Threats (SWOT) analysis is carried out [33]. In their research, they already tested some off-the-shelves products. To expand on this we use other items and focus on other aspects of the behaviour and preferences of the animals. Based on this analysis, observations and the interview, prototypes are picked to be tested. This SWOT analysis and the design process of these off-the-shelf prototypes are part of the *define and ideate* stage. It gives us a goal, questions, and conditions for these off-the-shelf prototype tests. The SWOT analysis guides the off-the-shelf prototypes on the topics of social dynamics & monopolisation and interesting interactions & preferred physical properties.

3.2 Off-the-shelf Prototypes

The proposed method to answer the questions posed in the previous stage is to introduce two prototypes. These are a Snufflemat for dogs and a Cardboard and Ball toy for cats. The products, as seen in Figures 3.2 and 3.3, are intended to be used with pets and are therefore made of animal-safe materials. The Snufflemat resembles bushes and leaves that the animals sift through to forage. The Cardboard toy is used without the ball. It mimics wood with holes in it as seen in the outside enclosures and it can be destroyed, which the Capuchins like to do with similar objects like cardboard boxes. Both cardboard and fabric are known materials for the carers and the animals. In the previous study, done by Snigdha, no such items like these were used, so they would give new insights into the kind of products the animals find interesting and how they interact with these materials [33].

FIGURE 3.2: The snuffle mat used in the off-the-shelf prototype tests [2].

FIGURE 3.3: The cardboard tubing used in the off-the-shelf prototype test connected into a ring [1]. The balls were not included during testing.

To find the effect on social dynamics, one of each item is introduced to one chamber of the inside enclosure and sprinkled with seeds and pits. They are placed further than two meters apart. Two objects are introduced instead of one to anticipate and mitigate the monopolisation of the item(s) by one high-ranking animal. The number of objects and space in between them allows other animals to approach another item that is not first claimed by one animal.

This off-the-shelf prototype test stage consists of five days during which the the items are introduced for about 30 minutes to a few hours, depending on the availability of the carers. In case the carers have to be present to supervise the introduction there is only limited time in their schedule. When the prototypes are deemed safe, they can be left with intermitted observation for a few hours. Two tests are done with the WFCs and three with the YBCs. During the introduction of the prototypes, video footage is recorded to later observe the interactions of the animals with each other (social) and with the items (interaction). A live feed using a Google Nest camera is present to monitor the interactions and safety of the animals without being close to the enclosure since this can influence the behaviour of the animals. The video footage is later coded using an ethogram (Appendix B Table B.3) to find the frequency and duration of the interactions with the items and each other. Each interaction is defined as directly touching or looking at the object while sniffing, observing, threatening, or other visible directed actions. Only walking past or grabbing food nearby is not counted as an interaction. Accompanying these video recordings, the carers present during the tests are interviewed for a brief moment during and after the tests. They will be asked to interpret the behaviour and preferences of the animals, see Appendix C for the interview questions and answers. With this information, we can inform the design of the hi-fi prototype regarding the social aspects and interaction aspects.

3.3 Hi-fi Prototype

Gathering all the knowledge from the previous stages of this research, we inform the design of the hi-fi prototype. The ideate, prototype, and test stages from the design thinking framework are repeated. This hi-fi prototype is tested on two days for 30 to 60 minutes. Preferably the prototypes are tested for around 15 days [66], however, due to the availability of the carers this is not possible. The tests will take place in one part of the inside enclosure of the YBCs. A live feed using a Google Nest camera is used to monitor the safety of the animals. These introductions are video recorded, coded using an ethogram (Appendix B Table B.3), and then analysed. This analysis consists of quantitative data on the one hand, in the form of the frequency and duration of the interaction, and the frequency of social behaviour like exploring together or chasing away other animals from an item. On the other hand, it looks at qualitative data such as the way of interacting with the prototype, form of social interaction, and other noteworthy events or behaviours. The data is acquired through observations, video recordings, and interviews.

Finally, the data from these analyses is gathered together with the data from all previous stages of this research to answer the remaining subquestions and research questions.

3.4 Ethical Framework

Safeguarding the well-being of the animals and the safety of the carers and researchers involved is one of the priorities of this research. This not only means having an animal-centred design method but also encapsulates the safety during testing and development of the design. This is done in three ways in this research: in the design of the prototypes, in the study design, and during the tests.

For the design of any prototypes, the carers are always asked what their opinion is regarding safety. It is one of the main questions in the group interview and the initial prototypes are first approved before being introduced. Since the hi-fi prototype contains electrical and smaller metal parts, it has a higher safety risk. To ensure everyone's safety, the prototype is checked by an electrical and physical systems expert from the University of Twente. This person is not affiliated with the research so should have an objective perspective on the design. After processing the feedback given by this expert the design is presented to a group of carers at Apenheul. This presentation takes place a week before the tests so the carers do not feel pressured to approve the prototype because the test day is too close. The main safety concerns are the materials (are they animal-safe), the construction (is it sturdy enough), and the electronics (can the animals reach the electronics or not). It should take the animals multiple layers to get to the electronics, giving the carers enough time to intervene.

The study design prioritises the consent of the animals and their well-being. The carers give proxy consent for the animals and understand the risk of the tests, that they are responsible for the safety of the animals, and for interpreting their behaviour. Testing is only done when the carers deem the situation to be safe, if any tense situations impact the well-being of the animals, the test is rescheduled. The prototypes are placed in enclosures such that the animals can always avoid them with ease if they do not wish to interact with them. The aforementioned measures are taken from the revised 3R worksheet for ACI [56] and ethical guidelines based on the 3Rs [85].

Lastly, safety during testing is ensured by having a set of rules and regulations. This means that the researcher will not enter an enclosure room when the animals are still inside or directly interact with one of the animals. Another measure is continuous video monitoring using a Google Nest. With this live feed, the researchers and carers can react timely when they suspect the animals are no longer safe.

4. User and Context Analysis

To design for the Capuchin monkeys of the Apenheul, we must understand what context and users we are working with. To gain this insight we will work with direct observations of the animals in their outside enclosure and interview the carers of the Capuchin monkeys, a well-being expert, and a dietician at Apenheul Primate Park. First, the Capuchins and the previous research are introduced to give an idea of the context.

4.1 Capuchin Monkeys

Environmental enrichment design applies to so many different contexts and species. To develop a design for Capuchin monkeys, we must understand the physiology of the animals, their way of interacting, and their cognitive abilities.

All the following information on Capuchin monkeys comes from the book *'The Complete Capuchin'* by Dorothy M. Fragaszy, Elisabetta Visalberghi, and Linda M. Fedigan [24]. The book contains information on the Genus Cebus and explains the characteristics of Capuchins from physical capabilities to cognitive skills and social interactions. The sources the authors used are all scientific research papers or journals, rooting the book in established scientific research. White-Faced Capuchins (*Cebus Imitator*) are part of the Genus Cebus and even though Yellow-Breasted Capuchins (*Sapajus Xanthosternos*) are not, the species are closely related, making the general observations applicable to both species.

4.1.1 Behaviour

Capuchins ranging patterns in the wild are very diverse and complex, they fill their days with travelling to new places to find food, feeding and foraging, resting, and socialising. Generally, they have to spend a lot of time to catch insects or to travel quite some distance to find new fruits. They are omnivores and depending on the season they eat fruits, leaves, insects, birds (eggs), nuts, seeds, small lizards or mammals. Even in some parts where they live close to the sea, they can be seen eating crabs, clams, and oysters. They wait for the perfect time when the tide goes down and rush to find the shellfish that remain on the now-dry patch of land.

4.1.2 The body

The main parts of the body that the Capuchins use to interact with their environment are their teeth, tail, and hands. The hi-fi design should accommodate these body parts. They use their incisors to pull and their (pre)molars to crush. The tail can be used to grasp objects or to support their weight. When walking or after leaping they use it to keep their balance. Even when pounding heavy objects, for example, a rock on a clam, they use it to

The data and analysis in this chapter are largely sourced from the Research Topics written for the same study, completed by Puck Kemper in December 2023 balance themselves. However, they rarely hang by their tail, only the younger ones tend to do this more often. Another interesting use is that they use their tail during foraging to free up hand space to hold other things. Their hands have pseudo-opposable thumbs, meaning they flex in parallel to their other fingers. Even though they do not have fully opposable thumbs, their grasp can be very powerful and precise. This means the prototype should account for precise and powerful movements.

4.1.3 The senses

Their vision is comparable with humans, at least for the amount of detail they can see. They are more sensitive to yellows, oranges, and reds, which is why they probably prefer fruits of the same colours. Males are dichromatic and females can be di- or trichromatic. Dichromatic animals mainly see yellows and blues, whereas trichromatic animals can see colours similar to humans. It can be beneficial to focus on these colours in the designs.

Hearing is very important to Capuchins. Not only do they have a wide range of vocalisations they use to communicate, but they also use their hearing to find hollow patches in trees for example. They are most sensitive to frequencies between 7 and 10 kHz and they can hear up to a frequency of 45 kHz, meaning they hear higher pitches sounds than humans can (20 Hz - 20 kHz). These frequency ranges should be taken into account for the sound design.

Olfactory senses are also often used by Capuchins. They use it for urine marking/washing and anointing. The latter consists of rubbing themselves with strongly scented substances like insect excrement, garlic, plants, or their saliva. They also use their sense of smell to test if food is ripe and to locate food.

Capuchins have high sensitivity in their hands and feet, for both friction and tactile purposes. They are able to find seeds in small holes when they cannot even see the seeds and they can use objects like small sticks to probe small spaces to retrieve whatever is inside. Thus, the hi-fi prototype design can contain precise challenges. Lastly, their proprioception, kinesthesis, and vestibular senses are well-developed. This makes them very skilled climbers, jumpers, and runners.

4.1.4 Perception, interaction, and manipulation

During their day, Capuchins spent a lot of their time foraging. When they do this they are often sifting through leaves, pulling at branches, or biting objects to open them and more. These actions range from extremely strenuous to extremely delicate. They are even known to open latches and locks in captivity. When interacting with their environment they can generate a lot of different actions and can combine objects and actions but also objects and surfaces. This indirect manipulation is something that we can see a lot in the behaviour of Capuchins.

Capuchins are also known for being quite inventive. Some individuals figured out how to move liquid from one place to another using cups and they often combine objects to create a sequence of actions. They can use this to acquire food, for example, by letting nuts dry for a few days before smashing them open with specialised rocks, but they also use tools to defend themselves.

When learning to interact with the world, Capuchins tend to be social learners. This means that they learn by looking, exploring, manipulating, and detecting the consequences of their actions and also others' actions. This type of social learning is not imitative learning, where they only learn *from* each other. They learn *with* each other by interacting when learning. They also let the actions of others influence their interest in certain events or places. Especially if their companions are interested in something, they will be too. This affects their feeding, food choice, actions with objects, reactions to other species, and social conventions. This way of learning also influences the way they will learn about the prototype design. It should accommodate for multiple Capuchins so they can sit together.

4.1.5 Social structure

The social structure of Capuchins is formed by their relationships, which are in turn formed by a chain of interactions with other animals. These interactions encapsulate communication, conflict and reconciliation. They communicate using visual, vocal, tactile, and olfactory cues. Their facial muscles are very mobile and developed so they can create a lot of facial expressions. An overview of facial expressions can be found in Table B.1 in Appendix B and these expressions can mean different things depending on context and the rest of the body language. Raised eyebrows can mean a friendly acknowledgement, however, when they jump forward with raised eyebrows it is a threat behaviour. They vocalise a lot and have a lot of different types like trilling, twittering, peeping, and cooing. With these sounds they communicate their internal state or about the state of their environment. They also use touch to communicate, for example, by sitting close to another individual, by grooming, touching, biting etc. This is another reason to have enough space around the prototype so they can sit together. Lastly, they communicate using scents like pheromones, urine washing, anointing etc.

Capuchins have strict hierarchies in their communities, which means higher-ranking animals have more power than lower-ranking animals. These higher animals often monopolise interesting objects or food (sources) and chase away the others. Lower-ranking animals will try to climb the social ladder by being brave towards possible threats for example. Animals will cling to their status by engaging in social behaviour like anointing together, vocalising to each other in certain situations, or being scared or angry together.

4.2 The Capuchins at Apenheul Primate Park

Apenheul houses two species of Capuchin monkeys. The Yellow Breasted Capuchins (YBC) and the White Faced Capuchins (WFC), of which there are 8 and 7 respectively. The group of YBCs is split into two groups of 4, each with one male and three females. Table B.2 in Appendix B shows the individual animals, their names, and any noteworthy characteristics. Some of the animals can be seen in Figure 4.1.

4.3 The Previous Research

During the interview, the research and prototype carried out by Snigdha were discussed [33]. This section elaborates on the research method and prototype, to give an idea of what this research looked like for later context.

Snigdha went through an animal-centred design process with lo-fi prototypes and one

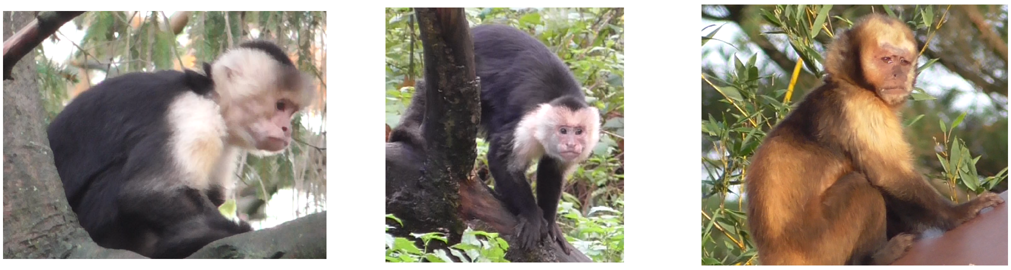

FIGURE 4.1: Two WFCs (left and middle) and one YBC (right) at Apenheul.

hi-fi prototype [33]. Because this research was not a result of the literature search, it is included here, in the specific understanding of the user and context chapter.

The method used in this research mainly follows the same lines as most of the other projects do: a familiarisation phase with observations and interviews, lo-fi and/or rapid prototyping, creating a hi-fi prototype and evaluating that. The first ideas were generated using literature, a group interview at Apenheul Primate Park, YouTube videos and documentaries. These initial ideas were then translated into off-the-shelf products which could be tested with the Capuchins. Using off-the-shelf products was rarely done in other previous studies. Rapid prototyping often consisted of creating prototypes instead of using existing products and modifying them. These tests were evaluated using observations and the expert opinions of the carers. Based on this a hi-fi prototype was developed, see Figure 4.2. To talk over any unclearities, Snigdha was invited to explain any important findings, lessons, and choices. Even though the concept involved multiple units of the prototype, the final test was only done with one because of time and resource limitations. This leaves a great opportunity for exploring the impact of using multiple prototypes on the dynamics of the group and the interest in the device. To avoid the same limitations issues, this project should focus on creating simple or simpler prototypes which are easier and faster to produce for the second testing phase.

The core idea of the prototype was playing interesting sounds when the Capuchins sifted through the leaves or swung the prototype back and forth. Light-sensitive sensors would be triggered when the leaves were (re)moved, and an accelerometer would measure acceleration on the x, y, and z-axis. LEDs and sounds like crickets and frogs were then triggered. The goal of the research was to investigate if such an interaction alone would be enough to satisfy ethological needs without using food.

4.4 Expert Interview

The animals are central to this research, however, the carers who work closely with the animals can give extra insights into the preferences and behaviour of the animals. They also have to work with the final product in the end, so they are end users and their requirements should be taken into account. That is why we interviewed the carers and other staff at Apenheul. The interviews were done in a group, with one head carer, two carers one of the WFCs and one for the YBCs, an animal welfare specialist and a dietary expert.

We asked the group their expertise on questions ranging from the animals' behaviours and preferences to already used environmental enrichments. After discussing the previous products used by Snigdha [33], some new product ideas were introduced. These new prod-

FIGURE 4.2: The hi-fi prototype as tested by Snigdha Guntuka with the Capuchins at Apenheul [33].

ucts were based on the literature on other enrichment projects.

A live transcript was made, however, it was not very accurate and contained a lot of unintelligible text. This was caused by using only one laptop to create the transcript since the meeting was offline, and the echo-like acoustics of the meeting room. Next to the transcript, we took notes and supplemented them with the transcript wherever possible or necessary. These notes, together with the posed questions and the added pictures and explanation of enrichment ideas, can be found in Appendix C on Pages C.1 to C.5 for the interview questions and notes, and Pages C.6 to C.10 for the prototypes. Note that the interview was held in Dutch since all attendees' native language was Dutch.

Ethical requirements	**Practical requirements**	**Behavioural requirements**
Designed from the experience of the animals, not humans	Strudy and monkey proof	Stimulate natural/normal behaviour
Must be avoidable if they do not want to interact with it	No small and/or loose parts	Can be used intuitively by the animals
Hard to monopolise by one animal	No sharp edges	Reduce stereotypical behaviour
No unsolvable frustration	No moving parts where fingers or can get stuck	
	Easy to maintain and clean	
	Easy to replace technology and parts	
	Waterproof in case it gets wet	

TABLE 4.1: The requirements as finalised together with the carers at Apenheul. This set of requirements will guide the designs.

The interview data can be categorised into Behaviour, Interactions, Enrichment, and Requirements. The requirements can be found in Table 4.1 and Appendix C on Page C.5.

Behaviour: The Capuchins spent most of their time walking around and foraging. They are very curious and have a lot of interest in their environment. There is little difference in how they spend their time in the inside or outside enclosure, just the environment is different but the behaviour is not. They can be quite cheeky and destructive as they like to bang with sticks or blocks on things. We can target this behaviour by creating a prototype that is safely destructible. Capuchins are social animals, whenever they experience big emotions they like to undergo these together. When they are scared, angry, or want to solve tension in the group, they are drawn to each other. When something is considered scary, the lower-ranking animals will often be more brave than the higher-ranking ones, since they have more to gain. When a new enrichment is introduced, the higher-ranking animals will often claim it.
Interactions: The main ways of interacting with their environment are hitting objects, making noise, picking, pulling, ripping, and shuffling things like leaves. They have great perseverance and are messy eaters. To play they like to bang things to make noise or to see if something is inside. They mainly use their teeth and hands to break things.
Enrichment: Currently, environmental enrichment objects that are used are food items like mushrooms and garlic, hiding food, balls and cylinders with hay and food, and puzzles. They also used a kids' toy known as a bead maze, see Figure 4.3. They were less destructive with that, maybe because they did not expect there to be any food. The carers note that most senses are targeted with the current enrichment, however, it lacks in levels of interaction. It is usually just hiding food, so having a more difficult and more layered interaction could be nice.
The previous prototype was a nice idea, the interaction was good and the sounds were fitting. However, the branches with leaves were too easy to remove and it is better to have multiple units instead of just one. The newly introduced options for off-the-shelf products were received well. The favourites were the light projections, a combination of a light sensor and sound, the snuffle mat, incorporating smells, a cube that makes sound when thrown, and a plush toy with a rubber ball inside.

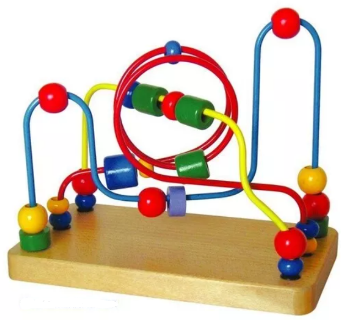

FIGURE 4.3: Kids toy with metal wires and wooden blocks sometimes used as environmental enrichment with the Capuchins [4]

4.5 Observations

To understand the Apenheul Capuchins better we have to get to know their personalities, their interactions with their environment, their preferences, and their capabilities. To gain insight into these 15 animals we made video recordings of the animals over three weeks, which were then used to make observations.

The goal of the observations is to find out what behaviours the Capuchins exhibit in their outside enclosure, how they interact with their surroundings, what they do near each other, and what structures they are often in/on/under. The book *'gedragsobservatie'* by J.P. van de Sande formed the basis for this behaviour observations pilot study [86]. It describes two types of behaviour: states and events. States are behaviours over a longer period like where the animals are located, if they are alone or together, and some longer behaviours like playing or foraging. Events are shorter behaviours like biting, pulling, chasing, yawning, and scratching.

To find these behaviours and interactions, we aim to record two videos of 5 minutes of each individual animal. These videos can be analysed and we can code them with behavioural codes (see Table B.3 in Appendix B). Next to the videos, scans will be made of their enclosure, noting where all individual animals are and what they are currently doing. There were a total of four scanning sessions: two for the WFCs and one for each of the groups of YBCs.

4.5.1 The videos

Over 3 weeks, the animals in Apenheul were recorded five times between the hours of 11:00 and 15:00. A total of 65 videos were recorded, with 36 for the YBC and 29 for the WFC. The average of 3:59 minutes and 42 videos of a run time over 4:45 minutes.

For every video, the starting and end time of every behaviour, state or event were noted down. This created an overview of what the time budgets are for all the animals and each individual animal. These results can be seen in Table 4.4 in a pivot table showing the recorded time per behaviour per animal in the percentage of total time for that animal. Per column, the values are coloured from low (white) to high (blue), to highlight the most observed behaviour. Find the description of the codes in Appendix B Table B.3.

Sum of Sec	Column Labels														
	1						2				3				Grand Total
Row Labels	Agil	Basio	Oemie	Quito	Ti Sento	Zinzi	David	Iba	Sella	Sophie	Xanta	Xena	Xomas	Xuxa	
LA	38,0%	30,0%	17,5%	0,3%	5,9%	20,5%	43,4%	39,8%	17,1%	7,9%	35,9%	31,3%	48,8%	80,2%	30,3%
EA		9,6%		28,4%		18,1%	17,3%	24,1%	38,7%	44,8%	23,5%	30,3%	18,7%	0,6%	19,6%
MO	16,5%	23,1%	24,0%	17,2%	40,2%	8,5%	3,7%	10,7%	28,2%	13,4%	15,3%	15,8%	13,4%	13,1%	16,9%
FO	9,4%	20,3%	50,3%	41,3%	24,3%	52,5%	6,7%	4,0%	13,8%	30,0%	13,1%	16,2%	0,3%		16,6%
CS							28,0%	19,7%		1,7%			8,0%		6,0%
OV	5,5%	11,0%		12,7%	11,3%			0,5%		2,2%	7,9%	4,4%	2,9%	1,1%	4,5%
SS	11,9%	4,0%			0,1%	0,3%	0,2%	1,0%	2,2%		1,9%	0,4%	1,9%	3,9%	1,9%
GS	15,8%	0,4%	8,1%								0,4%	1,6%	2,9%	1,1%	1,7%
P					8,7%			0,1%							0,7%
A					2,1%		0,5%				0,9%		0,3%		0,4%
OB	2,9%				1,1%										0,3%
AN					3,2%										0,3%
?											0,3%		1,5%		0,2%
L					0,2%		0,2%				0,8%				0,1%
SP													1,3%		0,1%
OP					1,3%										0,1%
G		1,6%													0,1%
AG					1,0%										0,1%
FL					0,3%										0,0%
ST					0,2%										0,0%
CH					0,2%										0,0%

FIGURE 4.4: The recorded time per behaviour per animal in the percentage of total time for that animal. Per column, the values are coloured from low (white) to high (blue), to highlight the most observed behaviour.

In the data, we see that the most observed behaviour is looking around, meaning the animals sit or stand somewhere while looking around and taking in their surroundings. The other three most observed behaviours are eating, moving, or foraging. This is in line with what the Complete Capuchin described [24]. Moving is a different case here than in the wild since they will travel to new areas to get a new supply of food, whereas in captivity they have limited space to migrate in the same manner. Moving this much could be a sign that the animals, or maybe the animals doing this the most, have an internal motivation to keep moving. On the other hand, moving is a very integral part of any interaction. One would move during foraging, when finding companions, playing etc.

During filming, some behaviours and interactions stood out as promising to use in designing an interactive enrichment setup. These were often seen during eating or foraging behaviour. The most relevant interactions during foraging were: pulling plants aside or apart, spreading vegetation with their hands, peeling off pieces of bark of trees, sifting through leaves on the ground, and bending and breaking bushes. For eating we noticed: peeling tomatoes, bending and breaking pieces of chicory or lettuce, peeling and eating the layers of leek, picking at the insides of nuts, rolling food on a flat surface, slamming food onto surfaces, and using teeth to break things apart or open.

4.5.2 The Scans

The scans were not focused on individual animals but instead showed trends in the time budgets of the animals, where they are, and finally, what they do where most often. The raw data can be found in Appendix C, on Pages C.11 and C.12, and in Figures 4.5 to 4.9 the results are displayed in graph form. Find the description of the codes in Appendix B Table B.3.

Looking at the graphs displaying the behaviours we see that foraging, looking around, moving, and eating are the most displayed behaviours. They spent almost a third of their time foraging, and close to a quarter just sitting alone and looking around. For the locations, they spent most of their time on the ground: 36%. This is not surprising if we look at the final graph in Figure 4.9. Since they spent most of their time foraging on the ground, this is an expected outcome. Another noteworthy thing is to see that eating is mostly done on something elevated, only two out of the twenty-one instances of eating was done on the floor, and the other times it was done on a branch, stump or other elevated platform. Looking around also follows this trend, which could be because of the function of checking one's environment. This is best done from a high vantage point. The Complete Capuchin [24] also notes that Capuchins will keep constant eyes on their surroundings.

Some categories are not mentioned separately in these graphs but they are grouped under 'other' because the behaviours or locations were too specific or only occurred once. Adding not much to the general conclusions we want to draw from this data.

4.6 Design insights

From these observations and the interview, we can distil some design insights to use in the next steps of this research. We see that most of the day, the Capuchins spent their time foraging. This seems to be one of their ethological needs. They do this by sifting through leaves, picking at trees, and moving vegetation. These interactions can be used to inspire the design. In addition, they also like to break things or make loud noises with objects,

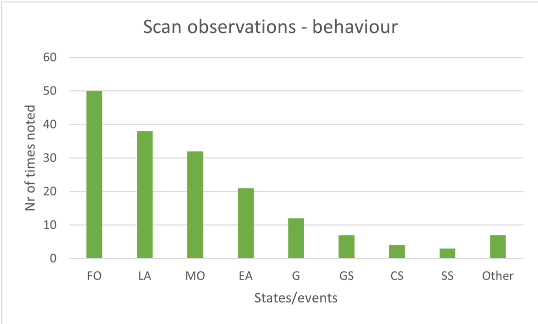

FIGURE 4.5: The number of times each state was noted down during the scans, the top five are FOraging, Looking Around, MOving, EAting, and Grooming.

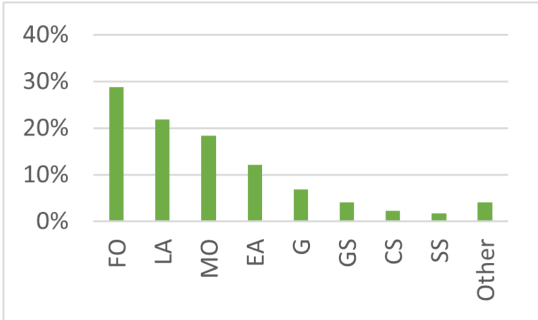

FIGURE 4.6: The time the animals were noted to do a behaviour, given in percentage of total times noted.

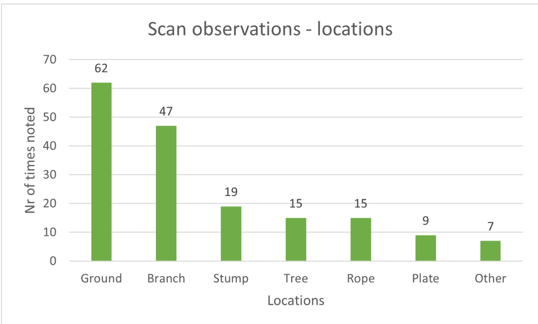

FIGURE 4.7: The number of times each location was noted down during the scans.

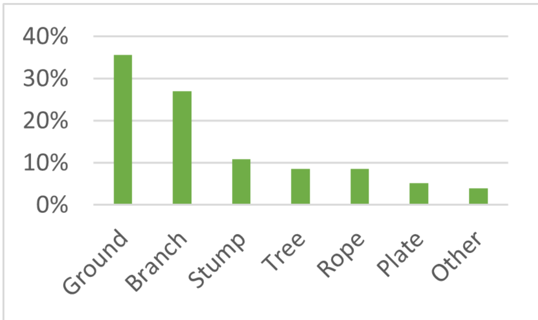

FIGURE 4.8: The time the animals were noted to be in a specific location, given in percentage of total times noted.

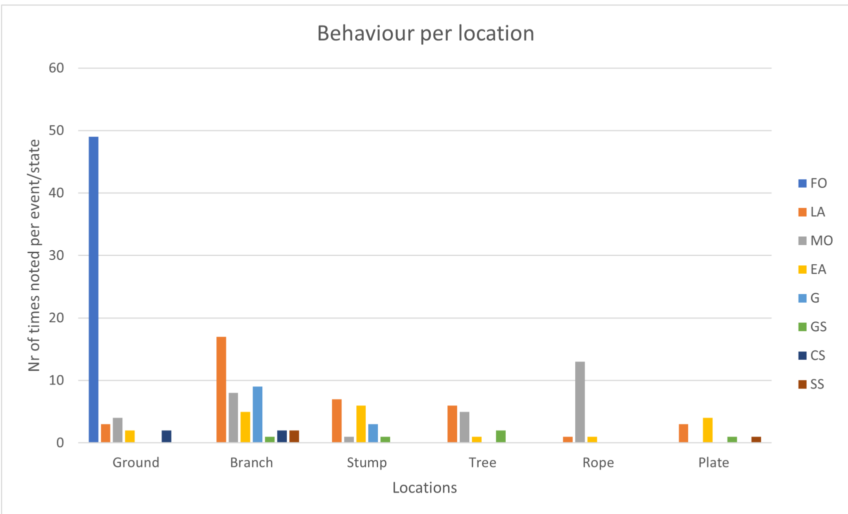

FIGURE 4.9: A cross reference of what behaviour the animals were doing in what location.

which could be an interaction we can incorporate into the prototypes. We speculated they might do this to find food inside or just for fun. Lastly, they mostly spend their time on the floor foraging or on an elevated surface eating and keeping watch. Placing the prototypes somewhere on the floor or elevated can have different functions and is a point of interest in the off-the-shelf prototype tests.

4.7 SWOT Analysis

Now that we have gathered information on the Capuchins at Apenheul Primate Park, we can define the exact aspect to focus on in this study so as to not replicate the previous study by Snigdha [33]. In that study, multiple off-the-shelf products were already tested with these populations of Capuchins. We must first find other opportunities so the products and questions for these off-the-shelf prototypes do not overlap with the previous study. This information is gathered using a SWOT analysis, which is then used to pick products for testing and determine a test design. These chosen prototypes can be found in the Methodology chapter (Figures 3.2 and 3.3).

In this analysis, as seen in Table 4.2, the focus is on the previous prototype and the observed interactions created by Snigdha Guntuka. The outcome of this analysis is used to pose questions for the next part of this research.

Strengths	**Weaknesses**
Triggered foraging behaviour	Some animals showed frustrations (possibly because they were unable to escape sounds, there was no reward, or a fight preceding the test)
Interesting to the animals	Threat behaviours towards the device (expected)
Solid and sturdy	One or two animals claimed the device
Social structures were not disrupted	Real leaves were not robust, had to be changed often
Worked without prior training	Hard to replace parts of the device
Opportunities	**Threats**
Shorter sounds (or less loud)	Novelty effect/habituation
Use food rewards	Food can elicit too much monopolisation
Multiple devices against monopolisation	Loss of interesting qualities after modifications of the prototype
Multiple devices to create multi-layered interaction	
Spring- or weight-based triggers to support greater force	
Simpler device to make it easier to replace parts	

TABLE 4.2: the outcome of the SWOT Analysis based on the hi-fi prototype and evaluation carried out by Snigdha Guntuka [33]

From this SWOT analysis, the following guiding questions are gathered to focus on for the off-the-shelf prototypes:

- *What happens with the social dynamic if we introduce more units of a prototype?*
- *How can we use multiple units to create a more layered interaction?*
- *What kind of interactions do the animals find the most interesting?*
- *What physical properties does a product have to spark this interest?*
- *How interested are the animals in specific prototypes?*

5. Off-the-shelf Prototypes

The chosen prototypes are the snuffle mat (SM) and the cardboard (CB) tubing, see Figures 3.2 and 3.3. The snuffle mat targets foraging interactions like sifthing trough leaves and looking in tall grass or bushes for food. The cardboard targets precise interactions by having small hiding places for food but it also targets the destructive tendencies in Capuchins by being safely but easily destructable. Both items were slightly modified so that they were safe to place in the enclosure with the Capuchins. The snuffle mat had its rope removed which could be used to bundle the mat up in a sack. This feature was not needed and the rope could be dangerous. The cardboard tubing had balls included in the package, which were not included during the testing. It also has some magnets at the two ends so it can be clipped together into a ring (as seen in Figure 3.3). These magnets were kept in the product when we could continuously monitor the animals but were taken out when the products were left in the enclosure for longer with the carers' (proxy-)consent. When the two magnetic sides are not connected, the product contracts itself back into a cardboard brick or it can be hung to extend and show the honeycomb structure.

5.1 Methodology

During these first tests, both prototypes were introduced to one part of the enclosure for three WFCs (Zinzi, Quito, and Oemie Table B.2) and four YBCs (Xomas, Xanta, Xuxa, Xena Table B.2). On the first day, the objects were introduced to the WFCs without food. This was done to get the animals used to the objects and ensure that monopolisation was not happening solely because of the item. The mat was placed on the floor and the cardboard on an elevated platform. On the second day, the objects were introduced to the same animals but now with food, and both items were moved to an elevated platform. With the tests with the YBCs, the objects were introduced on day one without food, both elevated. Then the objects were deemed safe enough to be placed in the enclosure for a longer time, also without food. On the last day, the items were introduced with food.

5.2 Results

The video data shows quantitative data on how many interactions there were with the prototypes, how long those interactions were, and what kind of movements the animals made. The summarised data is shown in the graphs as seen in Table 5.1 and Figure 5.2. Raw data can be found in Appendix D in Table D.1.

The total amount of interactions was higher when food was introduced. However, the interactions were generally much shorter, resulting in a higher number of interactions for the tests with food but a lower average time of the interactions. When there was no food introduced, we saw fewer but longer interactions. These longer interactions mainly consist of threatening movements towards the objects. Most interactions when food is introduced are touching the objects, grabbing food from the objects, or making threatening move-

Object and Food	F	NF	Tot
CB			
Sum of time	238	310	**548**
Nr of interactions	14	11	**25**
Average time	17,0	28,2	**21,9**
SM			
Sum of time	468	114	**582**
Nr of interactions	22	10	**32**
Average time	21,3	11,4	**18,2**
Total Sum of time	**706**	**424**	**1130**
Total Nr of interactions	**36**	**21**	**57**
Total Average time	**19,6**	**20,2**	**19,8**

FIGURE 5.1: Table displaying the total amount of time [seconds], number of interactions, and average time [seconds] per object and per food introduction type. The bold numbers are totals per object (right) or per food (bottom three). Finally, the right bottom three numbers are the total time [seconds], the total number of interactions, and the average time [seconds] of all objects and all foods.

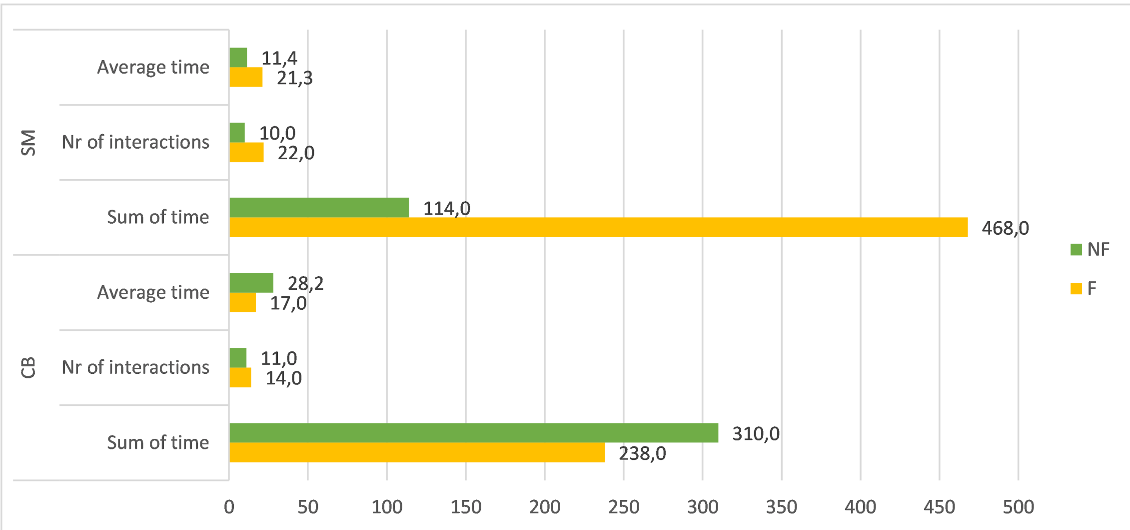

FIGURE 5.2: Graph displaying the total amount of time [seconds], number of interactions, and average time [seconds] per food introduction type and object.

ments.

The total length of the interactions for both objects is 548 and 582 seconds for the cardboard and the mat respectively. This is quite similar as well as the average length per interaction: 22 and 18 seconds per CB and SM. The types of interactions do differ per object. The Capuchins mainly interacted with the cardboard by making threatening movements towards it or in the case of the WFCs by smashing it against branches. The interactions with the snuffle mat were sitting on or next to it and grabbing food from the mat, there were less threatening behaviours towards the mat. When the mat was on the floor, one of the Capuchins rolled it up and over to look for fallen seeds underneath it.

The interview data was recorded using audio recording and handwritten notes. All information is bundled in a summary here and the full summary of each interview can be found in Appendix D on Pages D.1 to D.4.

During the process of introducing, observing, and interviewing the carers, some changes were discussed in between test days. The method was adjusted a little after almost each test day. After test day one with the WFCs, the mat was placed higher up instead of on the ground. After test day one with the YBCs, we wanted to test for longer periods of time without food and did some in-between long-term tests.

The cardboard was first placed in the enclosure of the WFCs in its brick form. So it was not extended into a ring but was contracted into a brick which could be pulled apart to show the honeycomb structure. Zinzi immediately approached the cardboard and started slamming it against one of the branches in the enclosure. The carer thought this was to see if it contained food or if it could be used as a tool. It was not used anymore after this first interaction. The decision was made to already pull it out for future tests to see how they would react to it then. They do not interact with objects like this usually, the action of pulling on both ends of the brick is not a normal interaction for them.
When the cardboard unit was stretched out, the WFCs interacted with it a bit differently, now they moved it around and looked for the seeds stuck between the honeycombs. After a few minutes, it landed on the floor of the enclosure. The WFCs only interacted with it when they had to come close to pick up seeds from the floor. They sometimes made threatening movements towards the cardboard unit. The YBCs were more hesitant when interacting with the cardboard. They touched it less than the mat and made threatening movements towards it longer. Eventually, Xuxa, who is lower in rank, was a bit bolder than the others and sat next to it and ate the seeds out of the cardboard.
For the WFCs, the **snuffle mat** was only interesting for the first minute or so. Only to Oemie, the elderly lady of the group, the mat seemed interesting for a little longer. She dropped it on the floor and rolled it up to search for the seeds left in the mat. They did not pick the seeds from between the pieces of fabric, while the YBCs did interact with it this way.
The Social behaviour was as expected. The carers explained that the higher-ranking animals got to the objects first and when they were done with them the other Capuchins started interacting with the objects. In one case, with the YBCs, we saw that the high-ranking animals were making threatening movements toward the objects with the two of them, while one of the other animals was less cautious and just sat next to the objects and started eating the food inside it. This ties back to the idea that low-ranking animals have less to lose and might try to climb the ranking by being brave.
We saw little to no monopolisation, probably because they receive enrichment items like cardboard and fleece more often. The food inside the objects was also not high-value (like garlic) but a bit more common and low-value (sunflower seeds). When items that are completely new or contain high-value treats, they tend to get monopolised a lot more. This was not the case, and especially the WFCs were not interested in the objects for long. Adding sounds or moving parts could make it interesting for a longer time.
The location seemed to influence how much they interacted with an object. We noticed that if objects were placed or thrown on the floor, the Capuchins were not as interested in it anymore. They preferred to interact with the objects placed on an elevated surface. The carers said they probably feel safer when up in the air instead of feeling more vulnerable on the floor. This was reflected in how only lower-ranking animals would briefly interact with the objects if they had fallen onto the floor.
The food also made a difference on how long they interacted with an object. When intro-

duced without food, the animals lost interest after about a minute. Only Oemie interacted with the snuffle mat on the floor for a little while, probably looking for food. In the other cases, the animals interacted with the objects for longer and kept coming back to them even after leaving the enclosure.
Further comments: During one of the tests with the YBCs, Xomas was holding a living frog, which he had been holding for the past two hours. They often do not want to let them go since they know the frogs will get taken away (and released) if they do not keep holding them. The carers suspected he did not interact with the objects as much because he prioritised the frog over the objects and food.

5.3 Evaluation

With these off-the-shelf prototype tests, we aimed to find the influence of introducing multiple units on the social dynamics and to find unexplored types of objects and interactions to base the hi-fi prototype on.

Both objects elicited more careful behaviour in the YBCs than in the WFCs, which is a known difference in the behaviour of both species according to the well-being expert and Snigdhas' study [33]. Overall, the Capuchins were mostly interested in the objects when they were introduced together with food, so adding food can serve as a motivator to interact. The goal would be to have them start interacting because of the food and keep interacting because it is interesting enough. The animals did not show a strong preference between the objects. Some interacted longer with the mat, others longer with the cardboard.

The main movements and actions when interacting with the objects were hitting the beams with the contracted cardboard block, picking seeds from the honeycomb structure or making threatening movements towards the cardboard in ring form. For the snuffle mat, the actions were mostly picking seeds from between the pieces of fabric, sitting on or next to it, and rolling the mat over to look under it.

The mat elicited slightly less threatening behaviour than the cardboard. However, since the interaction times do not differ significantly, this does not mean they prefer the mat over the cardboard or vice versa. We can only state that they find the mat less threatening or scary. Both objects can be good options for the later prototype, depending on what behaviour we want to target. The Capushins seemed to get used to the mat quicker, so it might also become less novel quicker. Whereas the cardboard might stay exciting for longer. Besides, it has a higher chance of raising stress levels, which should be treated cautiously.

The social dynamics played out as expected by the carers. Higher-ranking animals interacted with the objects first while lower-ranking animals had to wait. On the other hand, lower animals were more bold towards the objects. There was little to no monopolisation and all animals got to interact with the objects.

We saw that objects placed or fallen on the ground had less interaction, probably because the animals feel safer on beams, branches, and platforms. This means it would be valuable to place the hi-fi prototypes somewhere elevated as well.

When the Capuchins had something more valuable or interesting to hold, they preferred that. In the case of the frog, we saw that Xomas was not very interested in the objects anymore. It is important to be mindful of other external factors when testing enrichment.

The method was changed between testing days. These changes were based on observations from the researcher and the carers. This iterative approach makes the results less consistent, however, it also ensures that the experience and input of the animals can be reevaluated more quickly and allows their experience to be better incorporated into the final design. Using these prototypes as ways of communicating their preferences is part of the embodied interaction design theory.

5.4 Design insights

Following the results and considerations from these off-the-shelf prototype tests, we can gather everything into guiding insights:

1. Having two objects does not change the social dynamics of these groups so we can use two or more units in the hi-fi prototype.
2. Since there was no clear preference for one of the two products, each type of material and interaction can be included in the ideation process. These materials are fabric and cardboard. The interactions are plucking, picking, rolling over, banging, and throwing.
3. The hi-fi prototype will probably elicit more interaction when hung or placed on an elevated surface instead of the floor.
4. Introducing food saw longer interactions so including food in the hi-fi prototype can increase the length of interactions.
5. When the hi-fi prototype uses any animal sound, it should also include food so there is no false promise of food.
6. Lastly, having other distractions (like frogs) can impact the interest in the prototype. This should be considered during the hi-fi testing.

6. Hi-fi Prototype Design

In the hi-fi design, all lessons from the literature, context analysis, the previous study, and off-the-shelf prototype tests are combined. When accumulating all information in a hi-fi prototype, some design elements are left out because some sources are contradictory and others because of practical reasons.

6.1 Design Process

The hi-fi design is based on the previous design made by Snigdha [33]. The carers were enthusiastic about the base principle and thought the tangibility was a huge factor in meeting the ethological needs of the Capuchins. Using non-tangible technology like tablets was considered less fitting to target these needs. Tablets can anthropomorphise the animals, and therefore miss the goal of targetting the behaviour related to ethological needs. Some parts of the prototype have to be adjusted. Food is added to the interactions, the leaves are replaced with multiple different interfaces, the LEDs are removed, the sound volume is lowered, there are two separate units, and the interaction depends on how many times the system has been triggered in a certain way. The hi-fi design is explained in the upcoming sections.

The process involved gathering all requirements (Table 4.1), conclusions, and lessons from all parts of this research. This information was relatively straightforward, with no contradictory statements or requirements. The specific interface designs for the prototype units are created by doing a brainstorm. Based on all previously tested objects, some materials and interactions are selected. From these materials and interactions, sketches are made (see Appendix D, Pages D.5 and D.6) and two of the sketches are selected for the hi-fi prototype. These are the branch and the hay box. More sketches, notes, and storyboards can be found in Appendix D on Pages D.7 to D.15.

6.2 Interactions

In Figure 6.1, we see the prototype consisting of two units. The targeted interactions with this prototype are plucking, pulling, banging, and swinging. Unit one has a hay box on one side. This can be stuffed with hay or other materials like leaves or fabric, and the material can be pulled out of the box. Whenever something is pulled or plucked out of the box or added to the box, a distance sensor at the back of the box will be triggered. This interaction was picked because of the current enrichment the Capuchins enjoy, a hay box with hidden food, and their interactions with vegetation in their outside enclosure when foraging.

Another targetted interaction is the banging and moving of a thick branch. The Capuchins like to bang objects against beams or the floor. The branch can be moved up and down and when enough pressure is exerted, a load (or weight) sensor is triggered inside the unit. This can be done by moving the branch around or putting enough weight on the branch. Banging the branch around also makes a clanging noise, which the carers stated the Capuchins also like to do.

The final interaction is pushing and swinging the units. With the prototype from Snighda, we saw that the Capuchins pushed the prototype around a lot [33]. An accelerometer is added to both units to measure the x, y, and z acceleration. While these are the main targetted interactions, the design allows for other types of interactions. This can be sniffing around the distance sensor, putting their fingers in, or jumping on or off the units to trigger the accelerometer.

An overview of what components are in which unit can be found in Appendix D in Tables D.2 and D.3.

FIGURE 6.1: The two hi-fi prototype units. Unit one (right) with a hay box, and unit two (left) with a branch sticking out.

As can be seen in Appendix D, Page D.5, the goal was to accommodate both species at Apenheul Primate Park. While the WFCs are more destructive, the YBCs are generally more explorative. The branch is supposed to be more focused on destructive and sound-generating animals, whereas the hay box is focused on exploration. In Appendix D, Page D.5, the consideration was made to create two different interaction possibilities, depending on the use of food in the prototype. This created a matrix with six different options between no-food, easily accessible food, or food that will drop when triggered, and on the other axis destructive and exploratory behaviour.

Then there is the multi-level interaction, consisting of different puzzle levels the Capuchins must complete to get food from the units. As stated before, the units have one specific sensor (distance or load sensor) and one accelerometer. This makes for four types of input possible for the prototype. The levels are based on which input is triggered and when. Table 6.1 shows all levels and what sensors have to be triggered. When the level is completed it will have to be completed a number of times before moving on to the next level. With each completion of a level, both units drop food and play a sound (cricket, frog, fly etc.).

Level	**Required sensors**	**Number of completions**
0	Dist1 OR Acc1 OR Load2 OR Acc2	3
1	(Dist1 OR Acc1) AND (Load2 OR Acc2)	5
2	Acc1 AND Acc2	10
3	Dist1 AND Load2	15

Table 6.1: The different levels of the hi-fi prototype, with the level number, the required sensors to be triggered, and the number of times the level has to be completed to move on to the next level. Acc1 and Acc2 are the accelerometers of units 1 and 2. Dist1 is the distance sensor in unit 1 and Load2 is the load sensor in unit 2.

Because the test duration is around 30 minutes, the Capuchins are not expected to reach level 2 or 3. However, these levels are included to show the potential of the prototype. The code for the prototypes can be found in Appendix D: Code unit one and Code unit two.

6.3 Materials and Safety

The outside shell of the prototype is made of bioPlex, which is multiplex made from eucalyptus wood and glued together using non-toxic glue. Most regular multiplex is glued together using glue that contains formaldehyde, which is extremely toxic. The hardware is steel bolts, nuts, screws, and rods. All screws and bolts are countersunk so they do not poke out of the surface but sit flush with the wood. The branch on unit two is made from dried pinewood.

Inside the units are several electronics of which most are put in a plastic container. This way the prototype is not too messy inside and the plastic container acts as a barrier for dirt and curious Capuchins. Some sensors and actuators (the load or distance sensor, the speaker, and the servo motor) are located outside of the plastic container because they have to be placed in a specific spot to function properly.

All electronics are soldered together to lower the risk of loose wires. The power supply of the circuit is one power bank to power the ESP and all other sensors and actuators except the servo motor. The motor is powered by four 1.5V batteries. This gives it the power it needs to turn fast enough and still turn when something is blocking the feeder.

Pictures of the exterior and interior of the units can be seen in Figures 6.2 - 6.7

FIGURE 6.2: The top of the prototype with 6 countersunk bolts and a hook to hang it up in the enclosures.

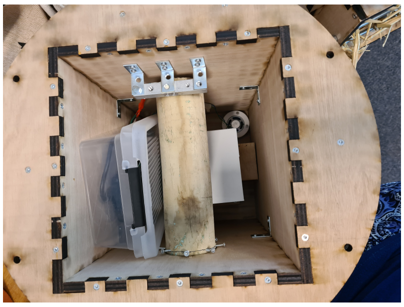

FIGURE 6.3: The inside of unit two viewed from the top with the bolt holes on the side.

FIGURE 6.4: The feeder system and speaker on the bottom of unit two, same principle for unit one.

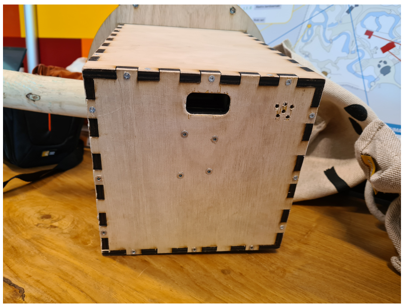

FIGURE 6.5: The bottom of the unit with the feeder hole and some speaker holes.

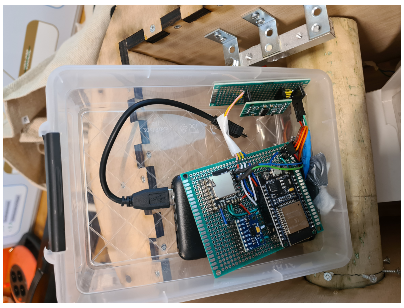

FIGURE 6.6: The electronics of unit two with the plastic container.

FIGURE 6.7: The load sensor of unit two.

7. Results

The prototype has been tested with one group of four Yellow-Breasted Capuchins (YBCs) (David, Iba, Sella, and Sophie, see Table B.2) for two 30 minutes on two days. The units were hung in the same place each time and the same food was used (sunflower seeds). The sessions were recorded using multiple video cameras, the animals were monitored using a Google Nest, and the carers present were interviewed about the interactions and behaviour of the animals, and their insights into the safety, design, and potential of the prototype. This yielded some quantitative and qualitative data.

During the first tests, the Capuchins were quite interested in the prototype. They investigated the units immediately but after they could not get any food out, they left. However, around 10 minutes later they returned and kept interacting with them for the last 15 minutes. Together with the carers, we looked at the frequency of their interactions and how they interacted. The overall interpretation was that the animals were interested in the prototypes, especially because they returned after a while. The Capuchins kept pushing the units and moving the branch (Figure 7.10 and 7.8), which were the intended interactions. With the distance sensor, they removed almost all the hay (Figure 7.3, 7.4, and 7.5) and after a while started to poke their fingers in the holes in front of the sensor. We suspect they did this to see if some food was inside those holes (Figure 7.6), which was not the case, but they did trigger the distance sensor this way. Even though it was not an intended interaction, it did work for the level design.

The prototype is programmed to make a random sound every 5 to 10 minutes. The Capuchins came back after the prototype made a frog sound. It is possible the sound of a frog triggered them to investigate and interact further. In general, there were little to no signs of frustration or of active monopolisation. We did see, however, that Sophie only appeared at the prototypes when the others were gone. She collected and ate some sunflower seeds that fell on the ground. When the others returned, she left again. She is the lowest-ranking animal in the group, so this behaviour makes sense.

The second test was very different because the Capuchins only interacted with the prototype for 2 minutes, after which they were not interested anymore. The interactions were only pushing and sniffing the units. The interview mainly steered towards the reason for the different reactions as opposed to the first test. The reasons mentioned were that the animals were tired from something that might have happened earlier, the corner enclosure that the prototypes were in was not very popular, they could hear us and knew it was almost feeding time, there was already some food in another enclosure, or they were distracted by the camera equipment.

Comparing the two test days, there is already a big difference in interaction frequency and duration. The first test day had a total number of 24 interactions, whereas the second day only had 4 interactions. The average length of the interactions only differs for unit two, with the branch, as seen in Table 7.1. More detailed results can be seen in Appendix D Tables D.4 and D.5.

Unit and Day	Day 1	Day 2	Tot
Unit 1			
Sum of Duration	244	73	**317**
Nr of Interactions	10	3	**13**
Average of Duration	24,4	24,3	**24,4**
Unit 2			
Sum of Duration	374	7	**381**
Nr of Interactions	14	1	**15**
Average of Duration	26,7	7,0	**25,4**
Total Sum of Duration	**618**	**80**	**698**
Total Nr of Interactions	**24**	**4**	**28**
Total Average of Duration	**25,8**	**20,0**	**24,9**

FIGURE 7.1: Table displaying the total amount of time [seconds], number of interactions, and average time [seconds] per unit and per day. The bold numbers are totals per unit (right) or day (bottom three). The most right bottom three numbers are the total time [seconds], the total number of interactions, and the average time [seconds] of both units and both days.

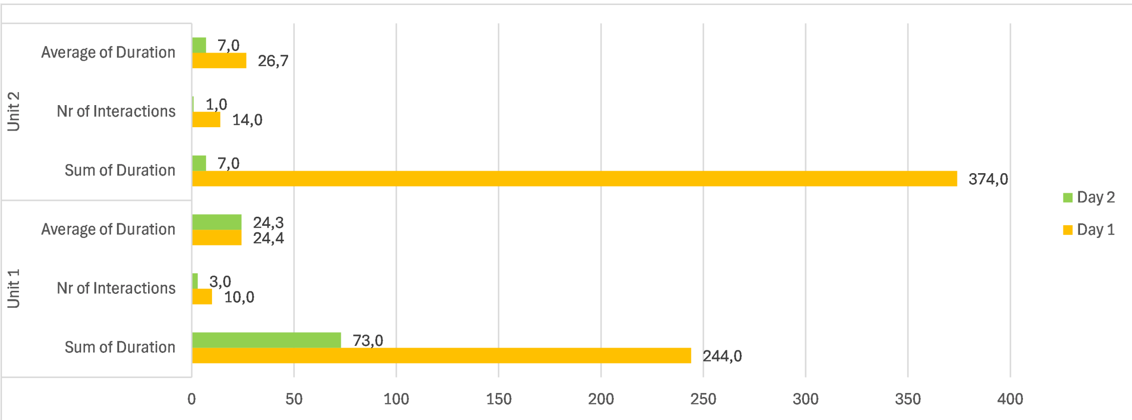

FIGURE 7.2: Graph displaying the total amount of time [seconds], number of interactions, and average time [seconds] per day and unit.

When comparing the interactions per unit, we see little difference in the average duration of the interaction per unit. As seen in Figure 7.2 and Table 7.1, this is 24.4 seconds for unit one and 25.4 seconds for unit two. The sum of the total interaction duration is 317 and 381 seconds for units one and two respectively. Finally, the total number of interactions for units one and two are 13 and 15.

Overall, the carers did see potential in the prototype. However, everyone expected the Capuchins to be more interested in interacting with the prototype than they were now. Especially the interface with the branch that invited them to move it around and make sounds was seen as a good interaction. The carers also liked the sounds that the units made, specifically the timed sounds that were played every 5 to 10 minutes to catch the attention of the animals.

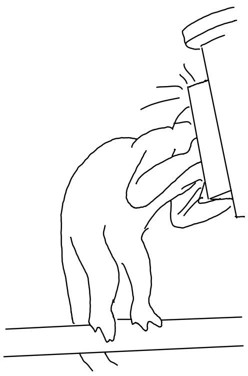

FIGURE 7.3: Iba investigating the hay box.

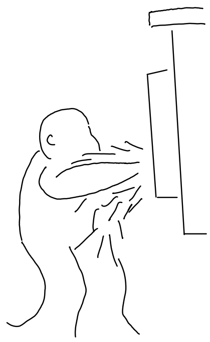

FIGURE 7.4: Iba pulling out the hay.

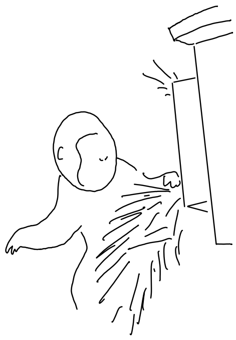

FIGURE 7.5: Iba removing the hay.

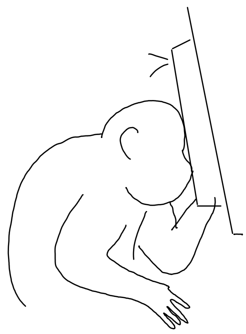

FIGURE 7.6: David investigating the sensor holes.

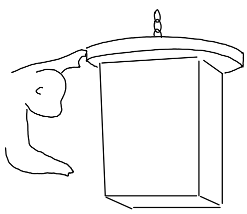

FIGURE 7.7: Sella looking at unit two while touching the top.

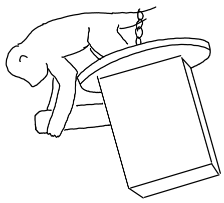

FIGURE 7.8: Sella sitting on unit two and moving the branch.

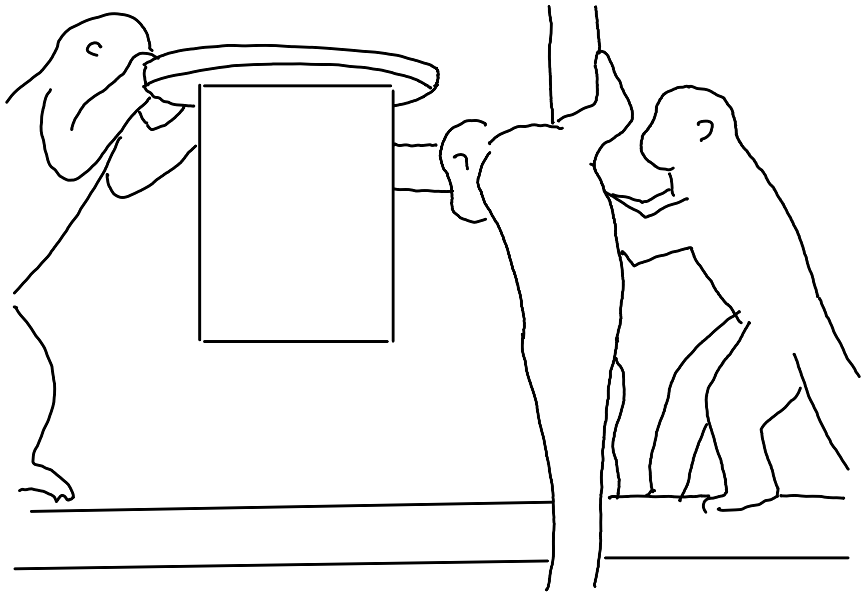

Figure 7.9: David, Iba, and Sella investigating unit two.

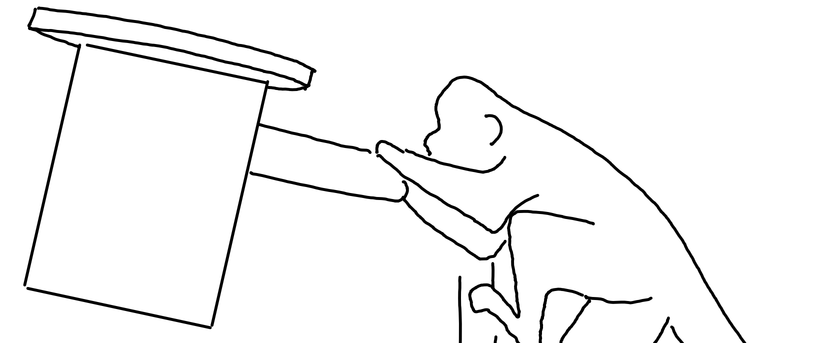

Figure 7.10: Iba moving the branch.

8. Discussion

With the results we saw from the two test days, we can already make some interesting observations. Firstly, the difference in interaction frequency and length of days one and two gives us an insight in the motivation of the animals. Together with the carers, we discussed what this might mean and it can tell us the animals are mainly food motivated. They did not want to interact with the prototype as much when there was food in another enclosure that they could reach. Especially because it was low-value food, they might not have been as interested in the prototype. This also tells us that the interactions alone are not interesting enough to invite more interaction. This could also mean that ethological needs are not met with this prototype. However, with only two tests, we cannot draw such a clear conclusion. In a document written by the British Association for Zoos and Aquaria (BIAZA), the preferred amount of test days is about 15 days. Five days observing the animals with the enrichment, five days of observing the animals without, and five days of no observation [66]. This is often not possible with limited time of carers, however, carrying out a more long-term test plan can be a possible solution to increase test days and data points. We also have to consider habituation and how that can influence the interest on even later dates.

8.1 Food and Contra-Freeloading

The low interest in the prototype, when food is also available in another part of the enclosure, ties into the principle of contrafreeloading. This principle can occur in different settings like zoos or experimental setups and describes a phenomenon of animals rather eating the food they worked for than freely available food [16, 41, 60, 81, 89]. It is measured in the time the animals spent with the contrafreeloading option. This concept does go against our logical understanding of survival and motivation. Working for food is less energy efficient than just eating readily available food. However, there are a few reasons why animals might prefer food they have to work for: 1. stimuli and stimuli changes associated with obtaining the food become secondary enforcers, 2. the animals are trained with the food they have to work for and free food triggers neophobia, 3. it can be a form of exploration, or 4. the behaviour linked to obtaining the food is self-reinforcing [41]. The first and last points are interesting for this research. If the stimuli and/or behaviour that are associated with getting the food are self-reinforcing or pleasant, the animals are more likely to go for the non-free food. Another theory is that working for food can give the animals information about their environment (again as a form of exploration) or serve as a way to express species-specific behaviour (or ethological needs) [89].

Since the Capuchins barely interacted with the prototype on day two, when there was food readily available elsewhere in the enclosure, it might mean that the interactions themselves were not self-reinforcing and did not satisfy their need to explore. However, there is too little data to draw a clear conclusion from this. There might be other factors at play that influenced the interest of the animals that day.

The food in the prototype was not the food as promised by the sound design of the prototype. The cricket, mosquito, and frog sounds might have given the animals the idea that these food items would be inside the prototype. This is the same problem as identified with the prototype from Snigdha [33]. That prototype made the same sounds but no food came out of the prototype, creating frustration in the Capuchins. This prototype does give out food, however, it is not the same as frogs and crickets. When talking to the carers, they suggested using more high-value food like crickets, however, they might get stuck in the food dispenser. Different food items can be tested with the food dispenser or a new design can be made to ensure no deception on the food.

8.2 Interaction Design and Open-Ended Interactions

The interactions were designed with the ethological needs and observed behaviour of these Capuchins in mind. The behaviours that could be targeted were hitting objects, making noise, picking, pulling, ripping, and shuffling things like leaves. Hitting and making noise have been mainly covered by the branch. However, it could be improved to facilitate other types of interactions. Picking and pulling were targeted by the hay box. Finally, ripping and shuffling remain under-utilised with the current prototype. Development of additional sides of the units could focus on targeting these behaviours.

Intended interactions might not always be logical for the user, especially when designing for users that are very different from the designer. In this study, the threat is to anthropomorphise when designing for Capuchins, because making assumptions about their behaviours, experiences, and preferences can be harmful to their well-being. Critical anthropomorphism can be used to close the gap between designer and user a little, however, the threat is still there. Another solution that can support critical anthropomorphism is to create a more open-ended design. This principle is already used in designing games for children and aims to give them the freedom to create their own rules, goals, and meaning [18]. In this case, it is called open-ended play, as it aims to give the children freedom to play. This same principle can be used in an ACI setting, albeit not for rules and goals but for interactions: open-ended interactions.

During the testing, we saw that the Capuchins interacted with the prototypes in multiple ways. The hay box can be cleared of hay or stuffed with materials, or the Capuchins can stick their fingers in the holes to trigger the sensor. The accelerometer can be triggered by pushing and swinging the units and by sitting on them and leaping off. These open-ended interactions might also mitigate some aspects of anthropomorphisation. If the designer only designed an interface to be interacted with in a specific way, this one way of interacting is more susceptible to anthropomorphisation than having multiple ways to interact. The key here is to give the Capuchins the freedom to create their own ways of interacting with the object, which is what open-ended design aims to do. Leaving room for own interpretation gives more aspects of the interaction design to the user, since they create the interactions. In the case of designing for animals, this can mitigate some anthropomorphisation. Together with co-design, this can be valuable for ACI design practices.

The individual sensors and units of the prototype make up a more multi-leveled interaction or puzzle. Creating more open-ended individual interfaces should also create a more open-ended multi-level interaction. The rules reacted for this prototype were close-ended: trigger specific sensors for a specific number of times. This can be improved by creating a more open-ended multi-level interaction next to the open-ended individual interaction.

Creating an open-ended system will also have a positive impact on the dignity of the animals together with the choice they have when interacting with the system. Designing with the dignity of the animals in mind means not putting them in unnatural situations or making them interact with objects in unnatural ways, as advised in the related work [87]. Giving them an open-ended system gives them the choice to interact how they see fit and how they are comfortable. A button only allows for a push interaction. It can be pushed using other body parts or a tool but the core interaction stays the same. Other types of sensors or sensor combinations can allow for more diverse interactions. This choice ties back in with the principle of giving animals a choice. They can choose how to interact with the system and still get a satisfying result, they get a choice and they control how to interact with the system.

Lastly, creating an open-ended system and the option for multiple interactions can also decrease the *training* aspect of introducing new environmental enrichment. You can train an animal to respond to certain cues in a certain way, such as teaching them tricks. You can also introduce a puzzle that they learn to solve. Both can be seen as training the animal but giving animals something they can interact with from their own motivation and learning from the experience can be seen as the animals adapting to a new situation. This is a sign of good well-being. This study aims to fall into this latter category where we do not want to condition the animals to perform a certain behaviour. We want to offer the animals the opportunity to express their ethological needs with whichever interaction they see fit. With a more open-ended system, the animals would not be conditioned to perform a certain behaviour because they can choose what behaviour they wish to perform when interacting with the system. When the animals have more agency in how they want to interact with the system, they are not conditioned to behave in a certain way, thus reducing the chance of training the animals.

8.3 ACI and HCI

Different principles from HCI can carry over to ACI. Open-ended play or open-ended interactions is one of them but we also explored co-design, participatory design, and user-centred design. ACI can also serve as a tool to gather more knowledge for HCI.

When creating a design for humans there are decades if not centuries of design history to take into account but also to build upon. Humans have been using some form of technology, from tools to computers, for millennia. We are used to levers, buttons, wheels, and other interfaces. The affordance between humans and these kinds of systems has been developing for years. When designing these kinds of more complex and technology-based systems for animals, there is a whole different history behind it. This raises questions like *"What does a button look like for a monkey?"* as posed in [44]. The pitfall here is thinking of a button as the logical input for a monkey, narrowing the input to only the form of a button. However, we should consider what an input looks like for monkeys, rather than what a button looks like. Take inspiration from how they interact with their environment already and use these interactions to design an intuitive input method. We are then forced to look at the basis of interaction design and go back to the basics. Designing from such a starting point forces designers to take a step back and rethink the design space, which could create a more intuitive interaction design.

These principles can also be applied in HCI for Tangible User Interfaces (TUIs) and embodied interaction design. TUIs take the tangible aspect and create interfaces based on embodied movements [46]. Pinching to zoom is an embodied gesture-based interaction and can feel more intuitive than scrolling a mouse or clicking a + or - button. This direct manipulation can be more intuitive since the controls are directly related to the action and reaction of the system. [21].

When using tangible tools, we can start to think through those tools. Using a pen or a brush means extending our body into the tools. Artefacts such as tokens are more than just their physical attributes, they communicate intention or preference. The core of embodied interaction is that an interaction exists of much more than the physical components, the background is just as important. Thoughts can become tangible through embodied interaction using artefacts or tools and we can use our full bodies to interact with someone or something [20].

Using objects or artefacts in ACI can be helpful in the design process because they can communicate preferences to the designers. With communication barriers that are prevalent in ACI, embodied interactions can serve as a valuable and empowering co-design method. This is also useful in Research through Design methods for ACI. Likewise, methods and philosophies from ACI can help further the embodied interaction design field by introducing new methods and getting to the core of embodied design.

In ACI and designing with young children, designers can experience the same communication barrier. Both disciplines can benefit from advancements in both fields. Methods of gathering knowledge and preferences can carry over from one discipline to another, as we saw with co-design for young children and non-verbal users (See Section 2.5.4). The main principle is embodied design, where verbal communication is replaced with embodied communication using artefacts.

8.4 Contextualising the Results

Placing this study in the theoretical framework, we see that it took appropriate steps to offer choice and control to the Capuchins. The majority of factors are present in the study design where we have to make sure the animals are not harmed and they have a choice in if they want to participate. The lessons learned from the theoretical framework were followed where the animals were not harmed and they could avoid the prototype if they wanted to. On the other hand, there is also the choice and control in the hi-fi prototype. Here the focus is to offer an environmental enrichment that they can interact when and how they want to. The timing is accounted for by hanging the units where they can be avoided and not having too loud or too obnoxious stimuli the whole time. This prototype did this by having the sound less loud and placing the units in a corner enclosure and not on a frequently travelled path. The way of interacting is again connected to being an open-ended system. If there are multiple ways of interacting with the system and sensors, the animals have a choice on how they want to interact with it.

Looking at the ethological needs and if they were targeted and met, we see that the process tried to identify the ethological needs of the Capuchins. Observations and interviews are well-established methods in the ACI branch. However, the results are not decisive as to whether the ethological needs were met. This also means that we cannot draw any clear conclusion on the effectiveness of this process to target ethological needs. On one hand, the Capuchins were interested in the prototype on day one and we did see them do some targeted behaviour like foraging in the hay and on the floor, and moving and banging the branch. On the other hand, they were less interested on day two. As discussed before, this might mean they were just food-motivated to interact with the prototype. This then means the interactions themselves were not satisfying enough and do not reinforce themselves, thus the prototypes did not target ethological needs. Another possibility can also be that there were no untargeted ethological needs and there is no need for additional environmental enrichment. All in all, we cannot draw a clear conclusion because there is too little data. Environmental enrichment tests have to be done over a longer period with a lot more test days [66].

Carrying out more tests is also beneficial for exploring habituation. Earlier research recommended accounting for habituation throughout the design process and not only at the end. During the design process of the hi-fi design, habituation has been taken into account by using multiple different interfaces on the prototype. The hay box was designed to fit multiple materials like fabric, cardboard, leaves, and hay. However, due to limited time and budget not every side of the prototype could get its own interface and because of limited testing time, there are no results on long-term use and impact.

The goal of this study is to follow and possibly adjust an animal-centred design process. Animal-centred was established as respecting the animals' dignity and well-being by looking at the design process from their perspective. It is important to avoid placing the animals in any unnatural scenarios and changing their natural behaviour. Interpreting behaviour and interactions using experts was also highlighted. The key here is to not make any assumptions about the behaviour and use experienced carers for support. Critical anthropomorphism plays a role here as well. The researcher can apply some anthropomorphism to gain a broad understanding but should never assume the experience of the animals by just their own empathetic judgement [97]. The most critical question towards designers was: *To what extent will this technology fundamentally alter the natural behaviour an animal can, and will engage in?* This research took special care to use natural behaviour as a core interaction principle. Using these natural behaviours and ethological needs, together with open-ended interaction design, are valuable methods when conserving dignity.

Next to animal-centred design, we also used user-centred design methods. These methods do not focus on the values and dignity of animals but rather on creating a fitting solution for the user. These methods were observations, interviews, and iterative prototyping such as crafting and using multiple prototypes. This was only done with one prototype round before the hi-fi prototype because of time and resource constraints. This part of the process could be improved with the context of designing for such a zoological institute in mind.

Looking at previous research, this study has managed to create a tangible and digital environmental enrichment system. Often digital environmental enrichment is focused on using screens and tablets [23, 32, 37, 47, 82, 83]. Screen-less digital systems [34, 70, 100], tangible systems [27, 29], or mixed systems [48, 63, 72] are usually not dynamic enough in the way that digital systems can be. One study that stands out is the Gorilla Game Lab which used modular puzzles that can be adjusted to the skill level of the individual animal [30, 16]. It achieves the changeability of a dynamic system without being digital. However, creating all these puzzles manually can take a toll on the time and creativity of the carers. Having an easy-to-adjust system can save time and effort. This study combines the tangibility of physical systems and the dynamic range of most digital systems while focusing on ethological needs.

8.5 Practicle Lessons

During the process, some restraints and obstacles came to light about working with a non-profit zoological institute like Apenheul Primate Park. The main constraints are time and budget. In an organisation that works with animals and guests, there will always be unexpected things happening and in those cases, safety goes first. The carers often have little time next to their daily tasks of caring for the animals to accompany a researcher with their study. Especially in a non-profit organisation, every minute is precious time. To account for this tight schedule there are a few things that can be done to ensure quality research in a limited amount of time:

- Tests and prototypes need to be prepared well. This way there is limited time necessary to set up for testing.
- The safety of the prototypes has to be checked with plenty of time before the test. This way there is enough time to make adjustments.
- Working around valuable carer time is a challenge, but working independently where possible can create more scheduling freedom. This can mean doing observational work alone or creating prototypes that can be hung without needing constant live monitoring.
- Off-the-shelf or already available products can serve as prototypes and can save time and resources.

Carrying out research and creating multiple prototypes costs money. There is no way around this except getting sponsors for example. However, the constraint of using as little budget as possible gave us some insights into what can be done to cut costs. The hi-fi prototype was made twice because the *technical check* pointed out that the wood type contained toxic formaldehyde, so it had to be remade using safer materials. It is better to include such a check at an earlier stage to avoid remaking a prototype. Allowing for such delays is essential since safety is a priority in this project. The technical check was deemed a vital step of the design and prototyping process. These following points can also help with budget-related constraints:

- Measure twice, decide once. This means to think before you buy supplies or make any other permanent decisions.
- Opt for cheaper materials and fabrication methods. Do-it-yourself is key here. However, be sure that safety is always the number one priority.

- Using off-the-shelf products or items that are already available can save budget and resources.

8.6 Limitations

Limited testing time influenced the conclusions on habituation and ethological needs. Working within this context brings time limitations but this being a Master Thesis also impacts the total runtime of the study. Having more test days gives more data to draw meaningful conclusions on habituation and ethological needs and improves the quality of the research in general. Preferably, environmental enrichment is tested for a two week period, with some days to introduce and observe the enrichment, some days to observe the animals without enrichment, and some days with no observation at all. Especially with a dynamic system, testing for habituation should be done over multiple weeks with multiple different settings [66].

The off-the-shelf prototype tests and hi-fi prototype tests were done with different groups of animals. This was the result of the availability of the animals and carers. During the observation, two of the WFCs were rarely outside so were not included as much in the observational data. In an ideal study, all animals would be included in the whole process. This improves the process and the hi-fi design because the design decisions are then made based on and by all animals. The process of co-designing environmental enrichment in such a way would represent all preferences of all animals and be more inclusive. This is again dependent on the availability of the carers and the well-being of the animals. If it is not safe to include the animals in the design process and testing, they should not be included.

8.7 Future Work and Recommendations

During the process of creating these prototypes, different ideas have been shelved in favour of other designs. These ideas were brought up by caretakers, well-being experts, or supervisors. Some are the results of the ideation process done by the researcher. Some untapped ethological needs that might have the potential for environmental enrichment are anointing and (the illusion of) travelling as wild Capuchins travel great distances. The ideas included using projections with tangible objects, multiple self-rolling balls that dispense food, or interactive tree logs. These, and other ideas, can still be developed and researched to further the ACI research and design space.

Further testing should be done with this prototype to draw clear conclusions on habituation and long-term effects on well-being. This can also improve the knowledge of ethological needs and if they are successfully targeted with this prototype. The dynamic puzzle system can then also be tested to see if the puzzles are well designed and if any changes have to be made to counteract habituation.

During the final tests, it became clear that open-ended interaction design has multiple benefits when designing for animals. It can be valuable to do further research into ACI and open-ended interactions. The focus can be on the choice and control of the animals, the minimisation of anthropomorphism or training, or the safeguarding of dignity. This prototype specifically can be further developed with a clear goal of being open-ended, which could improve the prototype.

The next step in development can be creating different interfaces for the sides of the prototype. They can use different sensors and materials and target different behaviours or needs. This prototype did not fully target all observed behaviours such as ripping and shuffling through leaves, so these could be considered for newer sides. Other ideas from this study that were not implemented in the hi-fi design are stacking cardboard that can be ripped away, having a side with multiple little holes, and wooden fruit-like structures that can be pulled out of the sides. It is valuable that new interfaces are open-ended and allow for multiple forms of interaction.

Further development can also include researching how to create a UI and UX for the carers with this prototype and similar projects. It is interesting to investigate how the parameters of this prototype can be translated into a usable UI for a diverse carer population. Each carer should understand how different interactions and different puzzle designs can impact the animals, their choices, and their ability to choose. This can affect their well-being, so having a clear UI to communicate the results of changes made to the system is necessary.

9. Conclusion

We conclude this research by answering the research questions. Using the results and discussion of the hi-fi tests, and all the gathered knowledge on the process. We first answer the subquestions and finish with the main research question.

What are the ethological needs of the Capuchin monkeys at Apenheul Primate Park?
With literature research, observations, and interviews, we determined the ethological needs of Capuchins encompass foraging, anointing, and social connections. For the Capuchins at Apenheul, a combination of potential ethological needs and observed daily behaviour yielded different forms of foraging and banging objects on other objects as targetable needs.

What methods and resources can be used to fit the context, constraints, and requirements of designing for a non-profit zoological institute like Apenheul Primate Park?
Working with limited time, budget, and resources is a challenge. There are mainly practical methods to ensure the design process does not invade the carers' too much and to use what is already available to cut production time and costs. Proper preparation, scheduling enough time for additional safety checks, and using cheaper and off-the-shelf products are such methods. Safety should be a top priority throughout the process, not only ensuring the safety of the animals but also of the carers and researchers.

To what extent does the design of the digital enrichment prototype target the ethological needs of the Capuchin monkeys?
The ethological needs of the Capuchin monkeys were identified using methods from previous research, such as observations and interviews. However, due to limited testing time the results were inconclusive if the prototype was successful in facilitating ethological needs. It was unclear if the animals were interested in the prototypes because of the design and targetted behaviour or only because of the food contained within.

To what extent does the design of the digital enrichment prototype incorporate choice and control?
The design process followed the recommended steps from the 3Rs frameworks in providing the choice of participating in the study and interacting with the prototypes. The volume has been lowered and the units were placed out of vital routes in the enclosure. The hi-fi design itself provided a partially open-ended system, supporting the choice and control the animals have when interacting with the prototype. Having the option to trigger the sensors in multiple different ways gives the animals the choice of how to interact with the system in their own way. This also contributes to the safeguarding of the dignity of the animals, since they are not forced to behave in an unnatural way.

To what extent is the design process animal-centred?
During the design process, dignity and well-being were central values. Critical anthropo-

morphism, using experienced carers as proxy users and iterative tangible prototype tests provided an animal-centred process. Especially using tangible prototypes can give the animals a physical way of communicating their preferences. This will help make the prototype a facilitator of natural behaviour and not place the animals in unnatural scenarios. These principles should steer a process towards being animal-centred, which focuses on designing in such a way that the values of the animals are safeguarded. This is different to user-centred design in the same way human-centred and user-centred are also different. A user-centred process can use co-design and participatory design methods, such as interviews, playtesting, iterative design etc. These methods do not specifically target the values and dignity of the animals but rather focus on creating a more fitting solution for the user.

How to design digital environmental enrichment for Capuchin monkeys focussed on their ethological needs?
Environmental enrichment can be designed using an animal-centred method by focusing on dignity and well-being. It is important to incorporate animal-centred methods so they can communicate their preferences and have room for open-ended interactions. Tangible prototypes and rapid prototyping are fitting tools for this animal-centred method. Critical anthropomorphism and using carer experts are important tools to interpret behaviour. User-centred methods can still be used to focus on finding the right solution for the user. These methods can be observations, interviews, and iterative playtesting. Ethological needs or other daily needs or interests can be identified beforehand and targeted in the hi-fi design by doing observations and using the experience of carers. Open-ended design can be a helpful tool to give the animals a choice in the hi-fi design, counteract anthropomorphism, minimise training and protect dignity. There will always be practical limitations when working within such a context as Apenheul Primate Park. it is important to ensure that these requirements are met while safeguarding the well-being and safety of the animals.

Ultimately, despite the inconclusive results on the effectiveness of this prototype, this study has identified more opportunities for research in ACI and HCI. Designing for animals can provide insights into designing intuitive interactions for humans. Design principles for humans, such as open-ended design, can enhance technology for animals. This research project brought us a step closer to creating dignifying, intuitive, and ethical technology to improve the well-being of animals.

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A. Literature Search

Table A.1: The literature search strategy with the three different searches. The first six rows contain the three papers on the inspiration project with Orangutans. The next four rows are the enrichment-focused search in four different conferences [22]. The last four are the co-design inspiration searches related to non-verbal target users [22].

0	Source	Search Terms/Relation Type	Nr of Results
1	Co-Designing [94]	Cited in this paper	79
2	Co-Designing [94]	Papers where this paper is cited	19
3	Kinecting [93]	Cited in this paper	65
4	Kinectings [93]	Papers where this paper is cited	50
5	Evaluation [13]	Cited in this paper	30
6	Evaluation [13]	Papers where this paper is cited	14
7	TEI	[All: "animal computer interaction"] OR [All: "pet enrichment"] OR [All: "digital enrichment"] OR [All: "environment* enrichment"] OR [All: "animal enrichment"] OR [All: "animal technology interaction"]	5
8	ACI	[All: "enrichment"] OR [All: "co-design"] OR [All: "user centered design"]	72
9	DIS	[All: "animal computer interaction"] OR [All: "pet enrichment"] OR [All: "digital enrichment"] OR [All: "environment* enrichment"] OR [All: "animal enrichment"] OR [All: "animal technology interaction"]	19
10	HCI	[All: "animal computer interaction"] OR [All: "pet enrichment"] OR [All: "digital enrichment"] OR [All: "environment* enrichment"] OR [All: "animal enrichment"] OR [All: "animal technology interaction"]	46
11	TEI	[All: "co-design"] AND [All: "non-verbal"]	8
12	DIS	[All: "co-design"] AND [All: "non-verbal"]	20
13	HCI	[All: "co-design"] AND [All: "non-verbal"]	73
14	IDC	[All: "co-design"] AND [All: "non-verbal"]	20
15	Total		520

B. Capuchin Monkeys

Table B.1: A shortened copy of the facial expressions produced by Capuchins. This table can be found in the book 'The Complete Capuchin' on page 204 as table 11.1 [24].

Facial expression	**Description**	**Accompanying vocalisations**
Silent bared teeth: grin, smile	Jaws are closed, baring of upper and lower teeth by retraction of the mouth corners	during courtship the female can squeal
Open mouth silent bared teeth: open mouth smile	similar to the grin but the jaw is somewhat open	A pulsed call given in bouts while head cocking
Open mouth threat face	The mouth is wide open, baring canines and incisors. Complete retraction of the corners of the lips	Bark-like staccato call
Lip smacking	Rhythmic lowering and raising of the lower jaw	Smacking sound
Relaxed open mouth: play face	Mouth is opened in an oval but the teeth remain largely covered by the lips	Low staccato vowel sound
Scalp lift	Eyebrows and forehead are raised	
Head cock: head tilt	The head is rhythmically tilted from one side to another	
Protruded lip face: duck face	Lower jaw protrudes anteriorly, lips are tensed together	

Table B.2: This table shows the names of all the Capuchins present at Apenheul Primate Park, together with their date of birth, gender, relations, and any noteworthy characteristics.

Name, date of birth, gender	**Relations**	**Description**
White Faced Capuchins		
Oemie, ?-10-1988, Female	Mother of Agil	x Older animal, missing part of her left arm
Quito, 13-12-2201, Female	Mother of Basio and Ti Sento	Inner arms and tail have bold spots
Agil, 03-12-2006, Male	Son of Oemi	Has one raised eyebrow, bald spot on right knee
Troncon, ?-01-1987, Male	Father of Zinzi and Ti Sento	Face like a boss: underbite, grandpa, scruffy tail
Basio, 16-05-2007, Male	Son of Quito	White spots in his tail, broad tail
Zinzi, 18-02-2009, Male	Son of Oemie and Troncon	Looks like Agil, frog mouth, spot under his eye
Ti Sento, 07-02-2012, Male	Son of Quito and Troncon	Smallest and youngest, bald spot on left knee, bald line on tail
Yellow Breasted Capuchins - Group Xomas		
Xomas, 05-08-2014, Male	Son of Xanta	Yellow face, brown tail
Xanta, 17-01-1997, Female	Mother of Xomas, Xena, Xuxa	Scruffy tail, bald spots on the side of her head, hair on her head standing up
Xena, 22-08-2012, Female	Daughter of Xanta	Lighter flanks, white moustache, lighter mouth
Xuxa, 03-07-2011, Female	Daughter of Xanta	Darker face, fuzzy moustache, full and darker tail
Yellow Breasted Capuchins - Group David		
David, 19-03-1991, Male	-	Older male
Sophie, 18-08-1984, Female	Mother of Sella	Older female, part of her tail is missing
Sella, 13-12-2015, Female	Daughter of Sophie	Skinny brown body
Iba, 03-04-2010, Female	-	Yellow flanks

TABLE B.3: This table shows the ethogram of expected behaviours of Capuchin monkeys. Mostly focused on expected ethological needs like foraging, grooming, anointing, and stereotypical behaviour and some social dynamics.

Behaviour	**State/Event**	**Code**
Looking around and not moving	S	LA
Looking at object	S	LP
Approaching object	E	AO
Leaving object	E	LO
Sitting close to object	S	CO
Touching object (will be described in more detail)	E	TO
Biting object	E	BO
Hitting object	E	HI
Sniffing object	E	SO
Licking object	E	LI
Moving object	E	MB
Eating (will be described in more detail)	E	EA
Locomotion (walking, running, jumping etc)	-	LM
Object play	S	OP
Self play	S	SP
Social play	S	P
Grooming	S	G
Grooming self	S	GS
Anointing	E	AN
Contact sitting	S	CS
Approach other	E	A
Leave other	E	L
Aggression to other	E	AG
Chase other away	E	CH
Stare at other	E	ST
Flee	E	FL
Hide	E	HD
Avoid	E	AV
Scratching self	E	SS
Yawning	E	Y
Stereotypical behaviour (sucking digit or lip, rocking, pacing, self clasping etc.)	E/S	SB
Out of view	S	OV

C. User Analysis

This Appendix includes the interview questions and the summary of Snigdhas' prototypes with the notes from the focus group interview. It also shows the requirements that were constructed together with the carers. This Appendix is in Dutch but the description and summary can be found in the chapter User and Context Analysis.

Later on, this Appendix shows the raw data from the scans.

Introductie (10 minuten)

We zullen beginnen met een korte introductie. Hierin vertel ik kort wie ik ben, wat het doel van mijn onderzoek is en hoe dat misschien anders is dan vorig jaar. Ik wil ook graag weten wie jij bent, wat je doet binnen de Apenheul en wat je belangrijk vindt in je werk. Dan bespreken we ook het consent form over de vrijwillige deelname aan dit interview en de opslag van data.

Deel 1: De kapucijn apen, hun gedrag, het verblijf en wat er nu gebeurt aan verrijking (20 minuten)

In dit deel van het interview gaan we wat dieper in de op de huidige situatie, de dieren en de context.

1. Wat doen de dieren het meest overdag?
    a. Wat doen ze het liefst overdag?
    Lopen en zoeken, ze doen veel samen en het zijn hele sociale dieren. Ze zijn erg nieuwsgierig en hebben veel interesse in hun omgeving. Ook buiten hum verblijf vinden ze interessant en ze gaan vaak voor het raam zitten als ze binnen zitten.
    Ze kijken vaak naar waar de verzorgers zijn.
    Binnen en buiten doen ze veelal hetzelfde, alleen de manier waarop is net anders. In plaats van onder struiken foerageren doen ze dat bijvoorbeeld in zaagsel.
    b. Waar zijn ze bang voor?
    Ze zijn mega brutaal. Ze zijn ook graag samen bang of boos en gebruiken deze samenwerking om de spanning op te lossen. De hiërarchie kan ook veranderen als ze bang zijn, de lagere dieren gaan dan juist stoerder doen. De hogere dieren hebben dat niet nodig.
    Vooral als je nieuwe dingen introduceert gebeurt dit. En als je hele gewilde dingen plaatst worden ze vaak geclaimd door de hogere dieren.
    c. Wat vinden ze interessant?
    Insecten, vogels, eieren vinden ze heel leuk. Ook dingen die geuren. Eigenlijk alles wat nieuw is, is interessant.
    d. Hoe ziet de huidige structuur van de groep eruit?
    Pas vooral op tijdens de bronsperiode. We moeten ook goed nadenken over hoe we de dieren neerzetten tijdens tests etc. Ze kunnen elkaar nogal opjutten.
        i. De witschouder kapucijners
        Hier is het nu even wat anders want een dier, Troncon, is een beetje verstoten.
        ii. De twee geelborst kapucijn groepen
2. Wat zijn de belangrijkste handelingen, zoals dingen scheuren, gooien of peuteren, die de apen doen om de volgende redenen:
        i. Hun omgeving te ontdekken?
        Slaan, herrie maken, peuteren, onderzoeken en dingen ergens uit trekken.
        Ze hebben een enorm doorzettingsvermogen.
        Dingen als graven of nesten bouwen doen ze niet echt.
        ii. Voedsel te zoeken?
        Gebruiken voor handen, zicht, geur. Ze schuiven of trekken veel.
        Ze zijn erg sneaky en stil als ze eten zelf willen houden.
        Velletjes en pitjes laten ze vaak liggen.
        Het zijn enorme knoeiers tijdens het eten.

Figure C.1

iii. Vermaak te zoeken of te spelen?
Samen ophitsen tegen een bal bijvoorbeeld. Dat gaat ook om elkaar steun te geven. Lichamelijk contact is erg belangrijk hier, daarmee vinden ze ook steun.

iv. Hun sociale contact te onderhouden?
Vlooien en geur aan elkaar afgeven door dichtbij elkaar te zitten. Ze doen heel veel samen.

b. Hoeveel hiervan doen ze alleen of juist in groepjes?
Vooral samen dus.

3. Maken ze dingen vaak kapot zoals speelgoed, takken, touwen etc?
Ze houden van dingen kapot maken, dingen als dozen bijvoorbeeld. Ze willen vaak weten wat erin zit.
Ze maken herrie door op dingen te slaan en dat vinden ze ook leuk of fijn om te doen.
Gebruiken vooral tanden en handen om dingen kapot te maken.
   a. Waarom doen ze dat? (Spelen, frustratie, etc.)
   b. Wat voor objecten maken ze vaak stuk?
   c. Hoe doen ze dat? (Tanden, handen, voeten, gooien etc.)
4. Welke verrijking methodes gebruiken jullie nu?
Gebruiken nu dingen als chapignons, ui, gember, knoflook. We verstoppen eten, grote en kleine stukken.
We gebruiken ook ballen en cilinders met hooi en eten erin, dan moeten ze eerst het hooi eruit trekken om bij het eten te komen.
Ook puzzels met brokjes erin.
Bakken en buizen aan de buitenkant van de hekken met eten.
Ook wel een speelgoed vastgemaakt aan het hek, van die houden platen met ijzerdraad erop met verschillende kleuren houten kralen eraan. Dat vonden ze ook heel leuk en gingen ze minder destructief mee om. Misschien omdat ze niet verwachten dat er wat te eten in zat?
   a. Gebruiken jullie daar een voedsel beloning voor?
   b. Hoe reageren ze daarop?
   c. Heeft dit effect op de sociale structuur van de groep?
   d. Of heeft de structuur van de groep veel effect op de soort verrijking die jullie gebruiken?
   e. Ik las in het interview van vorig jaar iets over een belletje, gebruiken jullie dat nog? Hoe reageren ze hierop?
   Dat is het signaal om naar binnen of buiten te gaan.
   f. Hoe reageren ze op geluid? Menselijk geluid tegenover natuurlijk geluid?
   Geluid wordt nog niet echt gebruikt. Ze reageren meer op andere dieren dan op 'menselijk' geluid.
   Ze reageren wel op sleutel geluid, door de associatie dat er verzorgers met eten aan komen.
   Als je hetzelfde geluid steeds gebruikt zal dat niet lang interessant zijn.
   Bij het Q gebouw is er wel wat geprobeerd met verkeersgeluid maar dat was geen succes, daar werden ze angstig van.
   Ideetjes: sambaballen, keyboard, klokkenspel.

FIGURE C.2

g. Welke zintuigen worden nu geprikkeld met de verrijking? Zien, horen, ruiken, proeven, voelen (textuur, warmte), beweging? En waar zie je nog kansen?
   Ze worden erg gevarieerd verrijkt. Alle zintuigen worden wel geprikkeld. Nu is het wel vooral een laag aan interactie, we zouden graag meerdere lagen aan interactie willen zien.
   Pas op als je foerageren stimuleert, dan moet er eigenlijk een etensbeloning aan vast zitten. Anders beloof je iets maar geef je dat niet.
   Gebaseerd op het prototype van Snigdha: liever meerdere units en wel met eten.
   Op het gebied van voeding mag het niet te voorspelbaar zijn, soms is het ook goed dat ze geen succes hebben, dat houdt het ook interessant.

5. Wat zijn goede voorbeelden van de makkelijke activiteiten, te moeilijke activiteiten, en de juiste moeilijkheidsgraad?
   We hebben wat er gebruikt wordt al besproken, omwille van de tijd gaan we door naar het volgende onderdeel.

FIGURE C.3

Deel 2: Het vorige prototype, nieuwe ideeën en vereisten (20 minuten)

We gaan het nu hebben over de evaluatie van het vorige prototype, of er ideeën zijn die je ook veelbelovend vond of dat je misschien nieuwe ideeën hebt en als laatste wil ik het graag hebben over de vereisten voor het nieuwe prototype.

Zoals genoemd in de uitnodiging zit er in de bijlage een korte samenvatting van het uiteindelijke prototype van vorig jaar en andere belangrijke stappen van het onderzoek

1. Ik heb een samenvatting van het vorige prototype bijgevoegd en ik heb het fysieke prototype meegenomen. Als jullie hier zo naar kijken….
   Leuk bedacht, goed uitgangspunt al was het er maar een, dat zorgt voor sociale problemen.
   De takken gingen te makkelijk los.
   Voor de verzorgers moet het makkelijk schoon te maken zijn.
   De interactie was wel goed, van het geluid en het zoeken onder de bladeren.
   Je zou het geluid ook als trigger kunnen gebruiken. Zo van: nu is het tijd om te gaan zoeken.
   Als je meerdere units hebt, kunnen ze bijvoorbeeld een geluidje maken om te signaleren dat ze kunnen gaan foerageren, de dieren moeten dan gaan zoeken.
   Het formaat is prima.
   a. Wat valt je als eerste op?
   b. Wat is goed aan het prototype?
   c. Wat is minder goed aan het prototype?
2. Vorig jaar zijn er ook eerst tests gedaan met voorwerpen om te kijken wat de dieren interessant vonden. Ik zal de voorwerpen laten zien en even kort doorlopen. Daarnaast heb ik nog wat andere opties gevonden, daarover hoor ik ook graag jullie mening.
   De trampoline was niet interessant.
   De projectie was het te licht voor, maar de interactie leek wel veelbelovend.
   De hangende buizen waren alleen interessant als er iets in zat, als er niets in zat vonden de dieren het niet interessant genoeg.
   Dingen die ze kapot kunnen maken of waar ze in kunnen zoeken zijn goed.
   Stimuleren om te zoeken is belangrijk.
   Misschien iets dat de dieren iets triggeren tijdens het zoeken, zoals een licht sensor, en dat dat dan ook weer ergens anders een geluid aanzet. Beetje zoals het originele idee van Snigdha.
   Skippybal zouden ze alleen maar stuk bijten, geen goed idee.
   Zo'n snuffelmat kan interessant zijn, dan kan je misschien ook werken met geuren.
   De geluidskubus moet wel sterk zijn, en niet te hard want pas op met gooien.
   Rubber ding in de scheur knuffel mag ook niet te hard zijn, maar het principe van zo'n scheurknuffel is wel interessant. Ze krijgen wel vaker stof en dekentjes om mee te spelen.
   a. Welke voorwerpen zijn uiteindelijk niet gebruikt maar hebben wel potentie denk je? En waarom?
   b. Welke voorwerpen zouden beter niet gebruikt moeten of kunnen worden?
   c. Zijn er nog meer voorwerpen waarvan je denkt dat ze als inspiratie kunnen dienen?
   d. Wat zijn (nog meer) belangrijke eigenschappen van interessante voorwerpen?

Figure C.4

3. Voor het nieuwe prototype heb ik de volgende vereisten opgesteld. Met welke ben je het eens? Welke zou je veranderen? Zou je nog wat toevoegen? Heb je nog tips of vuilkuilen waar ik voor op moet passen?
   Zie de schuine tekst hieronder om te zien wat toegevoegd is.

Ethische vereisten	**Praktische vereisten**	**Gedrag vereisten**
Geen onoplosbare frustratie opwekken	Stevig en aap bestendig	Natuurlijk gedrag stimuleren (zoals foerageren, vlooien, insmeren etc.)
Niet te monopoliseren zijn door een dier	Geen kleine losse onderdelen *=> Kijk heel goed naar wat vast moet, dat dat echt goed vast zit*	Stereotyperend gedrag verminderen (zoals krabben, rondjes lopen etc.)
Moet vanuit de principes van de dieren komen, en niet vanuit mensen	Geen scherpe randjes	Intuïtief te gebruiken door de dieren
De dieren moeten er van weg kunnen als ze er niet mee in aanraking willen komen	Geen dingen waar de vingertjes tussen kunnen komen	
	Het liefst makkelijk te onderhouden => *Makkelijk schoon te maken*	
	Het liefst met makkelijk te vervangen onderdelen	
	Waterproof genoeg stel het is vochtig of het regent	

Afsluiting (5 minuten)

Hier is nog ruimte voor als je nog vragen hebt voor mij of nog opmerkingen over het interview of het onderzoek. Ik zal ook uitleggen wat er verder nog gaat gebeuren in mijn onderzoek en waar ik eventueel weer input nodig heb. Ook heel erg bedankt voor het mee doen aan dit interview!

Laatste tips:

Kijk goed uit bij het testen dat je zelf heel erg het gedrag van de dieren kan beïnvloeden, zelfs al met je mimiek alleen. Daarom is de vorige keer de observaties met Google Nest camera gegaan.

Figure C.5

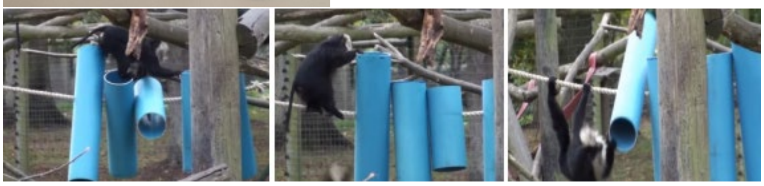
Samenvatting prototype(s) Snigdha

In deze samenvatting grijp ik terug op twee stadia van het onderzoek van Snigdha. Zij was ook bezig met verrijking maken voor de kapucijn apen en deed dit met een paar 1e objecten voor inspiratie en een uiteindelijk prototype.

Objecten ter inspiratie (relevant voor deel 2 vraag 2)

Na het lezen van literatuur en een interview met de verzorgers heeft Snigdha de volgende objecten bij de apen geplaatst om te kijken hoe ze hierop zouden reageren. Op basis daarvan zijn er keuzes gemaakt voor het latere prototype. De objecten die ze had gekozen zijn:

Rattleway: *bestaande uit pvc buizen aan een metalen ketting. De buizen maakten geluid zoals stenen die tegen elkaar slaan, maar ook het geluid van autoverkeer of Afrikaanse muziek.*



Basketbal:

Figure C.6

Sla de tegels: *licht tegels die van kleur veranderen als je ze aanraakt.*

Trampoline*:*

Laserpointer*:*

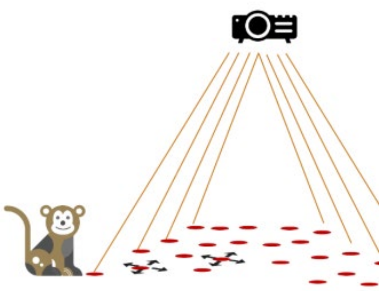


FIGURE C.7

Warm water badje:

***Projectie**: beamer projectie van gras of lava lampen*

Figure 44: Multicolour lava lamp transition video

Figure 45: Snip from the video of grass

FIGURE C.8

Extra ideeën

Naast deze objecten heb ik zelf nog wat andere ideeën geselecteerd waar ik ook graag jullie mening over hoor. Dat zijn de volgende objecten:

Snuffelmat: Dit wordt nu vooral gebruikt voor huisdieren. Het idee is gebaseerd op dat dat ik de apen vooral in het gras zag zoeken naar eten. Hier zou ik bijvoorbeeld een versie van kunnen maken die detecteert als hij gebruikt wordt en dan communiceert met eventuele andere matten in het verblijf. Dan zou een andere mat bijvoorbeeld geluid kunnen gaan maken.

Geluid blokken: Blokken met op elke kant kan een andere textuur hebben bijvoorbeeld. De buitenkant zou wel een zachter materiaal hebben dan hout (een stoffen hoes bijvoorbeeld). We kunnen later wat doen met geluid bijvoorbeeld.

Verwoestbare knuffel: Een knuffel. Uit eindelijk zouden die bekleed kunnen zijn met lagen stof die redelijk makkelijk opengaan met als kern een niet zo makkelijk te verwoesten speeltje. Onder de lagen stof zouden noten verstop kunnen zitten bijvoorbeeld.

Boomstronk: Een boomstronk (hier kunnen we later misschien verschillende interacties mee uitvoeren)

Skippybal: Was de vorige keer uiteindelijk niet geprobeerd, maar is misschien het proberen waard.

FIGURE C.9

Haar uiteindelijke prototype (relevant voor deel 2 vraag 1)

Na de eerste ronde prototypes heeft Snigdha een uiteindelijk prototype ontworpen. Hieronder kan je zien hoe het er uit zag. Dit prototype was voortgekomen uit de 'rattleway with pvc tubes' van de eerste ronde prototypes, zoals te zien op het laatste plaatje.

Het concept van dit prototype was dat wanneer de dieren de bladeren bewegen om eronder te kijken of ze eraf te halen, gaan de speakers onder in het prototype verschillende geluiden maken. Ook als de doos veel bewogen wordt door er bijvoorbeeld tegen te duwen of te laten slingeren maakt het geluid. De gekozen geluiden waren van verschillende insecten zoals wespen, sprinkhanen of bijvoorbeeld kikkers. Er was voor gekozen om geen eten uit het prototype te laten komen, het was dus gefocust op het aanspreken van de intrinsieke motivatie van de dieren. Het idee was om uiteindelijk meerdere van deze prototypes te hebben hangen in door het hele verblijf.

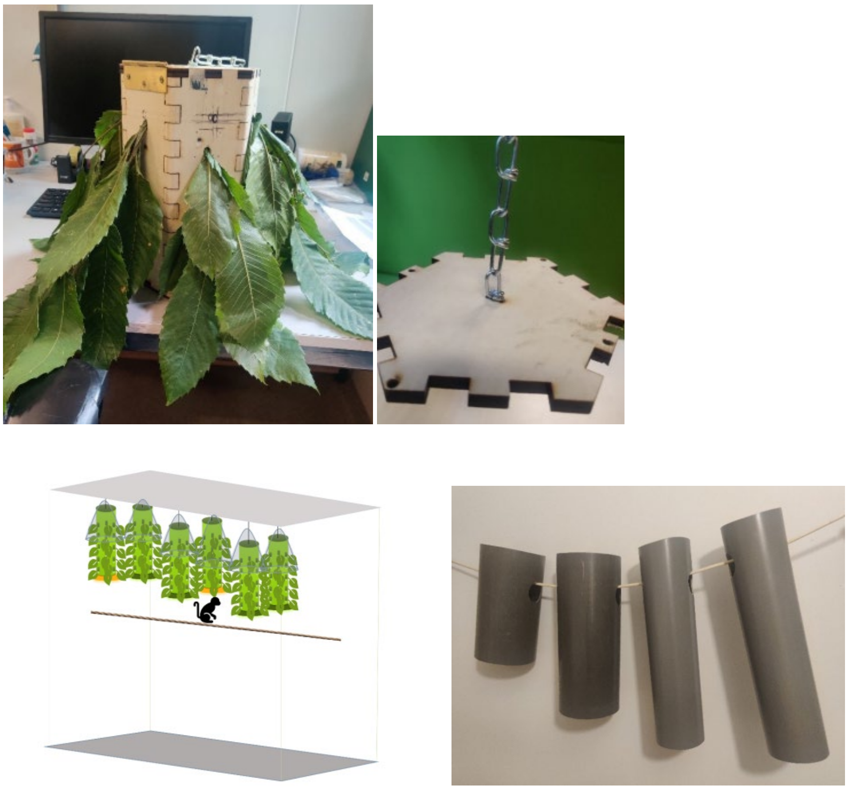


Figure C.10

Date 31-okt **Enclosure** WFC

	Animal 1		**Animal 2**		**Animal 3**		**Animal 4**	
Time	**Location**	**State**	**Location**	**State**	**Location**	**State**	**Location**	**State**
11:07	ground	MO	ground	FO	ground	FO	ground	FO
11:10	tree	MO	stump	EA	tree	MO	tree	LA
11:13	branch	LA	tree	LA	tree	LA	ground	FO
11:16	ground	LA	ground	FO	ground	FO	tree	MO
11:19	rope	MO	ground	FO	stump	LA	stump	LA
11:22	rope	MO	stump	EA	ground	FO	ground	FO
11:25	branch	LA	ground	FO	ground	FO	ground	FO
11:28	ground	FO	ground	FO	ground	MO	ground	FO
11:31	ground	MO	branch	LA	ground	FO	rope	MO
11:34	branch	LA	branch	G	rope	MO	ground	FO

Date 1-nov **Enclosure** WFC

	Animal 1		**Animal 2**		**Animal 3**		**Animal 4**	
Time	**Location**	**State**	**Location**	**State**	**Location**	**State**	**Location**	**State**
11:20	fence	MO	ground	FO	ground	FO	rope	MO
11:23	branch	LA	stump	G	stump	G	stump	G
11:26	branch	CS	branch	CS	ground	MO	stump	LA
11:29	rope	MO	branch	G	branch	G	stump	EA
11:32	branch	G	branch	G	rope	MO	branch	LA
11:35	branch	G	branch	G	branch	LA	ground	FO
11:38	branch	G	branch	G	ground	FO	ground	FO
11:41	branch	LA	branch	MO	ground	FO	stump	MO
11:44	branch	LA	branch	LA	ground	FO	ground	FO
11:47	branch	SS	branch	MO	stump	EA	stump	LA

Date 1-nov **Enclosure** YBC - David

	Animal 1		**Animal 2**		**Animal 3**		**Animal 4**	
Time	**Location**	**State**	**Location**	**State**	**Location**	**State**	**Location**	**State**
13:32	Branch	LA	branch	EA	ground	LA	ground	FO
13:35	plate	EA	ground	FO	ground	LA	branch	EA (breakir
13:38	plate	LA	branch	MO	ground	CS	ground	EA/CS
13:41	plate	EA	rope	MO	ground	CS	ground	EA/CS
13:44	tree	LA	ground	FO	ground	FO	ground	FO
13:47	tree	LA	ground	FO	hut	EA	ground	FO
13:50	tree	LA	rope	EA	ground	FO	ground	FO
13:53	plate	EA	tree	LA	plate	LA	hut	GS
13:56	rope	LA	plate	SS	hut	GS	stump	LA
13:59	bushes	FO	branch	EA	ground	FO	ground	EA

Figure C.11

Date 1-nov **Enclosure** YBC - Xomas

	Animal 1		Animal 2		Animal 3		Animal 4	
Time	**Location**	**State**	**Location**	**State**	**Location**	**State**	**Location**	**State**
14:22	ground	FO	branch	EA	plate	EA	branch	MO
14:25	tree	MO	branch	MO	branch	lifting eyeb	?	?
14:28	ground	FO	rope	MO	rope	MO	?	?
14:31	branch	SS	ground	FO	plate	LA	?	?
14:34	branch	GS	branch	LA	plate	GS	?	?
14:37	tree	GS	tree	MO	branch	EA	?	?
14:40	tree	GS	tree	catching in	stump	LA	?	?
14:43	stump	GS	stump	LA	?	?	?	?
14:46	branch	LA	rope	MO	branch	MO	branch	lifting eyeb
14:49	branch	LA	branch	LA	branch	LA	?	?

Figure C.12

D. Prototypes

In this Appendix, one can find the summary of the interviews during the off-the-shelf prototype testing and the sketches of some ideas for the hi-fi prototype and storyboards.

Date	**Object**	**Length**	**Food**		19-feb	CB	12	NF
22-jan	SM	23	NF		19-feb	CB	50	NF
22-jan	SM	21	NF		19-feb	CB	15	NF
22-jan	SM	5	NF		19-feb	CB	10	NF
22-jan	SM	11	NF		19-feb	CB	8	NF
22-jan	SM	4	NF		22-feb	SM	6	F
22-jan	SM	15	NF		22-feb	SM	6	F
22-jan	SM	16	NF		22-feb	SM	14	F
22-jan	SM	5	NF		22-feb	SM	40	F
22-jan	SM	3	NF		22-feb	SM	136	F
22-jan	SM	11	NF		22-feb	SM	39	F
22-jan	CB	82	NF		22-feb	SM	5	F
22-jan	CB	50	NF		22-feb	SM	12	F
22-jan	CB	23	NF		22-feb	SM	24	F
22-jan	CB	15	NF		22-feb	SM	4	F
25-jan	SM	19	F		22-feb	SM	15	F
25-jan	SM	4	F		22-feb	SM	8	F
25-jan	CB	15	F		22-feb	SM	21	F
25-jan	CB	22	F		22-feb	SM	45	F
25-jan	CB	18	F		22-feb	SM	6	F
25-jan	CB	16	F		22-feb	SM	4	F
25-jan	CB	8	F		22-feb	SM	28	F
25-jan	CB	18	F		22-feb	SM	6	F
25-jan	CB	8	F		22-feb	SM	18	F
25-jan	CB	2	F		22-feb	SM	8	F
25-jan	CB	12	F		22-feb	CB	5	F
25-jan	CB	5	F		22-feb	CB	76	F
19-feb	CB	20	NF		22-feb	CB	21	F
19-feb	CB	25	NF		22-feb	CB	12	F

Table D.1: This table contains the raw data from the off-the-shelf prototypes. The recorded data is the date of the test, the object which an animal interacted with, the length of the interaction and if food was or was not introduced with the prototype.

D.1 Hi-fi prototype interview questinons

Guiding questions for the interview with the carers were:

1. What kind of reactions do you see towards the prototype?
2. What unit do they find most interesting? Do they react as you would expect?
3. What do you see in terms of social dynamics? Are they different than usual?
4. What do they find interesting in this prototype and why do you think that is?
5. Did they react interested, excited, scared and why?
6. Did you see any stress signals?

Purpose	Component	Connected to
Haybox	Distance sensor	ESP32
Acceleration	Accelerometer	ESP32
Sound	Speaker	DF Player mini
Sound processing	DF Player mini	ESP32
Food dispenser	Servo motor	ESP32
Power	Powerbank	ESP32
Power	Batteries	Servo motor

Table D.2: An overview of all components in Unit 1, what they are used for, and what they are connected to.

Purpose	Component	Connected to
Branch	Load sensor	ESP32
Acceleration	Accelerometer	ESP32
Sound	Speaker	DF Player mini
Sound processing	DF Player mini	ESP32
Food dispenser	Servo motor	ESP32
Power	Powerbank	ESP32
Power	Batteries	Servo motor

Table D.3: An overview of all components in Unit 2, what they are used for, and what they are connected to.

The code for unit one with the hay box:

```
    // Include libraries used for sensors etc.
#include <Wire.h>
#include <Adafruit_Sensor.h>
#include <Adafruit_ADXL345_U.h>
#include <ESP32Servo.h>
#include "DFRobotDFPlayerMini.h"

// Pin definitions
// Not included here are pins for the ACC (SCL = D22, SDA = D21)
// And the DFplayer mini with RX2 and TX2
const int LDR_PIN_1 = 25; // Pin for LDR 1
const int LDR_PIN_2 = 26; // Pin for LDR 2
const int LDR_PIN_3 = 27; // Pin for LDR 3
const int servoPin = 14; // Pin for servo motor

// Variables and thresholds
const int LDR_THRESHOLD = 100; // LDR threshold for dimming
//(below 100 is when covered, reverse for prototype)
const float ACCEL_THRESHOLD = 2.0; // Accelerometer threshold for change
const int speaker_volume = 15; // speaker volume, between 0 and 30,
//however 30 is clipping, 17 is maximum for this type of speaker
const int puzzle_levels = 3; // How many times is one level played,
//example: 3 means level 0 has to be completed 3 times for it to move on to level 1

// Servo
Servo myServo;
unsigned long servoStartTime = 0;
bool servoActive = false;

// Accelerometer
Adafruit_ADXL345_Unified accel = Adafruit_ADXL345_Unified(12345);
float prevAccelX = 0, prevAccelY = 0, prevAccelZ = 0;

// DFPlayer
DFRobotDFPlayerMini myDFPlayer;
void printDetail(uint8_t type, int value);


void setup() {
  Serial2.begin(9600);
  Serial.begin(115200);
  myServo.attach(servoPin);

  //Initialize dfplayer
    if (!myDFPlayer.begin(Serial2, /*isACK = */true, /*doReset = */true)) {
    //Use serial to communicate with mp3.
    Serial.println(F("Unable to begin:"));
```

```
    Serial.println(F("1.Please recheck the connection!"));
    Serial.println(F("2.Please insert the SD card!"));
    while(true){
      delay(0); // Code to compatible with ESP8266 watch dog.
    }
  }
  Serial.println(F("DFPlayer Mini online."));

  myDFPlayer.volume(speaker_volume);  //Set volume value. From 0 to 30
  myDFPlayer.play(1);  //Play the first mp3

  // Initialize accelerometer
  if (!accel.begin()) {
    Serial.println("Failed to initialize the ADXL345 sensor!");
    while (1);
  }
  accel.setRange(ADXL345_RANGE_16_G);

  // Initialize puzzle sequence
  int puzzle_current = 0;
  // Set the current puzzle to puzzle 0, when puzzle_levels has been reached,
  //this will go to the next puzzle
  int puzzle_solved = 0;
  // Set the counter of how many times a puzzle has been solved to 0
  //(when this reaches puzzle_levels, it will be set to 0 again

  /*
  send puzzle_current to unit 1
  */
}

void loop() {

  /*
   depending on p0,1,2 do a check (maybe make seperate voids)

  if void returns true:
    servo this unit
    servo other unit
    add puzzle_solved

  if puzzle_solved = puzzle_levels
    puzzle_current ++ (so check next void)
    else
      nothing?
  */
```

```
if (!servoActive) {
  // Check LDR values
  int ldrValue1 = analogRead(LDR_PIN_1);
  int ldrValue2 = analogRead(LDR_PIN_2);
  int ldrValue3 = analogRead(LDR_PIN_3);

  if (ldrValue1 < LDR_THRESHOLD || ldrValue2 < LDR_THRESHOLD
  || ldrValue3 < LDR_THRESHOLD) {
    Serial.println("LDR triggered below threshold:");
    if (ldrValue1 < LDR_THRESHOLD) {
      Serial.println("LDR 1: " + String(ldrValue1));
    }
    if (ldrValue2 < LDR_THRESHOLD) {
      Serial.println("LDR 2: " + String(ldrValue2));
    }
    if (ldrValue3 < LDR_THRESHOLD) {
      Serial.println("LDR 3: " + String(ldrValue3));
    }
    // Move the servo for 2 seconds
    myServo.write(90);
    servoStartTime = millis();
    servoActive = true;
    myDFPlayer.next();
  }
  else {
    // Check accelerometer values
    sensors_event_t event;
    accel.getEvent(&event);
    float accelChangeX = abs(event.acceleration.x - prevAccelX);
    float accelChangeY = abs(event.acceleration.y - prevAccelY);
    float accelChangeZ = abs(event.acceleration.z - prevAccelZ);

    if (accelChangeX >= ACCEL_THRESHOLD || accelChangeY >= ACCEL_THRESHOLD ||
    accelChangeZ >= ACCEL_THRESHOLD) {
      Serial.println("Accelerometer value changed:");
      Serial.print("X: ");
      Serial.print(event.acceleration.x);
      Serial.print(" Y: ");
      Serial.print(event.acceleration.y);
      Serial.print(" Z: ");
      Serial.println(event.acceleration.z);
      // Move the servo for 2 seconds
      myServo.write(90);
      servoStartTime = millis();
      servoActive = true;
```

```
        myDFPlayer.next();
      }

      prevAccelX = event.acceleration.x;
      prevAccelY = event.acceleration.y;
      prevAccelZ = event.acceleration.z;
    }
  }

  // Check if servo should stop after 2 seconds
  if (servoActive && millis() - servoStartTime >= 2000) {
    myServo.write(0); // Stop the servo
    servoActive = false; // Reset servo state
  }
}

// INSERT VOIDS FOR PUZZLE 0,1,2

void printDetail(uint8_t type, int value){
  switch (type) {
    case TimeOut:
      Serial.println(F("Time Out!"));
      break;
    case WrongStack:
      Serial.println(F("Stack Wrong!"));
      break;
    case DFPlayerCardInserted:
      Serial.println(F("Card Inserted!"));
      break;
    case DFPlayerCardRemoved:
      Serial.println(F("Card Removed!"));
      break;
    case DFPlayerCardOnline:
      Serial.println(F("Card Online!"));
      break;
    case DFPlayerUSBInserted:
      Serial.println("USB Inserted!");
      break;
    case DFPlayerUSBRemoved:
      Serial.println("USB Removed!");
      break;
    case DFPlayerPlayFinished:
      Serial.print(F("Number:"));
      Serial.print(value);
      Serial.println(F(" Play Finished!"));
      break;
    case DFPlayerError:
      Serial.print(F("DFPlayerError:"));
      switch (value) {
```

```
        case Busy:
          Serial.println(F("Card not found"));
          break;
        case Sleeping:
          Serial.println(F("Sleeping"));
          break;
        case SerialWrongStack:
          Serial.println(F("Get Wrong Stack"));
          break;
        case CheckSumNotMatch:
          Serial.println(F("Check Sum Not Match"));
          break;
        case FileIndexOut:
          Serial.println(F("File Index Out of Bound"));
          break;
        case FileMismatch:
          Serial.println(F("Cannot Find File"));
          break;
        case Advertise:
          Serial.println(F("In Advertise"));
          break;
        default:
          break;
      }
      break;
    default:
      break;
  }

}
```

The code for unit two with the branch:

```
  //Incluse libraries for
#include <Wire.h>
#include <Adafruit_Sensor.h> //accelerometer
#include <Adafruit_ADXL345_U.h> //accelerometer
#include <ESP32Servo.h> //servo
#include "DFRobotDFPlayerMini.h" //dfplayer
#include <Arduino.h> //load sensor
#include "soc/rtc.h" //load sensor
#include "HX711.h" //load sensor
#include <esp_now.h> //espnow communication
#include <WiFi.h> //wifi for espnow

// Pin definitions
const int servoPin = 14; // Pin for servo motor
// HX711 circuit wiring for the load sensor
const int LOADCELL_DOUT_PIN = 2;
const int LOADCELL_SCK_PIN = 4;

long loadreading; //make variable globally for the checking of the values

//Setup variables for the interval timer
static unsigned long timer;
int set_timer;

// Thresholds
const int LOAD_THRESHOLD = 220000; //load sensor threshold for trigger
const float ACCEL_THRESHOLD = 4.0; // Accelerometer threshold for change

//HX711
HX711 scale;

// Servo
Servo myServo;
unsigned long servoStartTime = 0;
bool servoActive = false;

// Accelerometer
Adafruit_ADXL345_Unified accel = Adafruit_ADXL345_Unified(12345);
float prevAccelX, prevAccelY, prevAccelZ;

//DFplayer mini setup
DFRobotDFPlayerMini myDFPlayer;
void printDetail(uint8_t type, int value);

//Level structure
//The levels are determined in unit 1, only local parameters are used here on unit 2
```

```
//Setup communication with macadress of unit one
uint8_t broadcastAddress[] = {0xA0, 0xDD, 0x6C, 0x0F, 0xE1, 0x44};
// Define variables to store data to be sent
int Sacc2;
int Sload2;
int Sservo = 0; //should be 0 always
// Define variables to store incoming data
int Iacc2 = 0; //should be 0 always
int Iload2 = 0; //should be 0 always
int Iservo;
// Variable to store if sending data was successful
String success;

int acc2;
int load2;
int servo;

//Structure example to send data
//Must match the receiver structure
typedef struct struct_message {
    int acc2;
    int load2;
    int servo;
} struct_message;
// Create a struct_message called BME280Readings to hold sending data
struct_message Sending;
// Create a struct_message to hold incoming data
struct_message Incoming;

esp_now_peer_info_t peerInfo;

// Callback when data is sent
void OnDataSent(const uint8_t *mac_addr, esp_now_send_status_t status) {
  Serial.print("\r\nLast Packet Send Status:\t");
  Serial.println(status == ESP_NOW_SEND_SUCCESS ? "Delivery Success" : "Delivery Fail");
  if (status ==0){
    success = "Delivery Success :)";
  }
  else{
    success = "Delivery Fail :(";
  }
}

// Callback when data is received
void OnDataRecv(const uint8_t * mac, const uint8_t *incomingData, int len) {
  memcpy(&Incoming, incomingData, sizeof(Incoming));
  Serial.print("Bytes received: ");
  Serial.println(len);
  Serial.print("INCOMING SERVO: ");
```

```
  Serial.println(Incoming.servo);
  Iacc2 = Incoming.acc2;
  Iload2 = Incoming.load2;
  Iservo = Incoming.servo;

  //If the servo is triggered a level is complete so put the sensor values back to 0
  if (Iservo == 1) {
    if (!servoActive){
      servoStartTime = millis();
      servoActive = true;
      myServo.write(0);
      myDFPlayer.next();
      Serial.println("IServo: ");
      Serial.println(Iservo);
      Serial.println("SERVO triggered");
    }
  }
}


void setup() {

  Serial.println("Booted correctly, waiting 5 minutes");

  //make it so nothing is done the first five minutes.
  //This gives us time to place the boxes
  delay(500);

  Serial2.begin(9600); //dfplayer serial for communication
  Serial.begin(115200); //serial monitor communication
  myServo.attach(servoPin);

  //Setup timer for the sound
  timer = millis();
  set_timer = 300000;

  //loadcell configuration
  rtc_cpu_freq_config_t config;
  rtc_clk_cpu_freq_get_config(&config);
  rtc_clk_cpu_freq_to_config(RTC_CPU_FREQ_80M, &config);
  rtc_clk_cpu_freq_set_config_fast(&config);
  scale.begin(LOADCELL_DOUT_PIN, LOADCELL_SCK_PIN);

  //Initialize dfplayer
  Serial.println();
  Serial.println(F("DFRobot DFPlayer Mini Demo"));
  Serial.println(F("Initializing DFPlayer ... (May take 3~5 seconds)"));

  if (!myDFPlayer.begin(Serial2, /*isACK = */true, /*doReset = */true)) {
```

```
  //Use serial to communicate with mp3.
    Serial.println(F("Unable to begin:"));
    Serial.println(F("1.Please recheck the connection!"));
    Serial.println(F("2.Please insert the SD card!"));
    while(true){
      delay(0); // Code to compatible with ESP8266 watch dog.
    }
  }
  Serial.println(F("DFPlayer Mini online."));

  myDFPlayer.volume(17);  //Set volume value. From 0 to 30

  // Initialize accelerometer
  if (!accel.begin()) {
    Serial.println("Failed to initialize the ADXL345 sensor!");
    while (1);
  }
  accel.setRange(ADXL345_RANGE_16_G);

  sensors_event_t event;
  float prevAccelX = event.acceleration.x;
  float prevAccelY = event.acceleration.y;
  float prevAccelZ = event.acceleration.z;

  // Set device as a Wi-Fi Station
  WiFi.mode(WIFI_STA);
  // Init ESP-NOW
  if (esp_now_init() != ESP_OK) {
    Serial.println("Error initializing ESP-NOW");
    return;
  }
  // Once ESPNow is successfully Init, we will register for Send CB to
  // get the status of Trasnmitted packet
  esp_now_register_send_cb(OnDataSent);
  // Register peer
  memcpy(peerInfo.peer_addr, broadcastAddress, 6);
  peerInfo.channel = 0;
  peerInfo.encrypt = false;
  // Add peer
  if (esp_now_add_peer(&peerInfo) != ESP_OK){
    Serial.println("Failed to add peer");
    return;
  }
  // Register for a callback function that will be called when data is received
  esp_now_register_recv_cb(OnDataRecv);
}

void loop() {
```

```
// Check if servo has been active for one second
if (servoActive && millis() - servoStartTime >= 2000) {
  myServo.write(90); // Deactivate servo
  servoActive = false; // Set servo active flag to false
  Serial.println("Servo deactivated");
}

//timer for making a noise every 5 mins, increasing with 1 min every interval
if (millis() - timer > set_timer){
  timer = millis();
  set_timer += 60000;
  myDFPlayer.next();
}

//check loadcell
if (scale.is_ready()) {
    scale.set_scale();
    scale.tare();
    loadreading = abs(scale.read());
    Serial.print("LOAD: ");
    Serial.println(loadreading);
  }
  else {
    Serial.println("HX711 not found.");
}

//check Accelerometer
sensors_event_t event;
accel.getEvent(&event);
float accelChangeX = abs(event.acceleration.x - prevAccelX);
float accelChangeY = abs(event.acceleration.y - prevAccelY);
float accelChangeZ = abs(event.acceleration.z - prevAccelZ);
prevAccelX = event.acceleration.x;
prevAccelY = event.acceleration.y;
prevAccelZ = event.acceleration.z;
/*Serial.print("X: ");
Serial.println(accelChangeX);
Serial.print("Y: ");
Serial.println(accelChangeY);
Serial.print("Z: ");
Serial.println(accelChangeZ);*/

//accelChangeXYZ vs AccThreshold
if (accelChangeX > ACCEL_THRESHOLD ||
accelChangeY > ACCEL_THRESHOLD){
  Sacc2 = 1;
  Serial.println("ACC triggered");
}
//ldr123 vs ldrThreshold
```

```
  if ( loadreading > LOAD_THRESHOLD){
    Sload2 = 1;
    Serial.println("LOAD triggered");
  }

  if (Sacc2 == 1 || Sload2 == 1){
    // Send message via ESP-NOW
    Serial.print("Sending");
    Serial.print(Sacc2);
    Serial.println(Sload2);
    Sending.acc2 = Sacc2;
    Sending.load2 = Sload2;
    esp_err_t result = esp_now_send(broadcastAddress,
    (uint8_t *) &Sending, sizeof(Sending));
    //reset servo to 0 so it will send 0 on the next loop and stops turning

    Sacc2 = 0;
    Sload2 = 0;

    if (result == ESP_OK) {
      Serial.println("Sent with success");
    }
    else {
      Serial.println("Error sending the data");
    }
  }
  delay(200);

}

void printDetail(uint8_t type, int value){
  switch (type) {
    case TimeOut:
      Serial.println(F("Time Out!"));
      break;
    case WrongStack:
      Serial.println(F("Stack Wrong!"));
      break;
    case DFPlayerCardInserted:
      Serial.println(F("Card Inserted!"));
      break;
    case DFPlayerCardRemoved:
      Serial.println(F("Card Removed!"));
      break;
    case DFPlayerCardOnline:
      Serial.println(F("Card Online!"));
      break;
    case DFPlayerUSBInserted:
      Serial.println("USB Inserted!");
```

```
      break;
    case DFPlayerUSBRemoved:
      Serial.println("USB Removed!");
      break;
    case DFPlayerPlayFinished:
      Serial.print(F("Number:"));
      Serial.print(value);
      Serial.println(F(" Play Finished!"));
      break;
    case DFPlayerError:
      Serial.print(F("DFPlayerError:"));
      switch (value) {
        case Busy:
          Serial.println(F("Card not found"));
          break;
        case Sleeping:
          Serial.println(F("Sleeping"));
          break;
        case SerialWrongStack:
          Serial.println(F("Get Wrong Stack"));
          break;
        case CheckSumNotMatch:
          Serial.println(F("Check Sum Not Match"));
          break;
        case FileIndexOut:
          Serial.println(F("File Index Out of Bound"));
          break;
        case FileMismatch:
          Serial.println(F("Cannot Find File"));
          break;
        case Advertise:
          Serial.println(F("In Advertise"));
          break;
        default:
          break;
      }
      break;
    default:
      break;
  }

}
```

Name	**Unit**	**Nr interactions**	**Durations**						
David	1	1	27						
David	2	3	26	31	26				
Iba	1	7	6	36	25	63	13	9	43
Iba	2	7	25	16	12	29	7	47	69
Sella	1	1	6						
Sella	2	4	23	2	23	38			
Sophie	1	1	16						
Sophie	2	0							

TABLE D.4: This table shows the day-one interactions and their durations per animal per unit of the hi-fi prototype. Duration is in seconds.

Name	**Unit**	**Nr interactions**	**Durations**	
David	1	1	35	
David	2	0		
Iba	1	2	33	5
Iba	2	1	7	
Sella	1	0		
Sella	2	0		
Sophie	1	0		
Sophie	2	0		

TABLE D.5: This table shows the day-two interactions and their durations per animal per unit of the hi-fi prototype. Duration is in seconds.

Interview with the caretakers (audio and notes)

22-01 White Face Capuchins (Zinzi, Quito, Oemie)

The cardboard was placed on an elevated platform, the snuffle mat was placed on the floor.

The doors in the enclosure were opened and Zinzi approached to cardboard immediately. He slammed it against branched (probably seeing if something was inside or if he could use it as a tool for something). The cardboard was compact and hard, so it could be a tool. We lost sight of the cardboard for a bit but found it still in its compact form after the test. They probably didn't use the cardboard by pulling it and expanding it, which can be an opportunity for the next test: place the cardboard already extended so they know that is a possibility. Adding food can also give them the incentive to try to do this. We can also switch the locations around or place both of the items on an elevated surface.

Oemie approached the mat after a while. She smelled it and touched the mat an felt around in it for a few seconds. She approached the mat and left again quite a few times, just testing the object, being a little bit safer. Quito approached it too, sniffed it and left. Oemie rolled it up and over to see if something was underneath. Then she left the mat and went to a hay pile and looked around in there. After seven minutes she came back to look under it one last time.

Zinzi is the most dominant in the group, after that Quito. The caretaker interprets the behaviour as that Zinzi was interested in the cardboard, it was high up, which is the location they prefer. Quito tailed Zinzi and got to play with the object only after Zinzi was finished. Meanwhile, Oemie saw they were preoccupied and decided to check out the mat on the floor. She is hesitant and the mat being on the floor gives it a less safe position. However, she still approached it. This also shows that they did not find the objects scary.

We didn't see any unexpected behaviour. The animals were exploring the objects together or alone but did not show any monopolisation behaviour or aggression towards to object or each other. They mainly explored the objects together while relaxed instead of competing.

The caretaker states that the objects were quite familiar with the animals since they often get fleece blankets or carboard boxes/packaging materials to enrich their environment. This also meant they were not very interesting or wanted, making it a lower risk of monopolisation. The items also didn't contain any food or other wanted items like garlic. The caretaker says they just looked around if it contained food or if it was useful and when they saw it was not, they were not interested anymore. She also suggests that adding anything unexpected like sound or movement would make it more interesting. However, this can get old quickly.

The fleece is often used to sleep on (especially by Oemie) or as hammocks. It is also used to hide food in for example. Cardboard is used to hide food in, and they can and will break it. Bigger cardboard boxes can be a little bit more scary than small boxes. They cut holes in it for example, so they must grab in the box to find the food.

25-01 White Face Capuchins (Zinzi, Quito, Oemie)

The cardboard was extended and placed in a circle with the hollow part facing outward, the snufflemat and the cardboard were both placed in the same part of the enclosure on an elevated platform with some seeds as a food reward.

Figure D.1

When the doors opened, Oemie approached the items first. Quito and Zinzi were over at the connecting part to the other three WFCs. The other group noticed there was excitement in the group of Quito and started yelling. Probably because there was something interesting, they could not reach. Bacio probably vocalised to Quito, they are close, and Quito reacted. Zinzi joined with Quito to try and climb higher in the ranks.

Oemie interacted very shortly with the mat and the cardboard and tipped both objects over the edge to the ground. She then started searching and eating the seeds and pits that were still on the platforms. Quito joined her, they often like to eat together as the two ladies of the group they have a strong bond.

Zinzi went down to the ground to investigate the objects. However, he left them again shortly after. The animals all went down at some point to look at the objects, grabbing some left-over seeds from the ground. Quito also made some intimidation motions towards the cardboard object. The caregiver speculates this might be because it kind of looks like a snake and it does not resemble any other well-known objects.

Because the objects contained food this time, the animals kept coming back to them more often, to see if there was more to gain.

They probably pushed the objects on the floor to see what would happen. They are very explorative by just doing stuff and not by looking and waiting. If something is on the floor, it is also easier to observe it. They feel safer observing from above than from below.

The caregiver did not see any unexpected behaviour from the animals. The animals were a bit more reserved than she expected, they also reacted quite relaxed.

There was no monopolisation of the objects but the caregiver states that most often the monopolisation is done with well-known objects that the animals know contain food. Like water bottle puzzles with food in them. She advises to investigate the long-term effects of introducing these objects with food since if the objects are more well-known this can happen.

Because the group if split now, the experience when introducing new objects can be very different. This group did not have the support of the other group and them being in a different location was a little distracting.

Every introduction of an object will change the social dynamics. No matter what happens, every interaction also shapes the dynamic. The only thing you can do is to avoid designing for unnecessary monopolisation and aggressive behaviour. Introducing more objects is a good idea in that case.

The caregiver thinks the objects have potential for environmental enrichment especially because they can use their hands to explore and investigate. They like to fiddle around. She also advises to maybe hang the objects, so they can stay up instead of end up on the ground.

19-02 Yellow Breasted Capuchins (Xomas, Xanta, Xuxa, Xena)

The monkeys entered the enclosure where the items were placed. Both were placed on an elevated space, the cardboard more in the normal route of the animals and the fabric on the food bowls of the animals. The animals focused mainly on the cardboard and did not seem interested or seem to note the mat on the other side of the enclosure.

Figure D.2

During the whole session, about 30 minutes, the animals did not once touch the item. This was as expected since this group tends to be a bit more reserved when introduced to new things. They tend to wait and observe a lot instead of directly going up to the items and interacting with them.

We did hear a lot of vocalisations, which the caretaker interpreted as them being excited about the item(s) and communicating about the them.

Xomas and Xanta (mother and son) are highest in rank and were the first two to mainly go up to the object and look at it. This is not surprising since they are higher in rank and therefore have first dibs on new things like this. Later we saw Xena go up to the enclosure a bit more, since she new it was her turn only after Xomas and Xanta. Xuxa was rarely seen in the enclosure with the items.

The caretaker thought they were less interested in the fabric mat was because it was a little further away from their normal route. They could have missed it because they were preoccupied with the cardboard. They also said it could be because they more often get fabric to play with so it might have been more familiar. They do also get carboard as enrichment, however, not in this structure.

During the test, another caretaker was cleaning a nearby enclosure, this could have a little effect on the way the animals behave. However, the caretakers said that it is business as usual, and the animals are normally not very affected by this type of interruptions. Only when you enter the facility with food they will be distracted.

Also note that Xomas was holding a living frog (for two hours already) which he did not want to let go. Since the caretakers will take away the frog as soon as possible when he drops it. This might also influence his willingness to go and interact with the object(s). He probably prioritises his frog over interacting with something else.

The caretaker said that if the item(s) would be in the enclosure for longer they might approach it and start interacting with it.

When interacting with other cardboard things, like boxes, they often start destroying the boxes when the food is gone. They do this because they find it satisfying or fun, the caretaker says. They often destroy boxes and branches.

20/21-02 Yellow Breasted Capuchins (Xomas, Xanta, Xuxa, Xena) – Long term test

One caretaker noted that during one of the intermediate observation updates, Xanta and Xomas were grooming each other for a longer period. They and the well-being expert at Apenheul suspect this is because they found the objects quite exciting and tackling this together can result in a focus on social bonds.

From the observation forms we can see that they were initially more scared or anxious around the mat. Here Xena asked for support from Xomas against the mat. They were curious towards both objects but did not attempt to claim anything for themselves. Xomas was the only one to interact in some way with the objects initially. Xena, Xanta, and Xomas were socially involved with the mat. Other than that, they did not break or move the objects during the start observations.

In the intermediate observations the caretakers documented that the animals were not really scared of the objects anymore, they filled in 'neutral'. For all the other behaviours they said they weren't interested, they did not threaten or claim the objects, they didn't interact or investigate the object

Figure D.3

and there were no social differences. Both objects were still intact, and the mat was turned upside down.

On the end observations form the caretaker said that the objects weren't interesting for a long time, and it wasn't monopolised and didn't disturb the social dynamics. It was moderately scary for along period. They did note that Xuxa was playing/picking at the mat for a short time.

22-02 Yellow Breasted Capuchins (Xomas, Xanta, Xuxa, Xena)

The same group was already exposed to the two item(s) on Monday, Tuesday, and Wednesday. This means they are already a little bit familiar with the items. On Tuesday and Wednesday they were also introduced with some food. For this test we film the animals the whole time for half an hour, focussing on the interactions with the items and the food.

During this experiment the cardboard was placed on the same elevated platform and the mat was placed in the windowsill. Both locations are often used to provide the capuchins with food, so they are familiar with these locations having food items. Both items were also provided with seeds.

Xuxa almost immediately approached the mat and got some seeds from it. Later she even sat next to the mat while Xomas and Xanta were a bit hesitant. They were close to it and reached for a few seeds but also started to threaten the item. Alone and together. They mostly ate the seeds on top of the mat and the seeds inside the mat were mostly untouched.

Xanta at some point dragged the mat from the windowsill onto the ground. One animal also went to the ground to eat the fallen seeds but did not lift the mat or interacted with it on the floor in any way. They did not push the cardboard on the floor.

They kept coming back to the mat but after a while Xomas and Xanta did not return. Xuxa then moved to the cardboard.

They have used fake grass before as an enrichment, one of the caretakers was reminded of that because of the mat. They also speculated that the colours of the mat were more interesting and that is why they mostly interacted with that.

Xena was not really seen during the test and was probably outside or in other enclosures. She is lowest in rank and respects that it is not her time with the new and probably interesting items. Last week she was also chased around a lot, showing that she is low in rank.

The animals did approach the cardboard a few times and even sat close. However, only Xuxa really went close enough and even sat next to it and ate the seeds out of it. Xomas did reach for the cardboard a few times but did not approach it further.

There were frogs in the enclosure again, which might have been distracting the caretakers say.

There was no unexpected behaviour. Also, the social rank was as expected, and the animals acted accordingly. Xuxa is not the highest in rank but also has less to lose. She is probably also bolder than the others.

Figure D.4

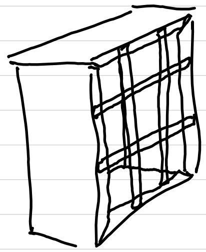
Brainstorm

	destructive	exploratory
no-food	- satisfaction has to come from interaction - don't promise food - detachable elements,	→ also applicable here - focus on making something happen (sound, movement etc.)
easy food	- hide food in breakable structure	- hide food in complex structure
triggered food	- extra sturdy! - small food so extra determined to get it - interaction focused on removing something	- can be trigered with small interactions - like trigering sensors in small spaces - complex design/interation

To battle habituatio switch out:

- which sensors have to be triggered
- "puzzle" pattern
- materials
- food (if applicable)

Modular panel ideas:



Box that you can put any material in (already used)

can put food in it too

Figure D.5

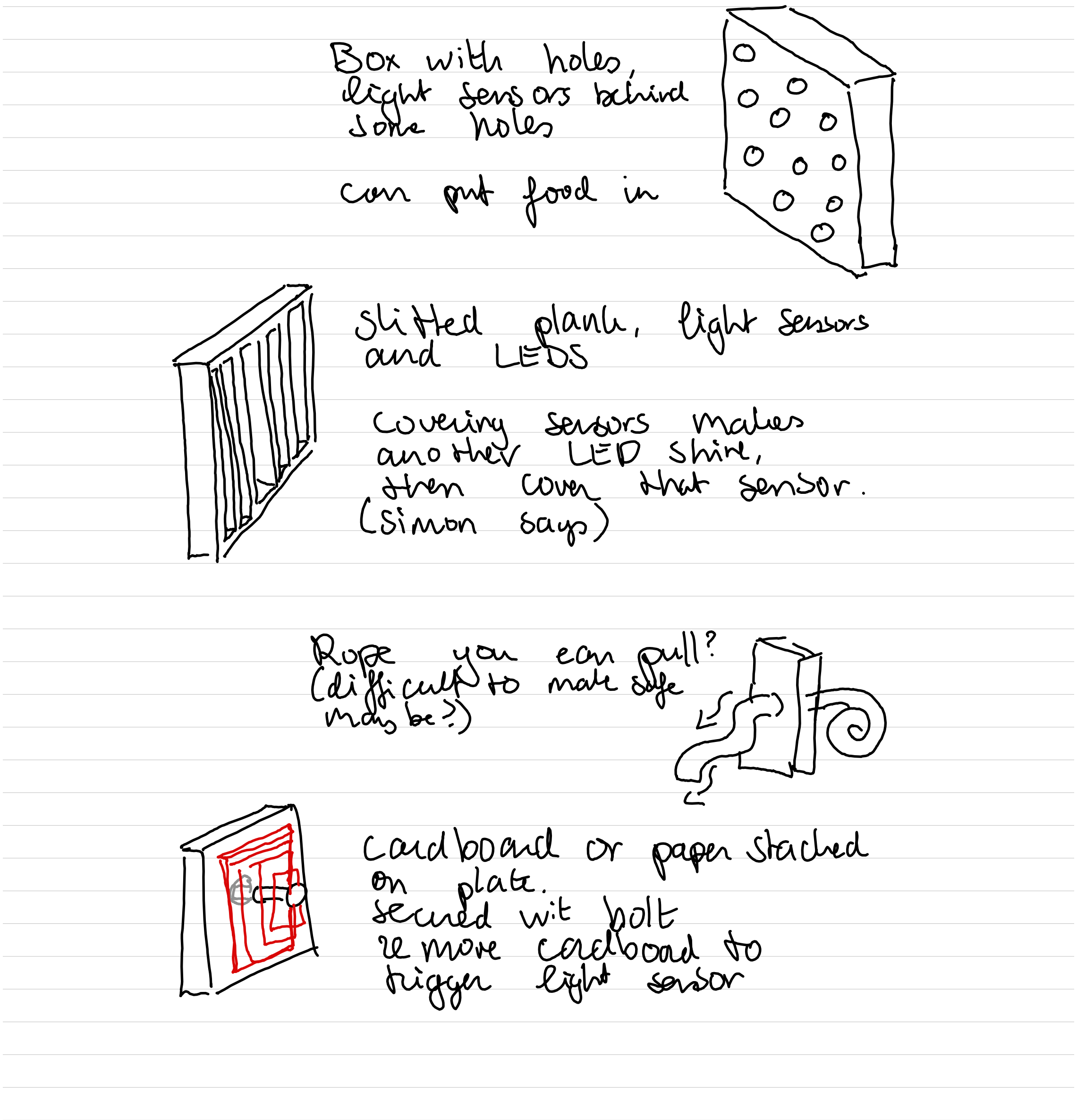

Box with holes,
light sensors behind
some holes
can put food in
slitted plank, light sensors
and LEDS
covering sensors makes
another LED shine,
then cover that sensor.
(simon says)
Rope you can pull?
(difficult to make safe
maybe?)
cardboard or paper stacked
on plate.
secured wit bolt
remove cardboard to
trigger light sensor

Figure D.6

From lit - lofi - hifi

- Lit + obser. + interviews
  - foraging + annointing
  - different materials then Snigdha
  - multiple units → social + monopolisation
  - forage a lot of the time
  - food vs no food difficult question

- Lo-fi tests
  = target foraging — pulling
  ↳ and type of interaction (D/E) — moving things around — smell — picking
  = multiple units
  = without food then with food
  = 2 different materials (and look at Snigdha's)

- Hi-fi prototype
  ① = multi-unit (Snigdha, lit, interv.)
  ①② = no food, easy food, rigged food (lo-fi)
  ②③ = Destructive or Explorative (lo-fi)
  ③ = type of materials (lo-fi, int.)
  ①②③ = type of interactions (lo-fi, lit, intv.)
  ① = puzzle type (lit, intv., obs.)

① multi-unit interaction
② single-unit interaction
③ detailed interaction

Figure D.7

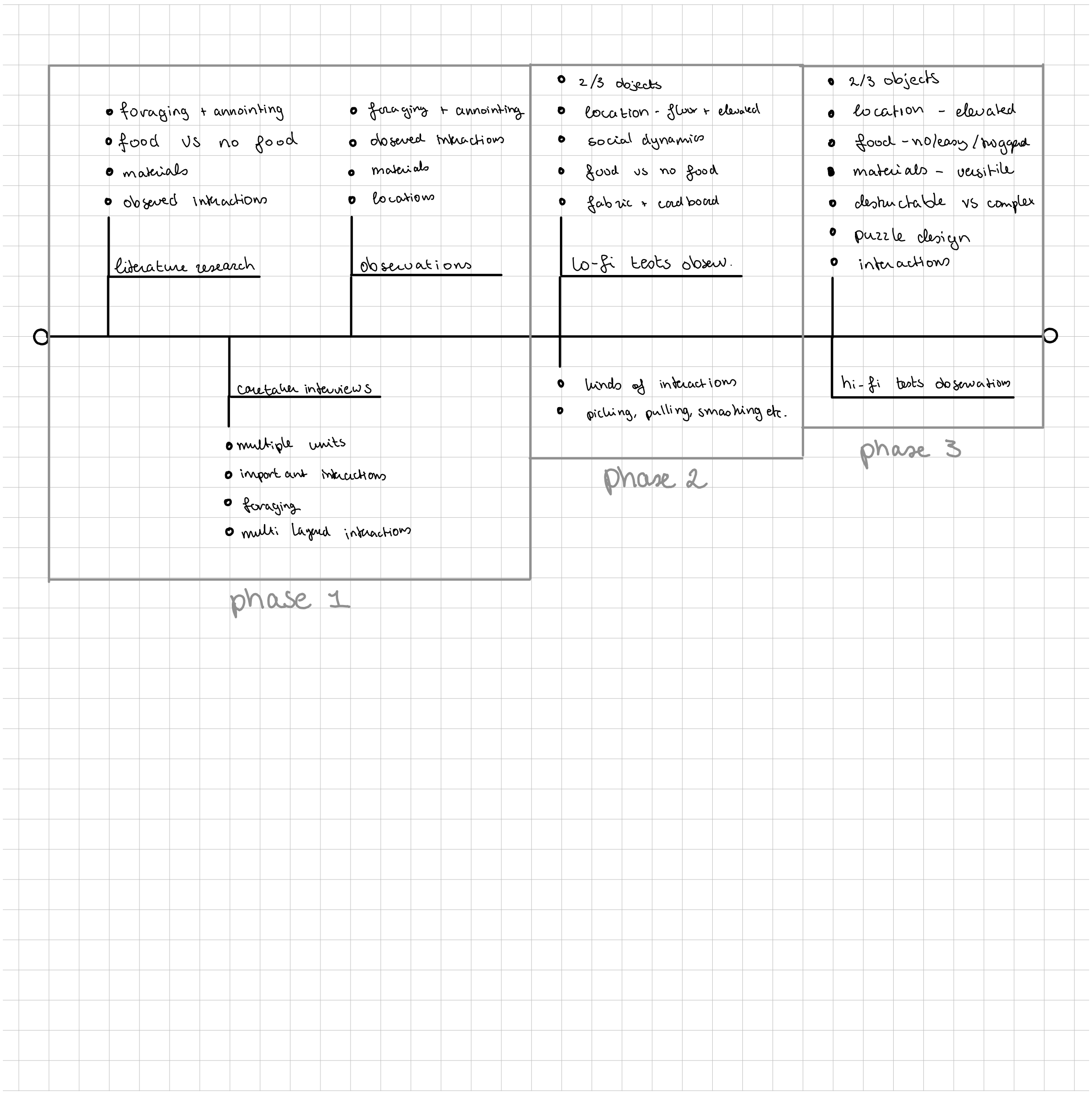

foraging + annointing
food vs no food
materials
obseved interactions
literature research
foraging + annointing
obseved interactions
materials
locations
observations
caretaker interviews
multiple units
important interactions
foraging
multi layered interactions
phase 1
2/3 objects
location - floor + elevated
social dynamics
food vs no food
fabric + cardboard
lo-fi tests observ.
kinds of interactions
picking, pulling, smashing etc.
phase 2
2/3 objects
location - elevated
food - no/easy/bogged
materials - versitile
destructable vs complex
puzzle design
interactions
hi-fi tests observations
phase 3

FIGURE D.8

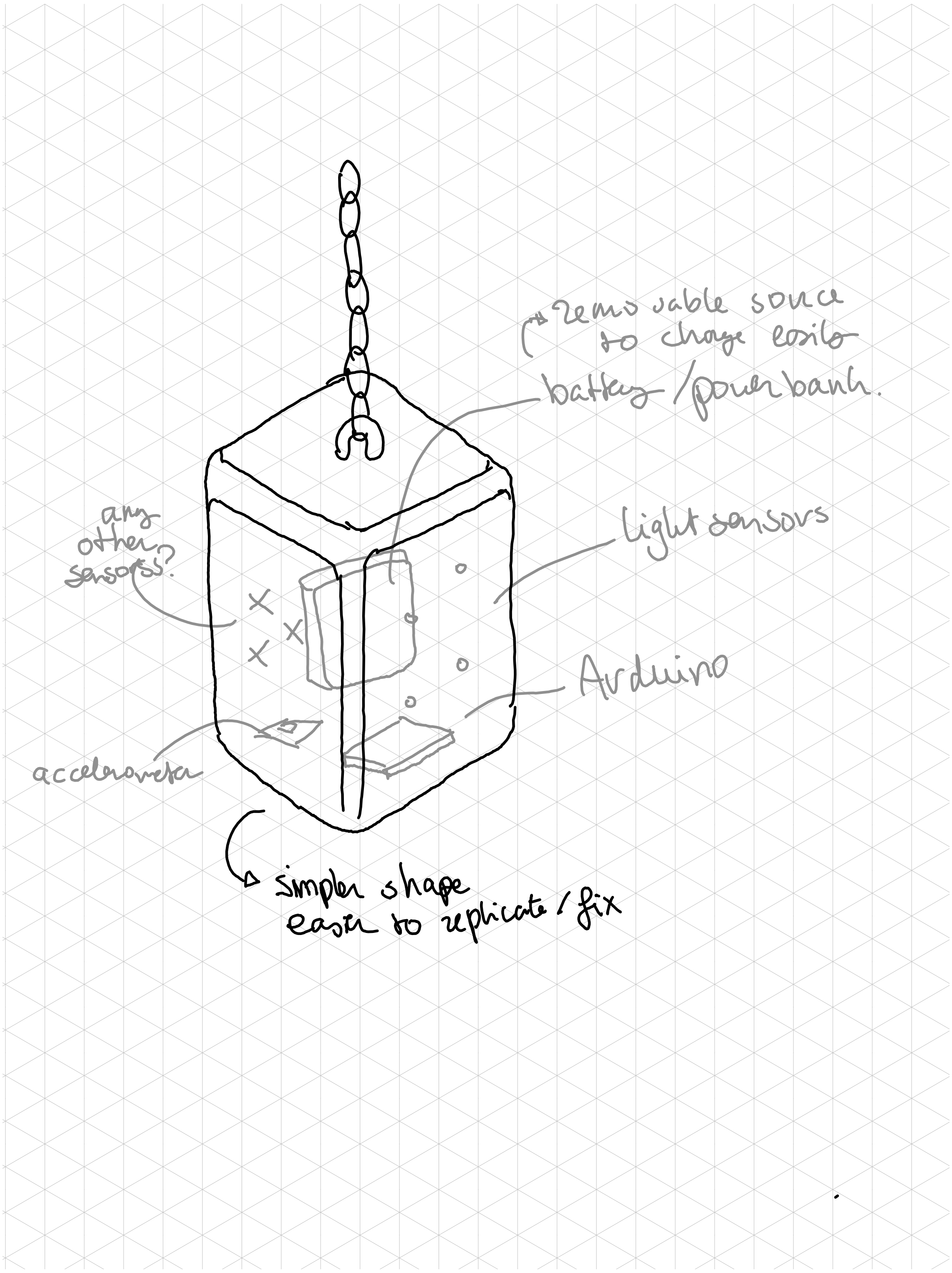
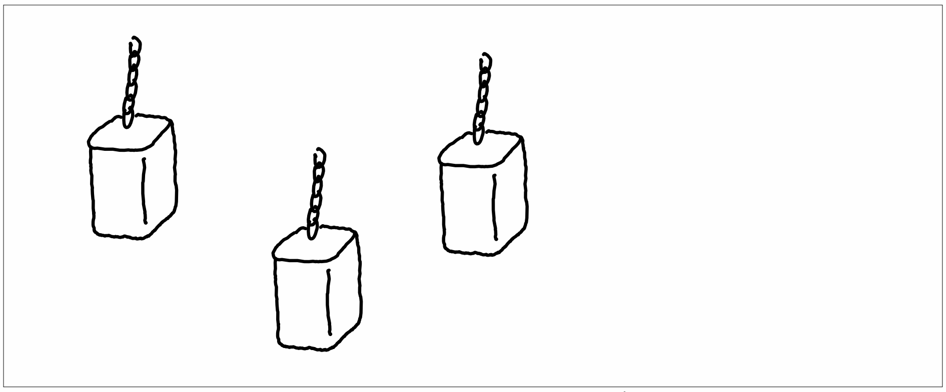
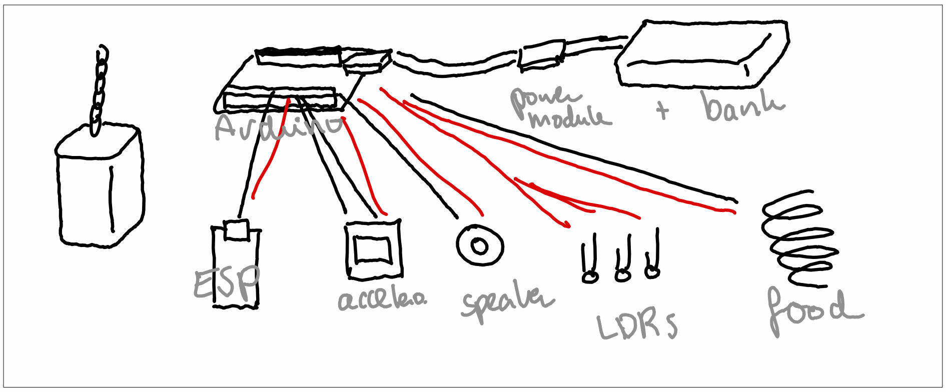

battery / powerbank.
light sensors
any other sensors?
Arduino
accelerometer
simpler shape
easier to replicate / fix

Figure D.9

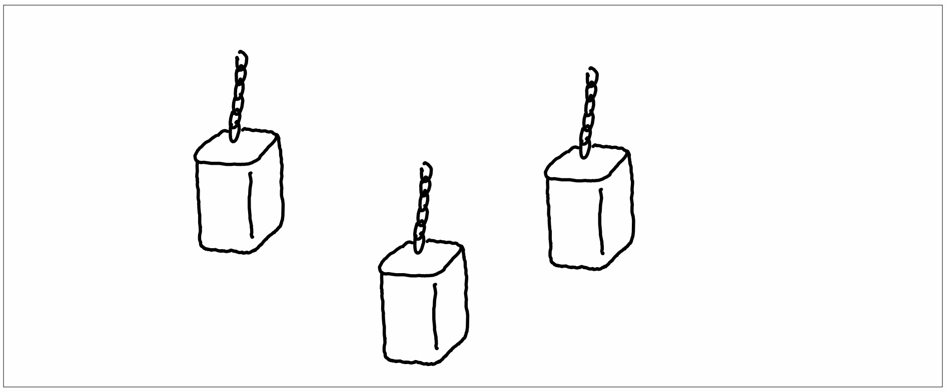


Three units hanging in the same
enclosure room
They each contain: ESP, accelerometer,
speaker, power bank + module, extra sensor.
Preferably they also all contain a food
dispenser. The main one also has an Arduino

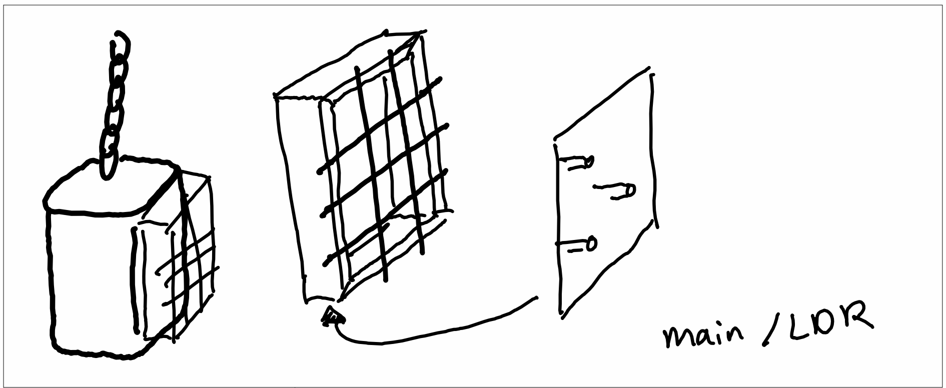


The main unit looks like this
switch out the LDRs for
① load sensor
② IR bridge
And remove the Arduino for both.

Figure D.10

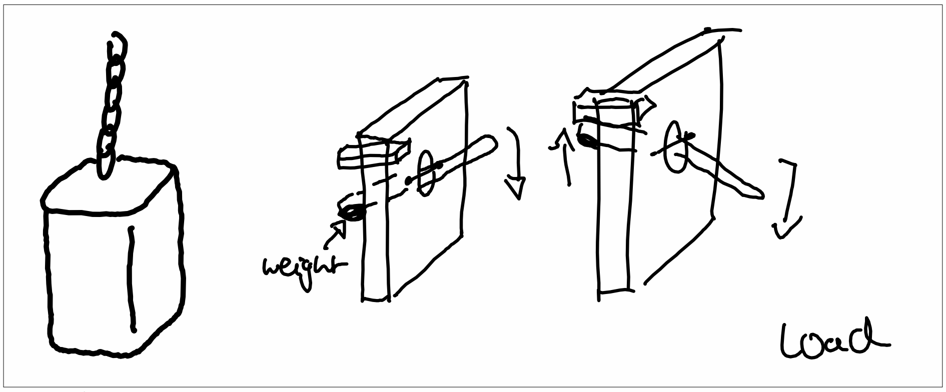


The 3 units will have one puzzle side each.



① main unit has a fillable grid with LDR behind it. You can fill it with cardboard, leaves, hay etc. When any material in front of an LDR is removed, it triggers.

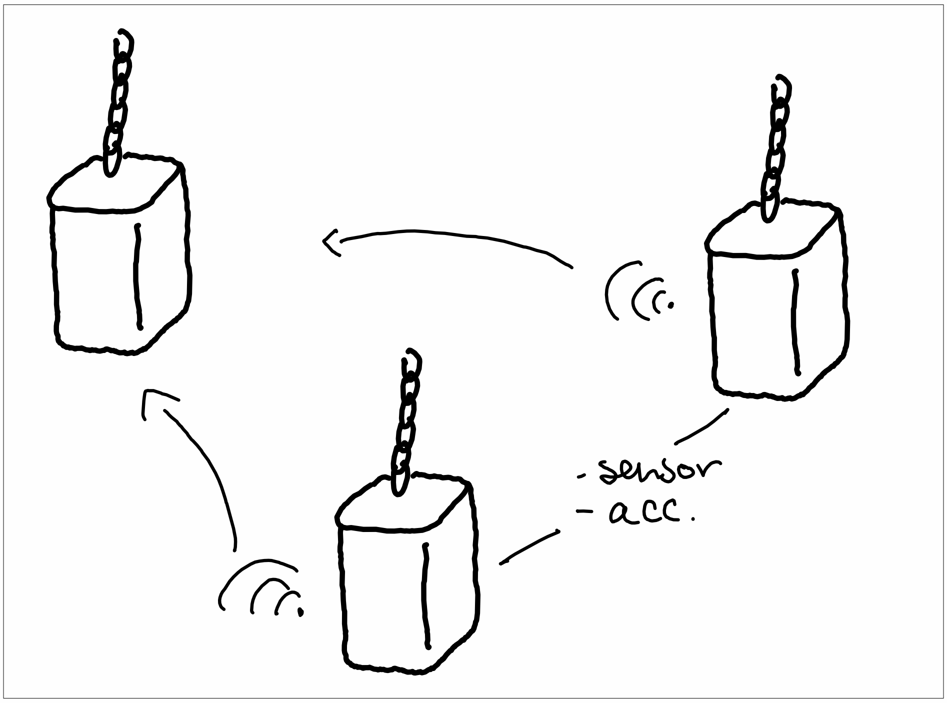
Figure D.11



(2) load sensor unit has a load sensor to measure pressure / weight,

(3) IR bridge unit has an IR bridge wich will detect a plate connected to a spring and a pressure plate. The plate has wooden fruit attached, if they pull it the IR bridge will register no plate.

Figure D.12



The main unit has the brain.
whenever something's triggered, it will
communicate with the Arduino
For both the sensor and acc.
The ESP decides if something passes
the threshold, Arduino
processes it.

Figure D.13

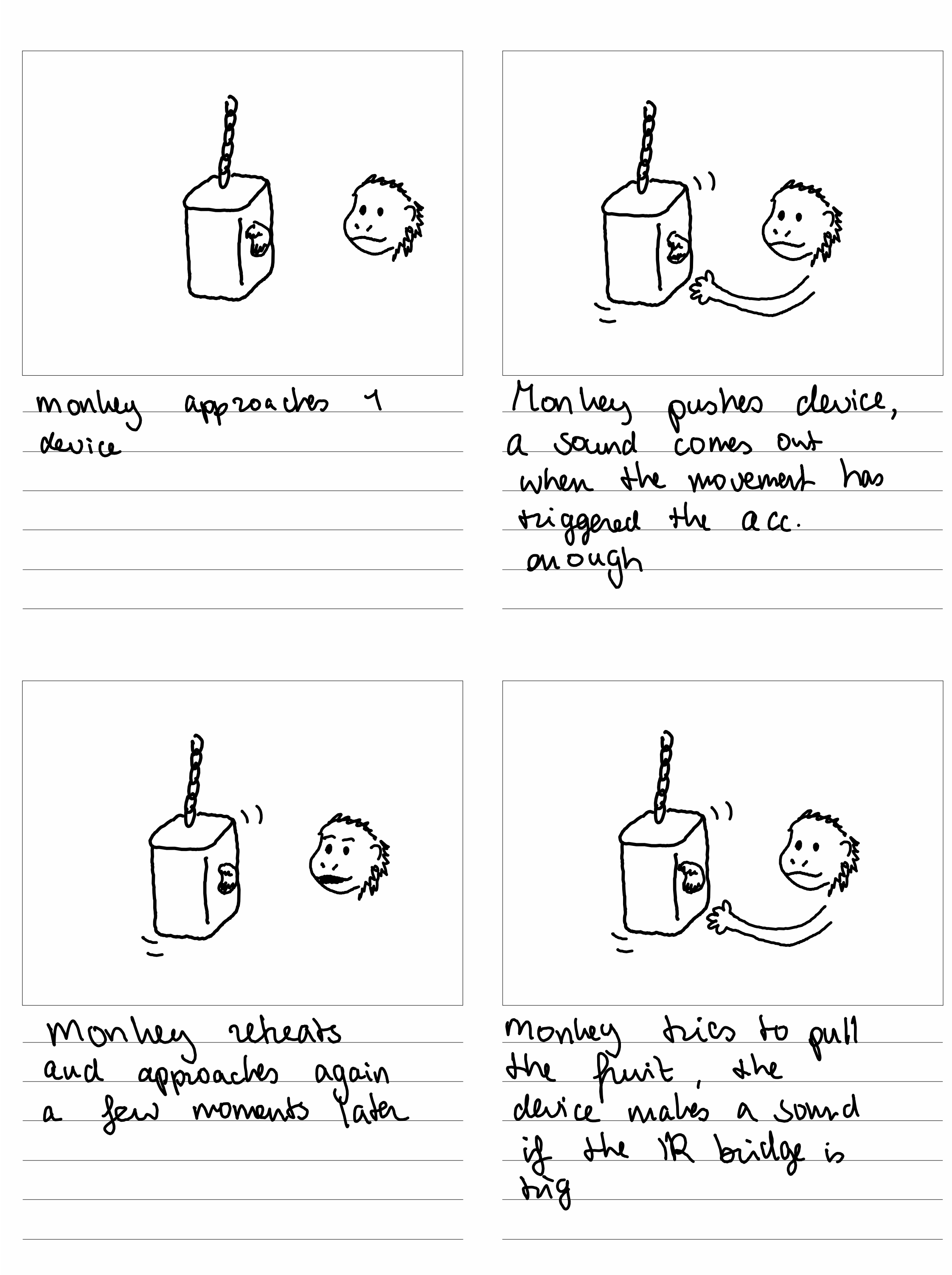

monkey approaches 1 device
Monkey pushes device, a sound comes out when the movement has triggered the acc. anough
Monkey retreats and approaches again a few moments later
monkey tries to pull the fruit, the device makes a sound if the IR bridge is trig

FIGURE D.14


Now both interactions have been triggered, the unit drops some seeds.
monkey pulls fruit again, no food comes out.
monkey pushes unit again, food can drop out.
(70% chance?)

FIGURE D.15