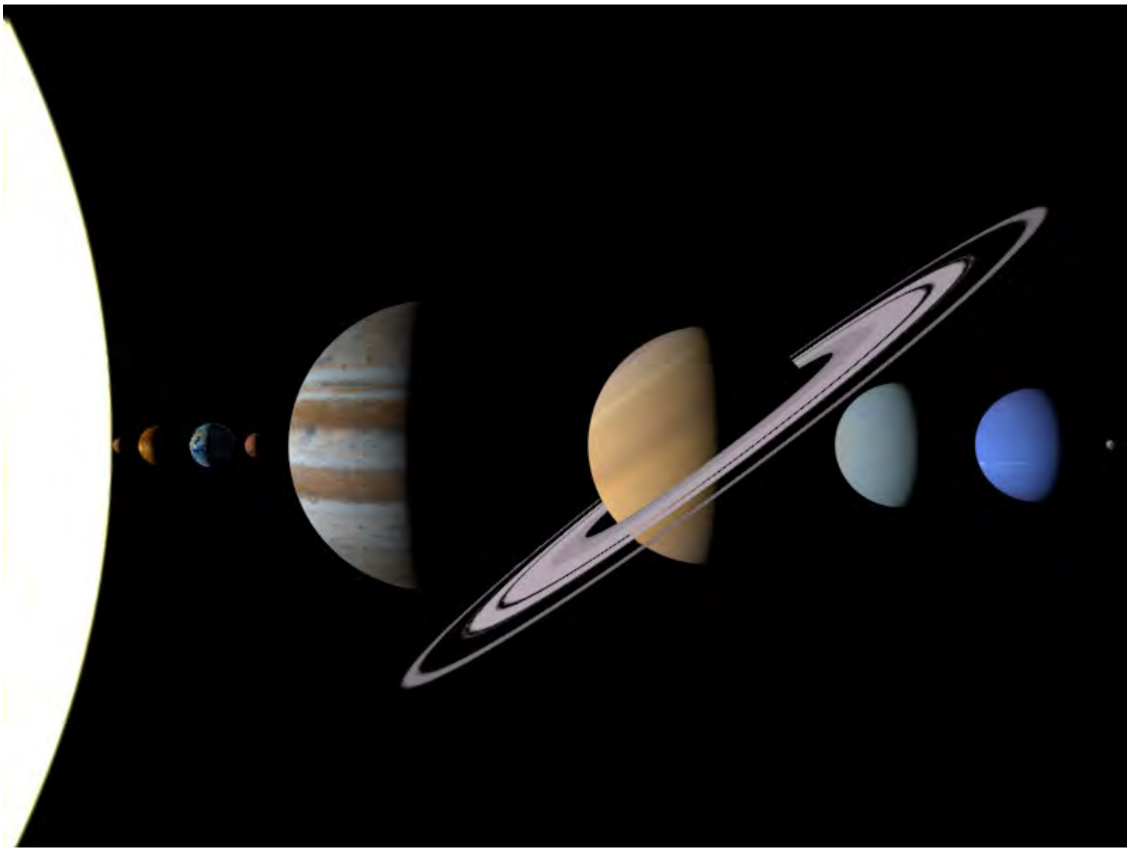

From Touch to Understanding: Tangible Design for Teaching Science

Exhibit for Teaching Scientific Scales to Adolescents

Master's thesis in Interaction Design & Technologies

PAULINE BJÖRK & SARA SEHDO

DEPARTMENT OF INTERACTION DESIGN AND SOFTWARE ENGINEERING
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2026
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Abstract

This thesis investigates how interactive installations at science centres can be designed, with tangible interaction as a focus, to increase science capital and teach adolescence between age 10 to 15 about scientific scales. The project was conducted in collaboration with Onsala Space Observatory and their visitor centre to redesign and improve an existing installation about scientific scales and magnitudes. A Research through Design approach was followed using iterative prototyping, user testing and semi-structured group interviews. The prototypes have been designed based on feedback from user testing with visiting school classes and a combination of researched theories such as experiential learning and gamification. The results showed that the implementation of tangible interaction, tasks driven by collaborative problem solving and clear visual communication positively influences the engagement from visitors and the installations independency from requiring a facilitator. It became very clear that intuitive interaction design and clear instructions are a important part of lowering the entry threshold for participation in informal learning environments. Ultimately, this project empathises that creating interactive scientific installations is not only about presenting scientific facts, but also about designing meaningful experiences that encourage young visitors to explore and engage with science in their own way, where tangible interaction serves as an effective approach for supporting such engagement.

Keywords: Tangible interaction, UX design, science centre, astronomy, interaction design, scientific scales.

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Pauline Björk & Sara Sehdo, Gothenburg, June 2026

List of Acronyms

Below is the list of acronyms that have been used throughout this thesis listed in alphabetical order:

OSO	Onsala Space Observatory
UX	User Experience
LY	Light Year
WOz	Wizard of Oz
HCI	Human-Computer Interaction
CTI	Child Tangible Interaction
TUI	Tangible User Interaction

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1

Introduction

In an era of constant digital stimulation, attracting the attention of young visitors has become one of the central challenges for science centres (OECD, 2015, Dancstep and Gutwill, 2019). Among the many scientific disciplines presented, astronomy has a distinctive ability to inspire fascination and imagination(Barban and Dole, 2005).

Recent advances in interactive exhibits have expanded the possibilities for engaging young visitors in science centres. Unlike static displays, interactive installations enables visitors to explore science through manipulation, experimentation and immediate feedback, which has shown to support conceptual knowledge and long-term interest in science learning (Bell et al., 2009). Such environments are particular valuable for early adolescents, whose cognitive development benefits from multimodal engagement and experiential learning (Muñoz-Losa and Corbacho-Cuello, 2025, Mathias et al., 2021).

Despite these advantages, Dancstep and Gutwill (2019) argues that interactive exhibits does not automatically sustain continuous engagement and curiosity. Studies suggest that design features, guided learning, and accessibility of interaction strongly influence whether visitors meaningfully engage with exhibit content (Dancstep and Gutwill, 2019). Installations that rely heavily on guides, risks limiting the independent exploration, therefore reducing opportunities for self-directed inquiry. This highlights a persistent challenge within science communication design: determining how interactive systems can be structured to support individual engagement without requiring guiding (Haywood and Cairns, 2006).

To address these challenges, principles from interaction design can be applied to the development of science centre installations that encourage intuitive and self-directed engagement. One of the main principles in interaction design is to establish a balance between user desirability, technical feasibility, and economic viability (Plattner et al., 2011). As environments designed for exploratory learning, science centres naturally promote interactive engagement with both digital and physical installations (Chen et al., 2026). Tangible User Interaction (TUI) is highly relevant for this project, as physical interaction can support the understanding of abstract scientific concepts such as astronomical scales and magnitudes. Lindgren et al. (2016) suggests that learning through interactive and physically engaging environments can improve both engagement and conceptual understanding in physics education.

In the context of design, problems are initially often not well understood and difficult to describe. Nevertheless, the problem becomes more apparent and defined as the design process moves towards a solution (Meinel et al., 2011). According to Meinel et al. (2011), this is what defines a *wicked problem*. Design thinking implies that the focus is not solely on analysing a predefined problem; rather, it is important to explore both the problem space and the solution space simultaneously.

These challenges are relevant for exhibits intended to communicate scientific scale, a concept known to be difficult due to its abstract and non-intuitive nature (Tufte, 1997). Understanding scale is fundamental for grasping many scientific domains, including astronomy, where phenomena extend far beyond everyday human experience. Therefore, designing installations that clearly convey such concepts requires careful consideration of the balance between interaction design, cognitive load, and comprehensibility (Sharp et al., 2019).

This project was therefore initiated at the visitor centre at Onsala Space Observatory, a Swedish national radio astronomy facility operated by Chalmers University of Technology, where an existing installation has been identified as offering strong potential for increased visitor interaction. Preliminary observations and interviews indicate that visitors often require guidance to initiate engagement and fully explore the installation's content, suggesting that aspects of its design may not sufficiently support intuitive use.

In summary, the thesis investigates how interactive exhibit design can be adapted to support self-directed engagement among young visitors. Therefore, the research questions we aim to answer are:

RQ1: *How to design a tangible interactive installation to support adolescents', 10-15 year old's, engagement with scientific scale?*

RQ2: *Which interaction design and tangible interaction principles used during this project are the most helpful for communicating scientific scale in a science centre context?*

1.1 Design Problem

The aim of this thesis is to develop, evaluate and improve an installation at Onsala Space Observatory (OSO), in order to enhance independent visitor interaction and conceptual understanding of scientific scale.

The focus will be specifically on their exhibition, the Scaling Sorting Drawer, to improve its user experience. At its current state it is a minimal viable product that seems to work somewhat depending on the visitor engaging with the station. Currently, it does not converge to the average visitor exactly how the station works, and there is no feedback presented to the visitors if an external instructor is not present. The idea is to teach the visitors about magnitude, size in space, compared to size on earth, essentially teaching the understanding of size. This is, at present, not very clear when interacting with the Scaling Sorting Drawer.

This project would include conducting user studies, determining how users interact with the station at its current state, and prototypes developed based on gathered feedback. The project will have a focus on visitors from the age 10 to 15, as this is the most excluded group for the current state of the station, determined by visitor centre staff. Accessibility will be a part of the design process, as it is important to include as many children as possible in this learning experience.

1.2 Delimitation

As the aim of this study is to improve an existing installation, the project is delimited to design and evaluation work that can be completed within a project period of approximately 14 weeks, which is not sufficient for full-scale redevelopment. Consequently, the outcome will consist of the concepts, prototypes, and validated improvements that can reasonably be achieved within this time frame.

Collaboration with the science centre at OSO further constrains the execution of the study. All empirical activities must be coordinated with their schedule, including observations and interviews with visiting school classes as well as testing sessions and consultations with on-site staff. Access to participants is dependent on scheduled school visits, meaning that the selection of classes and schools is predetermined. As a result, both the research and design processes are adapted to this specific focus group.

Additional constraints arise from fixed conditions established prior to the project. Alongside temporal and participant limitations, the installations must be developed for a predetermined physical environment within the visitor centre. Spatial layout and environmental factors are therefore treated as fixed parameters than variables, which excludes major spatial och architectural modifications from the project's scope. This also constraints the testing simulation, for when using the WOz method the 'wizard' should not be visible. Consequently, in this limited space, the 'wizard' was always visible, which, thus, can skew results.

One of the main constraints was to not use any elements with any sort of frequencies, as it can disturb the equipment at OSO, since they work with radio waves. This halted the process of developing a fully functioning prototype within the time of this project.

An analogue solution was preferred by the stakeholders at OSO. However, as the study was conducted within the Interaction Design and Technologies division, the project was required to incorporate a technological component.

1.3 Ethical Considerations

As this project's focus group will have the age range from 10 to 15, one of the main ethical aspects of doing this project is that they are under the age of consent. Since they are under the age of 18, which is the age of becoming an adult in Sweden, we will have to get the consent of participation from the children, their caregiver and also their teachers. This will be done through a consent form, stating all the details regarding data handling, what the project is about and what their role will be in it. These forms will be sent out to the teachers prior to their visit at OSO, so that the collection of their signatures of consent will be as smooth and understanding as possible. There will also be a verbal information before collecting data. The data that will be collected will not have any sensitive personal data, only the practical outcomes of the tests, such as interaction and user experience, along with their school grade.

Another aspect on age is that the thesis students are not trained in how to work with children, and therefore will have to read up on how to formulate information and questions in pedagogic manner for users to understand and how to safely build an installation they can interact with properly based on their physical needs. To our advantage we have two supervisors, one of which is a certifies teacher, available for help that have years of experience developing science installations at, for example, Universeum and Tekniska museet.

While developing the installation we will aim to include a focus on inclusivity to address the needs of people with, for example, reduced hearing, variations of colour blindness and reduced mobility. Throughout the entire design phase, accessibility will be treated as a fundamental design principle. During the design phase, accessibility will continuously inform our decisions regarding interaction, visual communication, spatial layout, and sensory elements. Once a final design is selected, we will conduct an accessibility review though an accessibility lens to make sure to accommodates a diverse range of user needs.

There is also the ethical issue of what facts we present at the visitor centre and they scientific correctness. As this installation will be presented at a space observatory visitor centre, it will be important to be critical towards sources and make sure the information used to teach visitors are factually correct. Misinformation is a big problem in today's society on, for example, social media (Muhammed T and Mathew, 2022). It could have negative consequences if a place created to correctly teach society about a specific topic provides the wrong information.

AI is as of currently not planned to be incorporated into any aspect of this project.

1.4 Background

This chapter presents important information about the location, functionality, and interaction design of the original Scaling Dresser. Earlier and similar projects related to the Scaling Dresser will be discussed, along with relevant background that adolescents has of science and astronomy through school education.

1.4.1 Onsala Space Observatory

OSO is the only national radio astronomy facility in Sweden, located Onsala, 45 kilometers south of Gothenburg (unknown, 2023). The facility is run by Chalmers University of Technology and provide researchers with the opportunity to observe both Earth and the rest of the universe with their equipment, such as several dish antennas and one of the LOFAR[1] telescope stations.

[1]Stands for Low-Frequency ARray - a massive, pan European radio telescope operation

One of the buildings located on the OSO property is their visitor centre, which is used to host group visits to the observatory. Their main audience are school classes with children from the age of 10 to 15. The main goals of the visitor centre is to teach the general public more about what they do at OSO, hopefully contribute to create a personal interest in wanting to learn more about space afterwards and provide the opportunity to gain a personal connection to science.

The Scaling Dresser

This project focuses on one of the visitor centres installations, called the Scaling Dresser, shown in figure 1.1. The installation contained a dresser with 16 drawers marked with different sizes, 23 images of scientific objects, a globe of planet Earth and 4 posters on the wall above the dresser. The mission for the visitors to complete was to put all the images into the drawer with the size that corresponds to the object in the image. There were no instructions presented to the user, they either had to figure out the rules by themselves of have a facilitator present to give them the instructions.

The object in the images were taken from four categories visualised on the posters: tiny, small, large and huge. However, there are no identifiers, such as name tags, attached to the image about what the object is. The sizes on the drawers were also grouped into these four categories. In each group there are 4 drawers with one of each coloured green, red, blue or yellow. They are also sized into one big drawer, two medium and one small. The colour and size of each drawer affects the images meant to be placed there. On each image there is a coloured sticker. The stickers colour indicates what coloured drawer the image should be placed in as a hint to the users.

Each image is also made into one of three different sizes. The images are divided as following:

- 4 smaller images in the size of 20,5cm x 15cm.
- 14 medium sized images in the size of 29cm x 21cm.
- 5 larger images in the size of 30,5cm x 25cm.

Due to their sizes, the larger images will only fit in the larger drawers while the smaller images are the only images that will fit into the smaller drawers. User could therefore use the exclusion method as a helpful tool to distinguish what images can fit into which sized drawers. By combining the sizes, colour stickers, poster categories and general knowledge to identify the objects in the images, user should successfully perform the task. However, the lack of initial instructions is the main problem that makes it hard for visitors to use the installation.

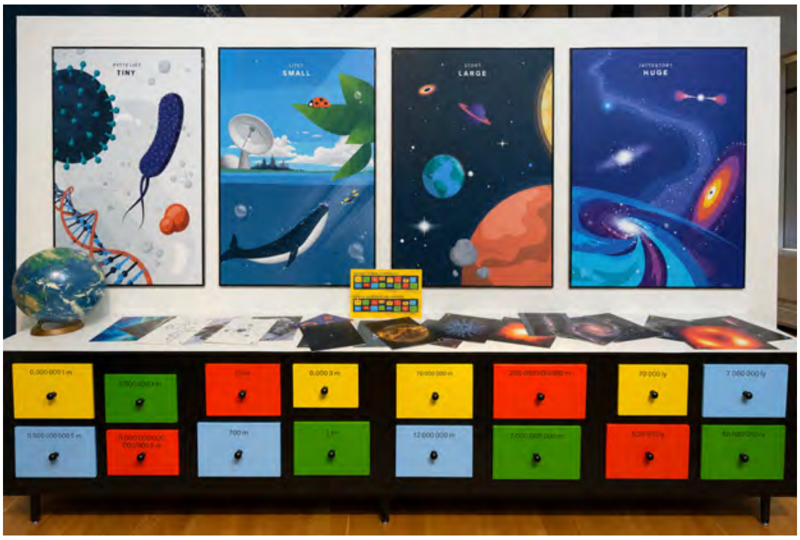


Figure 1.1: How the original Scaling Dresser looked.

One of the images did not contain a scientific object, but instead works as a numeral translation of what the numbers marked on the drawers are, both in text and scientific notion. The image also contains a conversion of 1 light year to kilometres, to accommodate for the users that does not know how big a light year is. This image does stand out among the other images as it is the only one that has text and something other than a scientific object. However, it is not fastened to the wall as a sign or placed in any other special way as an image of importance other than being leaned against the wall sometimes for easier access. Otherwise, it has the same size, is made of the same material as the other images and is often scattered among them.

Figure 1.2: Image of dresser sizes and definition of LY.

1.4.2 Swedish school curriculum

(Tog från Theory - education) The difference between a 10 year old's and a 15 year old's knowledge in physics is quite big. In Sweden, students in grade 4 to 6 should learn about the celestial bodies in the solar system, especially the difference between a star, a planet and a galaxy, along with their movements and relation to each other (Skolverket, 2021). They should also learn about humans in space and how satellites works and are being used. Compared to students in grade 7 to 9, who, on top of what they learn in 4th to 6th grade, should be able to understand and explain what the Universe is built of and how it became, along with how astronomers measures distance and how they find new planets (Skolverket, 2021).

Knowing what the students come from in terms of theoretical background in physics, OSO has a few wishful educational expectations of the students, prior to visiting the Visitor Centre ("Studiebesök Onsala rymdobservatorium: lärarhandledning | Chalmers", 2025). This would help understanding tougher concepts, and would make the concepts less hard to approach. They have written a guideline, which helps teachers in learning their students for their upcoming visit, to help the students' understanding of the installations better. The reason is especially to decrease the confusion of the new information that is bound to be relayed during the visit.

1.4.3 Similar work

The design of this projects prototypes has been mostly based on user feedback during the testing stage. However, inspiration has also been collected through other sources such as reading academic papers on similar subject and fieldwork by visits to science centres and interactive museums. The inspiration supported the development of certain solutions to problems found during the testing stage of the project. Information on how these sources inspired specific design choices will be described in Chapter 4.

Two years prior to this project, an academic paper was written on quest-driven exploration in science centres, where OSO was one of the centres used for the research (Wideström et al., 2023). The results of this paper was useful as it showed that children were more prone to participate in action filled quests compared to discussion-related questions. Even if the discussion-related quests were not as popular, informal learning still requires social interaction as it is an important tool (Rogoff et al., 2016). According to Wideström et al. (2023) research, there is a difference in how visitors from primary school and secondary school work in groups. However, they also stated that on an individual level there are large differences within all groups regardless of age. These are all good things to keep in mind going into designing an installation aimed at adolescents in primary and secondary school. To create a task that can be performed as a collaborative and social experience by multiple people as a group, while also making it interesting to both users with minimal scientific knowledge and users with a personal interest in the subject.

There are multiple locations in Sweden that are aimed a children learning that proved visitors with an opportunity to explore subjects such as sience. Universum is Sweden's national science centre and is listed among the top ten most visited attractions in Sweden unknown, n.d. At Universum visitors get to explore the world through their experiential learning in different focus areas, such as science, technology and mathematics. One of the centres zones is called *Mathrix* and contains three of the most inspiring installations for the project. The first installation is called *Nördlig*, in english *Nerdle*, and is a mathematical version of the game *Wordle*. Instead of finding the correct word in six turns by placing letter correctly, the player need to find the correct calculation by placing numbers and mathematical symbols, such as plus, minus or equals signs, in the correct place. If a number or sign is placed correctly in a guess its square turns green and if incorrect it turns red. If the player were to place a number or sign incorrectly, but it is a part of the unknown calculation, the square will turn yellow as a hit to the player that it needs to be moved to be correct. The game also comes in with two different difficulty levels, *easier* and *challange*.

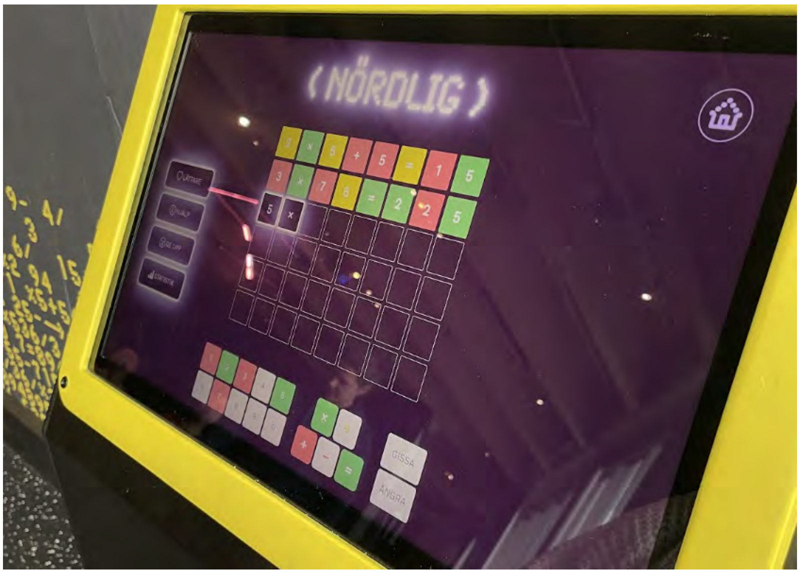


Figure 1.3: *Nördlig* installation at Universeum.

The second inspiring installation is called (*Sifferjakt*), in english *Numberhunt*, and is a game where the user chooses a challenge to point out all number between either 0 to 100 or 0 to 199 that are included in a certain mathematical number classification, such as prime numbers. One thing that makes this installation stand out is the size of it. There are two rows of 100 round buttons each, one for each number between 0 to 199, spread over approximately 10 meters. The user chooses their challenge on the touch screen and must then walk back and forth pressing all the buttons of the numbers they believe are a part of the number classification.

The last installation is called *Vågade ekvaktioner*, in english *Balanced equations*, and can be seen in Figure 1.5. This installation consists of a screen with information on what to do, a basket filled with three different types of blocks and one scale to place the blocks on. The task, presented on the screen, is to solve a mathematical formula formula by placing the blocks on the scale and reach equilibrium. This is one of the few installations that let the visitors interact with and move physical objects in this manner. Comparing this to the Scaling dresser provides examples on how loose interactive objects can be stored, how users know where to place the objects and what information there is to putting them back in their original place.

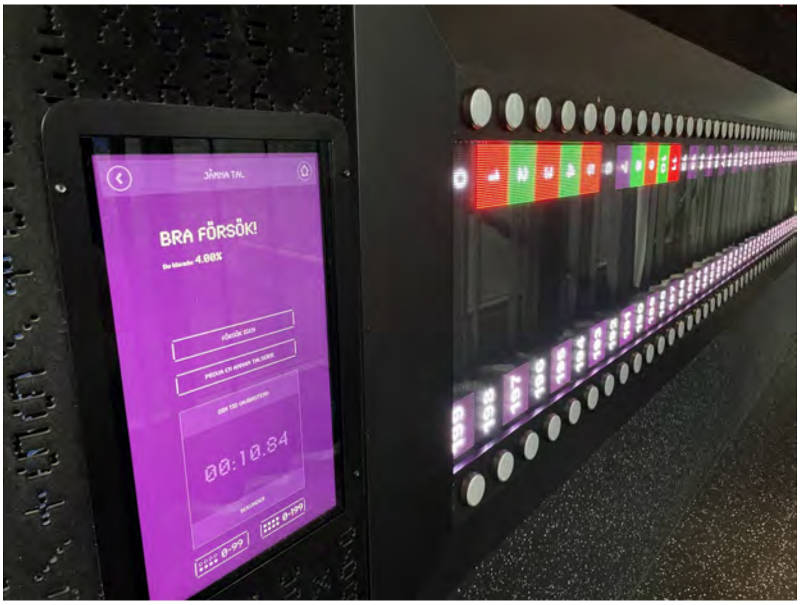


Figure 1.4: *Sifferjakten* installation at Universeum.

Figure 1.5: *Vågade ekvationer* installation at Universeum.

2

Theory

This chapter establishes the theoretical foundation for tangible interaction as a medium for communicating scientific scales. It utilises principles from interaction design, informal learning theory, and user experience research to construct an analytical framework for evaluating physical-digital installations aimed at adolescent audiences.

2.1 Theoretical Framework

The shape of the problem is that the installation is hard to engage with without any prior knowledge of how it works. As it is not self explanatory it becomes intimidating, which results in the visitors ignoring it completely. This affects the experience of the visitors in a negative way as they can not partake in the entire exhibition and the high knowledge threshold can make them feel like they are too dumb to understand. It also affects the staff negatively as they need to be present at they installation for it to work, but they physically can not be in multiple places at ones. One of the most important improvements that we will prioritise to make is for the installation to work unassisted.

As the installation currently is not used by many visitors there is little to no information on how they would interact with it at its present design. To define the existing problems with its design we will have to approach this through relevant theories of user engagement, affordances and cognitive accessibility. Rather than understanding the installation as a simple object, we can view it as a commutative interface between the visitor and abstract subject, such as scientific scales.

2.2 Academic Context

The academic context for this project is to improve an interactive designed and learning object with the whole Interaction Design master as a background. It will touch several of the fundamentals of the education, such as methodology, design processes, prototyping, user studies and evaluation.

The research areas that are necessary to work with in this project are:

- Science Communication and Education.
- User Centred design.

- Tangible Interaction and Interaction Design.
- Inclusive and Accessible Design.
- Human Computer Interaction.

Interaction design is the practice of designing different kinds of products, systems or environments to achieve a specific responses from users (Cooper et al., 2014). This design discipline is created to have user needs as the main focus to develop user friendly graphical and physical interfaces. A subcategory of interaction design is tangible interaction. Tangible interaction focuses on the user experience and interaction with different systems (Shaer and Hornecker, 2010). As the main focus of this project is going to be the physical interface of the dresser, as the current analogue interaction does not work independently and requires a facilitator, the project has a *expressive-movement view* and *space-centered view*. These views are categories within tangible interaction that focuses on for example physical movement or actions from users and how the dresser is designed to host groups of people to collaborate. However, there will also be a graphical interface integrated to work in collaboration with the physical interactive part of the prototype to easily present instructions to the users.

A first for both refreshers, is working space-related. As the project itself does not display any facts about space rather than size and comparing it to other objects and there are space researchers available for questions, it will not be a huge learning curve. However, it would probably be in our best interest in learning more about it for unforeseen use in the project.

Another aspect is the user group, neither of the students has worked with the younger age group of adolescence (10–15 year old's) previously. Thus, it might become another challenge of understanding and evaluating their needs as best as possible.

The skills that will be used in this project are skills we have learnt throughout our whole university education, from an software engineering bachelor to an Interaction Design and technologies master's program. The original goals of the project are to make a more technological interactive prototype, so that is where the software engineering skills will be useful. Since we will focus on the experience and learning outcome from an adolescent perspective, the use of user experience and interaction will use a great part of our skills from the master's programme. Interviewing skills along with data collecting and sorting skills will come handy. There are some soft skills that will probably be useful, such as one of us having been a gymnastics coach for kids and adolescents.

Although we will be using those skills, they can and will always be improved. By engaging in a project in which a field as different as physics and space science is prominent, despite our background in a different scientific discipline, our skills in adaptation, learning, and applying domain-specific information will be significantly improved.

2.3 Literature Review

This project is derived from the installation presented in *Quest-driven exploration of interactive installations in science centres* (Wideström et al., 2023). Although based on social interaction emerging from collaboration (Karlén, 2017), the installation was later described by its designer as having a high entry threshold, requiring prior visitor knowledge to enable meaningful interaction (Josef Wideström, personal communication, January 2026).

Accordingly, this literature review is grounded in the results, discussions, and conclusions presented in that work. However, rather than replicating the quest-driven framework, this thesis explores alternative design approaches aimed at improving interaction in the context of the present project.

2.3.1 Science Communication

Most children learn science in formal school settings, which is considered formal education (Haywood and Cairns, 2006). In contrast, informal education occurs in designed settings such as science centres, museums, and exhibitions (Bell et al., 2009; Wideström et al., 2023) and has been shown to foster active, self-directed exploration, unlike the more didactic methods often used in schools (Rogoff et al., 2016). Informal learning is not limited to designed environments; it also takes place in everyday contexts such as discussions at home, watching television, and recreational activities like fishing or gardening, each supporting science learning in their own ways (Haywood and Cairns, 2006).

There are several differences and similarities between formal and informal education. The most notable difference is that formal education is typically compulsory, whereas informal learning generally arises from personal interest (Bell et al., 2009). Visitors to science centres engage with exhibits through exploration, experimentation, and problem-solving, which can foster both understanding and curiosity about scientific concepts (Wideström et al., 2023). Informal STEM education should not be considered a replacement for classroom instruction, rather, it complements school learning by providing more individually tailored experiences rather than generalized teaching (Allen and Peterman, 2019). Research also indicates that informal STEM experiences can influence students' long-term engagement and even their career aspirations. Students often report that participation in real-world, meaningful STEM activities can spark interest in pursuing STEM fields, particularly when learning is connected to personally relevant problems (Maiorca et al., 2020).

According to Allen and Peterman (2019), developing research designs and methodological approaches in informal settings remains challenging, particularly within museums and exhibition contexts. While museums provide clearly bounded informal learning environments compared to everyday experiences, evaluation is complicated by voluntary participation, differing depths of engagement, and the often brief and self-directed nature of exhibit interactions. Much of the informal STEM education literature has therefore concentrated on museum and exhibition contexts, drawing on approaches such as visitor observations, exit interviews, and comparative designs that examine patterns of engagement and learning across different exhibit conditions (Barriault and Pearson, 2010). In particular, Barriault and Pearson's framework uses observable visitor behaviours as indicators of engagement, providing a practical method to assess informal learning in museum exhibits.

Science centres do more than communicate scientific content. Through spatial organisation, exhibit arrangement, lighting, interactive elements, and visual framing, they actively guide visitors' attention, engagement, and perceptions of meaning (Wideström et al., 2023). Parents and caregivers also play an important role, subtly guiding children's attention by connecting exhibits to their prior experiences or knowledge (Rogoff et al., 2016). Drawing on the Wideström (2020) conceptualisation of exhibitions as *seeing places*, these design decisions can be understood as forms of staging that structure perception and participation. This perspective highlights an ethical responsibility for science centres, as design choices influence which scientific narratives are foregrounded, which perspectives are visible, and whether young visitors are positioned primarily as observers or active interpreters of content.

When thoughtfully designed, science centres can support curiosity, sustained attention, and reflective engagement, which are central to learn STEM subjects in informal learning environments during early adolescence (Wideström et al., 2023; Allen and Peterman, 2019; Maiorca et al., 2020). Informal STEM experiences in such environments have also been shown to influence learners' long-term interest and aspirations in STEM fields (Maiorca et al., 2020). Understanding these dynamics provides a foundation for examining how interactive and technology-enhanced exhibit designs can further enrich children's engagement, facilitate deeper learning outcomes, and strengthen motivation for STEM learning, thereby forming a bridge to discussions on interactive learning in museum contexts (Amran and Admodisastro, 2017; Wideström et al., 2023).

2.3.2 Science Capital

Science capital refers to the accumulation of science-related resources that an individual gathers throughout their life (Gonsalves et al., 2021). This framework builds on the conceptualisation by Archer et al. (2015), who argue that science capital should be understood as a survey-based tool used to assess students' engagement with science, rather than as a traditional form of capital. The purpose of this tool is to make visible inequalities in science education and access to science-related resources across different social groups. In turn, this provides a basis for understanding how science capital can be increased within society. Gathings and Peterman (2021) describe science capital as consisting of three distinctive areas containing eight dimensions, which is described below.

Science-related cultural capital

Holding four of the eight dimension such as *scientific literacy*, following the explanation of Archer et al. (2015), which is includes scientific knowledge and skills. It also translates to understanding science enough to apply those abilities onto your daily life. Moving to *science-related attitudes, values and dispositions*, which is described to be measuring the value of science in society. This essentially describes the feeling towards science rather than knowledge of it, in the cultural and social sense. The third dimension being *knowledge about the transferability of science* is interpreted as the knowledge of how science stands in the job market, which translates to having an advantage when making decisions for their future.

Science-related behaviours and practices

Archer et al. (2015) discusses that *Science media consumption* and *participation in out-of-school science learning contexts* are the two dimensions related to behaviours and practices. Consumption of science media proves to be beneficial in promoting childrens' science achievements and self-belief in performing in science tasks. These media forms would be to watch TV programs, reading books and research online. The latter dimension is essentially to seek out designed spaces for informal science learning, such as OSO, but also bring those contexts home such as with experiments, have a walk in nature or programming computers.

Science-related social capital

The social relates to *knowing individuals in science-related roles*, which is also benefitial for those who might want to pursue a career in science. Archer et al. (2015) explains that this can provide information, role models and encouragement. *Parental science qualifications* is also thought of as a key contribution to children's science capital, however, Archer et al. (2015) states that they do not have enough reliable data to prove this, as the children did not know enough about their parents educational background. Though it is believed in enough to remain in their conceptual model. The last dimension, *discussing science in everyday life*, is believed to help students in being more comfortable with science and scientific discussions, as frequent conversations beyond classroom settings may help normalise science thinking.

Informal science learning environments have been shown to increase science capital. In a study of science festival participation, Gathings and Peterman (2021) found that science capital increased more significantly among participants from STEM minority groups, suggesting that such environments may help reduce inequalities in science participation rather than reinforce existing advantages. This, in turn, may increase the likelihood of young people pursuing science-related careers in the future Archer et al., 2015. However, active engagement and extended time spent in these environments were found to be important factors for achieving a meaningful increase in science capital.

2.3.3 Experiential Learning

What is the optimal experience? According to Csikszentmihalyi (1990) it is a state characterised by eight key factors. The optimal experience is often referred to as a flow, and occurs when (1) individuals engage in tasks that they perceive as achievable while still presenting a challenge. (2) It requires a high level of concentration and (3) is supported by clear goals and (4) immediate feedback. (5) Individuals become deeply and effortlessly involved with the activity, leading to a temporary loss of awareness of everyday concerns and frustrations. (6) A reduced sense of self-consciousness is often reported during the activity, (7) although sense of self may emerge stronger afterwards. Additionally, (8) the perception of time is altered, with individuals often feeling that time passes more quickly than expected (Csikszentmihalyi, 1990).

When we learn something new we want to reach an optimal experience. Experiential learning is a concept where teaching shifts from teachers-focused to experience-focused (Bartle, 2015). Instead of teaching information which makes students disengaged, experiential learning makes the teacher a facilitator that provides students with the opportunity to actively participate in their own learning process through collaboration, reflection, and hands-on experiences connected to real-world situations. By letting students combine prior knowledge and personal experiences with new information, it allowing them to develop a deeper understanding and interpretation of the subject.

French developmental psychologist and genetic epistemologist Jean Piaget's research on cognitive process and development among children focused on children's reasoning for coming up with answers instead of how correct their answers were (Kolb, 2014). He came to the conclusion that younger children were not less knowledgeable than older children, different age groups simply have separate ways of thinking. To test his hypothesis a test was conducted, where a schools curriculum was changed to explore more previously thought to be too difficult subject for younger children, but through experience-based learning. The children got to explore the subjects through interactive segments that let them come to a conclusions on how things worked on their own instead of memorising facts or formulas from books or a teachers explanation. Results showed a higher motivation to learn and excitement to participate in the educational activities compared to the previous teaching methods. However, it was not a success with all students as some did not learn the principles through the exercise. This experiment can be compared to science centres aimed at children, where most installations are interactive with the aim to teach through experiential learning.

2.3.4 Educational Games

To make the exhibition more exciting and enjoyable for the user we have decided to include game design elements and create a gamified learning experience. Educational games have become a popular tool for learning a variety of tasks in a more fun and engaging manner through technology such as mobile phones or virtual reality (Lane, n.d.). Hwang and Kang (2023) explains that educational games easily attracts users as they are designed for our pleasure and entertainment. The sense of immersion a game provides creates an environment that requires less effort than tasks without gamification. Most educational games does not only make the users develop cognitive skills, but also social and emotional skills. Due to these results educational games have come to be accepted as a prominent part of children's learning.

2.3.5 Information Visualisation

When designing interactive systems designers must think of what the system is supposed to show its users. By visualising information users' cognitive effort is reduced, enabling them to quickly gain an overview of large datasets, identify details, detect patterns or uncover errors (Ware, 2019). It is important for a system to take into account the main users needs as unwanted information can make the system too complex and harder to use (Spence, 2001). Furthermore, poor explanations can impair the user experience and, depending on the application, may even lead to harmful consequences (Tufte, 1997). Although, it is important to make sure improvements to a complicated system does not create misleading simplifications, as they can be just as confusing to the user.

Before deciding whether to make static or dynamic visual objects, it is important to take note of certain goals and issues (Wang et al., 2018). Static objects need to coincide with language and text, to fully reach out to the students. In contrast to dynamic objects, which rather needs to be manipulated in terms of focus and speed. In addition, according to Wideström (2020), the physical and digital space are complementary to each other and can enhance one another. This can be backed up by Spindler et al. (2010), where physical objects function simultaneously as display and interaction devices, allowing users to manipulate visualisations directly in three-dimensional space through tracked movement that controls visualisation parameters. This makes virtual representations physically graspable, increasing user engagement and facilitating intuitive interaction.

Wang et al. (2018) state that words along with static visualisation, better help students in understanding compared to without words. Combining the visual and verbal representation leads to better comprehension of scientific concepts. While they (Wang et al., 2018) also suggest that dynamic visualisation can increase students' interest and initiative in learning, a verdict regarding learning ability and comprehension of scientific theories cannot be drawn from this.

2.3.6 Designing for Children

When designing for children it is important to be aware of what kind of feedback will be the most helpful for understanding the task presented to them. There are many types of feedback and for this project it is necessary to look at what type of feedback that is essential to present educational content. Based on the results of Hwang and Kang (2023) player testing it will be good to have in mind that repeated feedback might make children feel agitated and sceptical towards the game they are playing. If a task at hand is failed and children are not presented with any additional explanation to how they can improve their execution of the task, children can show signs of exhaustion towards the repeated feedback that was meant to encourage. However, Susan Weinschenk (Castella, 2018) states in an interview that repetition is cognitively beneficial for learning as it strengthens neuron connection for long-term memory. As designers we must make sure that the repetition used is meaningfully structured and developmentally appropriate for the target audience. As adults cannot reliably assume they understand children's mental models, design ideas should be tested thoroughly to reduce the risk of misalignment between the system's intended logic and the child's interpretation.

Given children's developmental needs, designers should have in mind that an optimal learning opportunity is via peer collaboration and engagement, as learning may be easier through social interactions and focused engagement (Haywood and Cairns, 2006). To reach this, it can be valuable to focus on academic data on when engages children. Active participation through play has been proven as a tool to engage children (Amran and Admodisastro, 2017; Haywood and Cairns, 2006). Children use their fantasy through pretend play and role-playing to create their own narrative of the current position they are situated in. This supports the possibility of using game-based interactive elements in the prototype to enhance the learning environment. Since studies also has shown that digital interfaces are mostly designed for adults, they are not really suitable for children (Rodić and Granić, 2022). Therefore, a tangible user interface seem to be a good substitute for expanding learning opportunities, especially when they incorporate familiar elements of play.

The framework Child Tangible Interaction, CTI, was developed by Antle (2007) to present the benefits of and help designers develop more suitable tangible systems for children's cognitive development. CTI describes five main aspects of children's interaction: Space for Action, Perceptual Mappings, Behavioural Mappings, Semantic Mappings and Space for Friends. Space for Action refers to the opportunity for children to manipulate objects and explore physical environments freely, as physical interaction is essential component for children's development. It emphasizes the importance of designing for children's size, motor skills and natural curiosity. Perceptual Mappings involves how children sense and interpret feedback from objects or systems through sight, sound, and touch. The focus is on making the system's reactions perceivable and understandable, so children can notice what changes occur when they interact. For example, a button that lights up and makes a sound provides clear sensory cues that the child can detect and interpret. Behavioural Mappings focuses on the consistency and predictability of system responses to children's actions. It is about ensuring that interactions follow understandable cause-and-effect rules to support learning and exploration. For instance, in a science centre exhibit, pulling a lever or moving a block should consistently produce the same effect, helping children understand and anticipate outcomes. Semantic Mappings is about how easily children can understand what an object represents and what they are supposed to do when interaction with it. Strong semantic mappings leads to less demanding comprehension and meaningful engagement. Space for Friends highlights the importance of social interaction, encourages collaboration and communication among peers during interactive learning activities. By combining all five aspects of CTI one could develop an interactive installation, mainly towards children, that will fulfil their needs for good cognitive development, which is precisely what science visitor centres are looking for.

2.4 Iteration of Prototyping

It is not easy to make a game that is challenging yet not too difficult nor too easy and, at the same time, fun. Therefore, Bostan and Öğüt (2009) argues that integrating difficulty levels that can be adjusted is important for an optimal experience. This can be achieved in two ways, consistency towards the storyline and level adjustments either dynamic or static, or both.

According to van de Watering and van der Rijt (2006), children that underestimate their own abilities tend to perform the best. They also argue that teachers often underestimate the difficulty levels, which leads to more difficult assignments for the children, than necessary. While the children often underestimate the easiest items. The students reported that the presentation of the task laid the ground for the assessed difficulty level.

As claimed by Dow et al. (2005) Wizard of Oz (WOz) is typically used in Human-Computer Interaction (HCI) research, especially in the iterative process of rapid prototyping. Using WOz in the iterative process makes it easy to test the prototype while removing the technical limitations. Meaning that the user experience and especially the HCI is assessed in a simulated way (Baudoux and Gronier, 2025). The simulation is made by a wizard, a (preferrably hidden) human controlling the undeveloped technology, so that functionalities can be evaluated and then realised. However, Dahlbäck et al. (1993) argues that this method raises ethical concerns, as it involves deceiving participants into believing that they are interacting with a real technical system. This creates a dilemma, since the effectiveness of the method relies on participants perceiving the interaction as real, while simultaneously limiting transparency toward participants.

3

Method

When starting a project it is important to be aware of what methods are available and asses which ones will be most useful to reach a good result of effectively gaining user engagement and increase interest. Every design process is unique as designers choose the route most suited for the problem at hand. The choice of how to schedule their time, what design methods and tools to use and how their user group or certain designers will or will not be included in the design process are all things that will affect the final outcome. Therefore, the result of design work is impossible to predict (Lowgren and Stolterman, 2007).

In this project designing takes a more scientific route as a majority of the work will consist of conducting research. Christopher Frayling published a paper in 1993 called *Research in Art and Design* (Frayling, 1994) where he defined three categories of design research. The first category was research **into** design, where one studies, for example, the history of a specific design or its theoretical perspective, such as political, cultural influence or technicalities of the design. Research **for** design is the second category, which entails conducting for example user studies before designing and basing the design on research results. The third category was research **through** design, a method where you design and create artifacts to explore a concept and gain more knowledge about it through the results of the interactions with the artifact (Zimmerman et al., 2007). The planned structure of this project will follow this exact approach by first conducting initial research to create a design space with a research question and will then begin the designing of a solution that will later lead to new knowledge by observing, for example, unexpected behaviours from users. In this section, a literature grounding on the methods used during the duration of the project will be presented and a description of how each method will be useful.

3.1 Relevant Methods

During this project we will be following the double diamond structure. By using the double diamond each prototype iteration will be split into four phases: *discover*, *define*, *develop* and *deliver*. The double diamond is particularly well suited for this project because, as Shen et al. (2024) states, it fosters creativity in scientific research. The *discover* phase provides creativity with no restrictions to explore different possibilities and existing designs based on investigations on, for example, how visitors physically interact with the exhibit or how to catch interest and keep visitors engaged. After researching and exploring different ideas it is time for the *de-*

fine phase. Here defined boundaries should be narrowed down to follow the projects learning objectives, budget constraints or interaction principles known to support the wanted outcome. Now you have a well defined problem and it is time to come up with ideas to create a solution through the *develop* phase. The *develop* phase includes ideation methods, such as, prototyping and sketching through an iterative process. The final phase is *deliver*, which is where you refine and implement the solution. When you have a final product you can go thought the process again as many times as needed to reach a final solution to the original problem. By iterating through this process multiple times you can refine a product's usability and ensure that the final design achieves both its intended learning outcomes and a meaningful visitor experience Shen et al., 2024.

3.1.1 Research

The first prototype was based on previously collected and analysed academic research and personal observations made at OSO when user interacted with the original scale dresser. However, it's design was based on results from a method called Importance/Difficulty Matrix. A Importance/Difficulty Matrix is a 2x2 chart where notes of problems and needs within the projects area are placed depending on how important they are to solve and how difficult they are to solve Institute, n.d. Then notes relatively close to each other can be categorised into more detailed areas the project needs to focus or not focus on depending on their placement on the matrix. This projects matrix can be seen in Figure 4.1 in Chapter 4.

3.1.2 Initiation process

When coming up with ideas and designing the first low fidelity prototypes brainstorming methods, such as, sketching, paper prototyping and storyboarding were used to be fast and rapidly be able to explore many ideas over a short period of time. By working with pen and paper to becomes easier to try out and imagine different designs instead of putting all money and effort into one physical prototype, which makes it hard to abandon even if its results does not fulfil the designers goals (Omgreen, 2006). The concept to *"kill ones darlings"* is an important part of a design process where multiple designers are involved or conditions might change. It entails the importance of designers to be able to let go of and detach themselves from their ideas when they, for example, have to handover the design process to another designer or the idea no longer fits the concept, even if the design means a lot to them as an individual (Rouse, 2013). To avoid developing strong emotional attachment to design ideas during the initial design process quick sketching sessions and interactive prototypes made from paper were the easiest available and cheapest option. As pen and paper also is easily modified, issues with the paper prototype can be changed on the spot without further complications or delays to further testing improved versions (Snyder, 2003). As no users in within the projects focus age of 10 to 15 years old were available outside of scheduled user tests, the idea development relied on storyboarding as a tool to gain insight on how a interaction with the improved prototype could look in both positive and negative ways. Storyboarding was considered useful in this stage of the design process as it provides a structured way of mapping out and visualising interactions and scenarios before implementation (Mangtani, 2024).

In later, more high fidelity prototypes the Wizard of Oz, WOz, method came in handy when getting user to interact with non-functional prototypes as is entails users interacting with a prototype they believe works by itself, but is actually controlled by a third party behind the scenes. The WOz method allows designers to explore more complex design systems even if the time, budget or proper knowledge on how to implement it is available (Dow et al., 2005).

3.1.3 Evaluation

An important part of the project is to interact with the users during user testing and collect qualitative data. By observing users when interaction with the installation their work flows, emotions and faulting functionalities can be mapped. To add on to the collected data, semi-structured interviews can also be conducted. Semi-structures interviews are a good option to gain as much information as possible from interviewees as the method allows the use of both open ended and closed questions to be asked (Sharp et al., 2019). It is important as interview facilitators to make sure questions are not biased or encouraging a specific answer. Especially when working with children as they are particularly prone to answer accordingly to not offend the interviewer (Sharp et al., 2019). Sharp et al. (2019) mentions a method used when interviewing children that uses a set of smileys that represents different feelings that they children can pick and choose from as it can be harder for them to express their feeling only though words. This might be a good thing to keep in mind when preparing interviews with younger participants.

Thematic analysis

The qualitative data collected during the evaluation phase was analysed using thematic analysis (TA). According to Clarke and Braun (2017) TA is a qualitative analytical method used to identify, organise, and interpret patterns of meaning across a dataset, allowing for a structured breakdown of the data and supporting systematic interpretation.

4 Design Process

This chapter presents the development process of the prototypes used in this study. Building on the insights obtained from the initial brainstorming sessions and concept development, the chapter outlines how the selected concepts were translated into functional prototypes and evaluated through user testing. The insights gathered from these sessions guided iterative improvements to the prototypes, allowing the design to be refined and adjusted throughout the development process.

4.1 Planning

Table 4.1: Weekplanning

Week 1	Literature review / Ideation
Week 2	Literature review / Ideation
Week 3	Location grounding / Writing planning report / Paper prototyping
Week 4	Literature review / Writing planning report
Week 5	Location Grounding / Prototyping / User tests
Week 6	Location grounding / User testing / Prototyping
Week 7	Thesis / Prototyping
Week 8	Observation grounding / User testing / Prototyping
Week 9	Observation grounding / User testing / Prototyping
Week 10	Thesis / Prototyping
Week 11	Thesis / User testing
Week 12	Thesis / Build
Week 13	Thesis / Build
Week 14	Thesis / Build
Week 15	Build final installation
Week 16	Build final installation
Week 17	Write thesis
Week 18	Write thesis
Week 19	Presentation and opposition of thesis
Week 20	Presentation and opposition of thesis

The table above is a rough estimation on what we thought the most focus would be on each week for this project in the timespan of 20 weeks. This time plan was followed. The first four weeks were mainly spent on writing the planning report, along with planning the project with our supervisor and the staff at OSO. Since the project is based at OSO, location grounding was conducted, meaning observing the area, the exhibit and questioning the staff. Observation grounding was also done, which implies on being on site and joining school classes in different ages, observing them while they interact with the exhibition. Since we were not located at Onsala all the time, we spend the rest of the time at the school facilities where we prototyped and tested our tangible prototypes. The final report was planned to be written alongside doing other things each week, but the last four weeks was also dedicated to prepare for finalising the thesis and preparing for presentation and opposition.

4.2 Initial brainstorming

At the start of brainstorming the Importance/Difficulty Matrix, which can be seen in Figure 4.1, was used to understand and realise key points of this project. The main points chosen to focus on during the projects were:

- To create understandable instructions to make the installation easy to use.
- To create an interactive installation that is fun to use and that promotes collaboration.
- To catch users interest to learn more and not be scared that they do not know enough to participate.
- To design an installation design for adolescence that successfully support all the points above.

After the matrix was created and all the most important focus points for the project was defined we started sketching. Both reasonable and unrealistic ideas were created to see what functionalities would be possible to both create with the knowledge, time and budget available. Some sketches and functionalities were combined to see how they could work together and storyboards, such as the one in Figure 4.2, were created to see how it could look when users interact with the installation. When a more refined idea was defined a paper prototype was created, see Figure 4.3, to show supervisors and try out how the interaction would look physically played out instead of on paper.

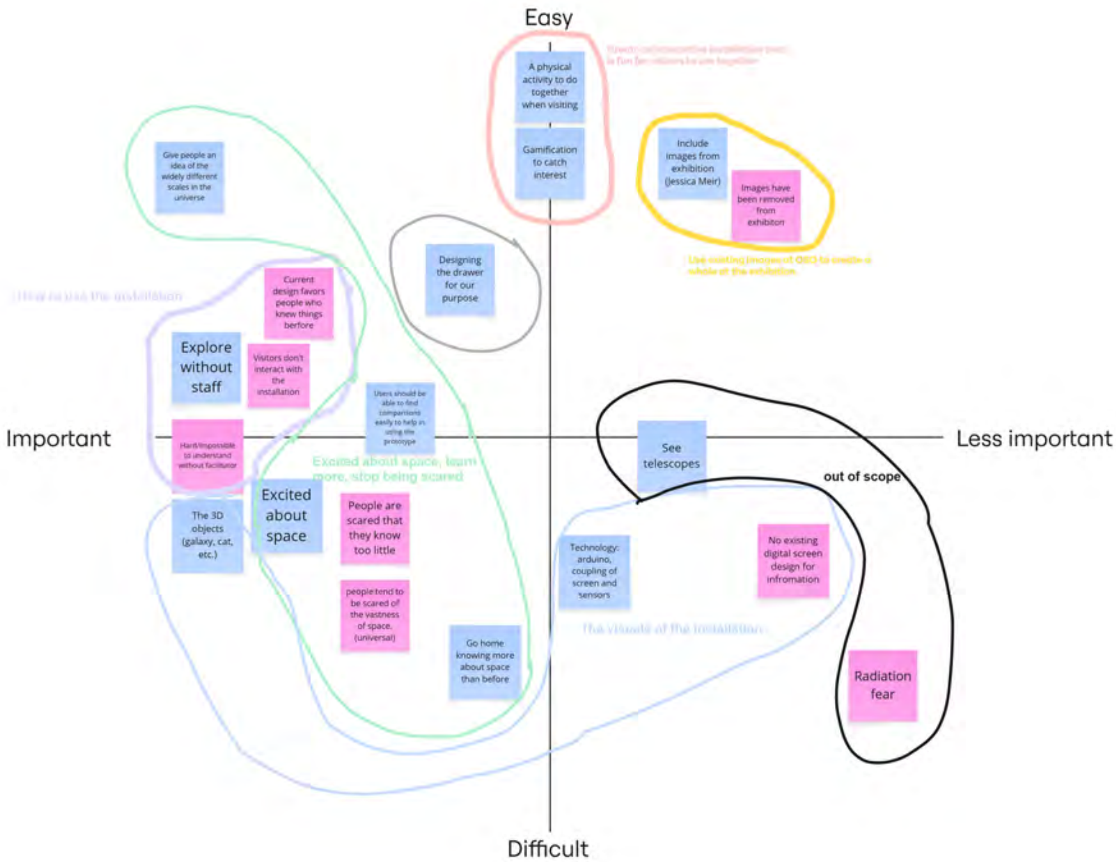


Figure 4.1: Importance/Difficulty Matrix (LUMA-institute, n.d.)

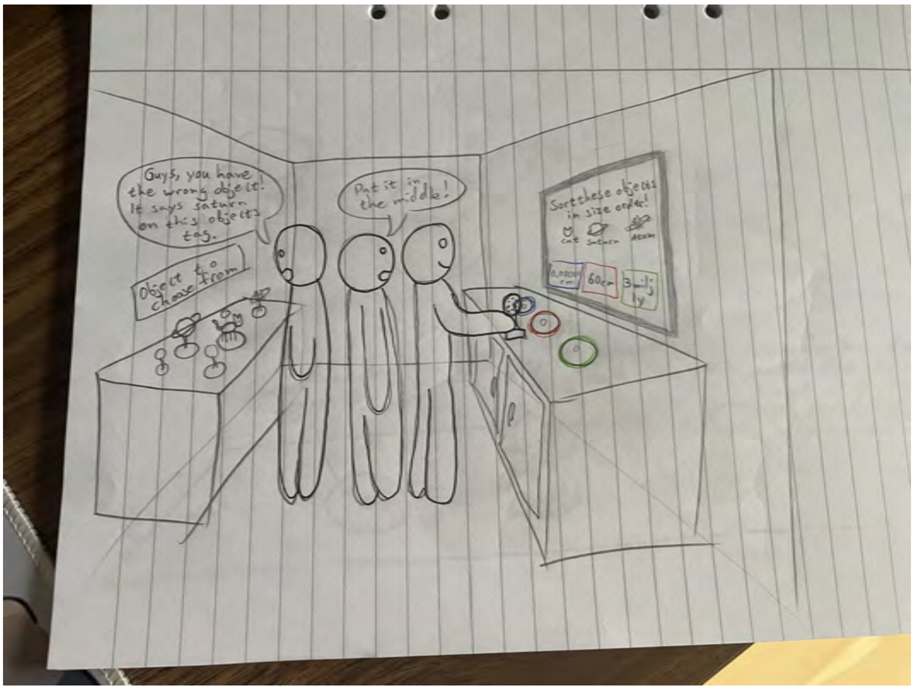


Figure 4.2: Initial storyboarding

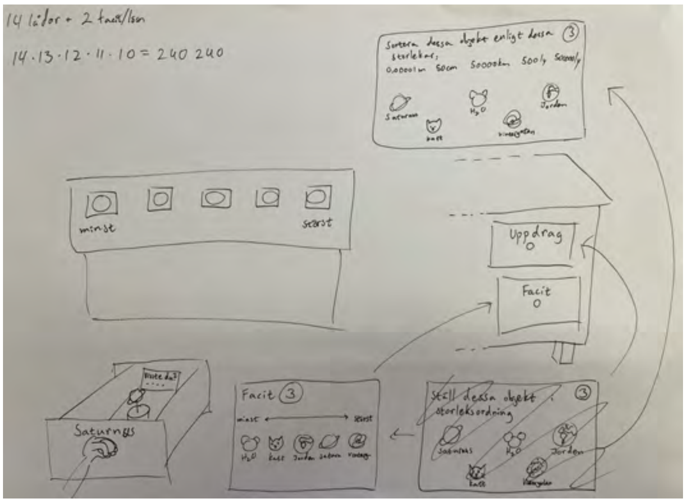
Figure 4.3: Paper prototype

4.3 Prototype One

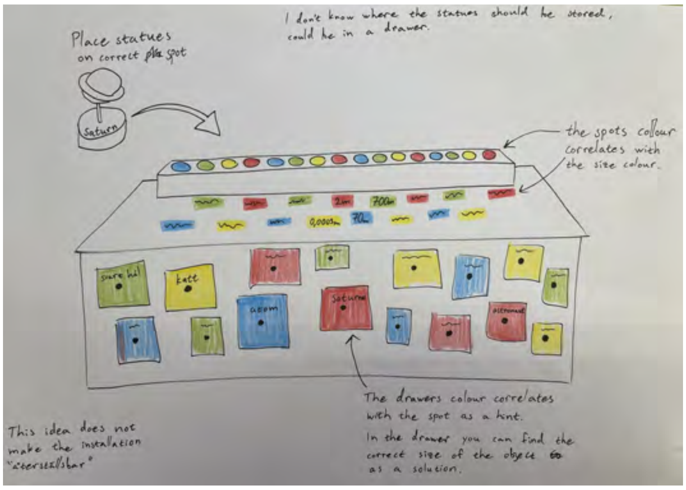
From the brainstorming sessions, several designs were created. Three new sketches were drawn, shown in Figure 4.4 taking inspiration from the initial brainstorming and worked as the base for the first prototype. Sketch 4.4(c) show how 3D models of certain scientific objects could be created an placed in the dressers for storage. In sketch 4.4(b) the placement of the models was unknown as it instead uses the dressers as the solution to the correct sized of the models. Each dresser is depicted to have the name of one object and in the dresser user would find the correct size of the object. Although there was no clear definition on how user would be informed on what the task at hand was. By combining sketch 4.4(b) and 4.4(c) with functionalities from the initial brainstorming, such as sorting a limited number of objects and being provided with hints of the objects size, sketch 4.4(a) was created. Sketch 4.4(a) depicts 3D models of scientific objects being stored in named dressers together with a fun fact about the object. Challenge papers would be available for users to choose from with a correlating solution paper. The challenge would entail picking out the named objects models from the paper and sort them according to a number of dimensions also named on the paper. The models should be placed on podiums on the top of the dresser unit. The podiums were inspired by the *Vågade ekvationer* installation mentioned in section 1.4.3 and how it provides a clear understanding to the user of where its object should be placed to interact with the game. This definition is what the first physical prototype was based on.

The design choices for the first prototype were mostly based on feedback from a previous user test on the original installation on a class of last year high school students. As they are outside of this projects age group the results from their user test will not be used in any further development of the installation.

After defining what was needed to create the first prototype, 3D models were modelled, printed, constructed and painted, 3 different challenge papers with correlating solution papers were also designed and printed along with fun facts about each object. All STL files for models not created by us, as well as any photographs not taken by us, were obtained under Creative Commons licenses from their respective creators. The implementation of the physical prototype at OSO can be seen in figure 4.5.



((a)) Sketch 1



((b)) Sketch 4

((c)) Sketch 5

Figure 4.4: Prototype 1 sketches

Figure 4.5: Prototype 1 implemented at OSO

4.3.1 User testing one

The user group which was tested on for the user test of the first prototype were two classes of year 5 students, split in two days. This resulted in approximately six sessions per day. The first day was dedicated to extracting feedback on the original installation, whereas the second day focused on the prototype.

To collect fair data of the original installation, all students were provided with the same initial instructions to provide them with a basic understanding what the task they should perform entailed. They were observed in how they used it, what they found around the installation, if they needed help and how focused they were on performing the task. As can be seen in Figure 4.6, this installation uses images in which the children should identify the objects and then match with their respective size.

The results from this user testing provided valuable feedback on which functionalities did or did not work in the original dresser. As year 5 students are at the lower range of this projects age group, they provide an insight into how much scientific knowledge they have learned in school. According to the teachers they learned about the planets in our solar system and big bang in year 2, but not too much about chemistry. Due to this, some pictures were too hard to identify for the students, which caused them to place the pictures into the dressers without trying to identify the objects. They also did not know that LY, the abbreviation of light years, meant. The sign containing the translation of LY into kilometres had to be pointed out for the usewrs to see it and gain a some what better understanding of how long 1 light year is.

One thing that worked well were the colour coordinated stickers on each image. A majority of the children caught on to the hint that the picture should be put into a dresser with the same colour as the sticker. It was a great support for them as there was a general understanding that the task was very tricky to solve, especially when trying to sort the tiny and huge objects. Even if pictures, such as a cat and astronaut, were the easiest to identify, users were conflicted as they thought there was no dresser marked with an exact size to put them in. Both the picture of the cat and the astronaut are, according to the solution, to be places in the dresser labelled 2 meters, which can be quite confusing as they are not the same size in reality. There were also no instructions available to the users that two pictures were allowed to be put in the same dresser, causing users to directly ask us about the rules.

There was also the realisation the some pictures were too big to fit in the smaller boxes.

A feature to the original installation that worked very well with the year 5 students were the four posters on the wall over the dresser. Their depictions of a few different objects related to the scale categories tiny, small, big and huge allowed the users to visually compare pictures to the posters, helping them come to a conclusion to what dressers the object should be placed in.

For the second day the installation transformed into the first prototype for the second round of year 5 students to try. Compared to the previous day, the prototypes

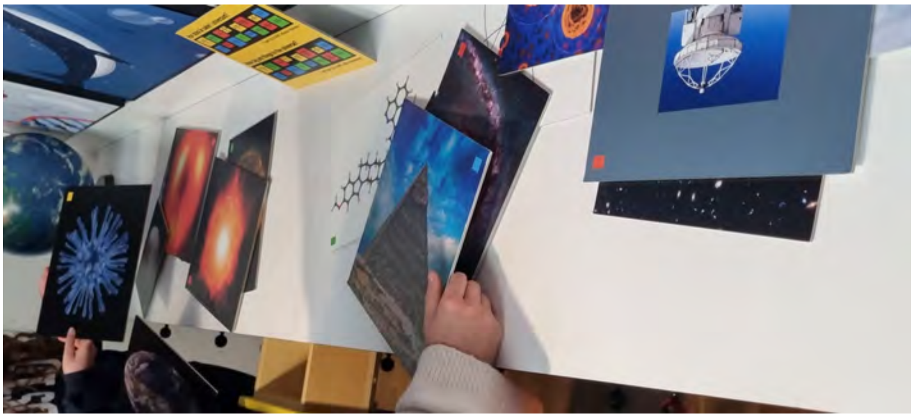


Figure 4.6: Testing the original installation design on year 5 students

challenges were too easy and that it would be even more fun if there were challenges available that were a bit tricker to solve. All groups focused on solving the task or were discussing relevant topics that would help them solve the problem. One of the problems was the size of the groups. The students were sent to the installation in groups of six. When given the instructions on what to do, most split up into two groups of 3, solving two challenge papers at once. This made the installations very crowded and hard for the users to navigate. Some models needed to be used by both groups at the same time, making them clash over who should use it first. Another problem was that only six out of ten groups found the solutions dresser that can be seen in figure 4.7. The groups who did not find it were struggling with what to do and ended up needing to be told the location of the solutions.

Figure 4.7: Testing first prototype on year 5 students

4.4 Prototype Two

There were two main changes made to the prototype for the second iteration. The first change was to put the challenge and solution papers on top of the dresser in a magazine collector instead of inside two of the dressers.

The second big change was the addition of difficulty levels to the challenges. Three difficult levels were implemented, named 1, 2 and 3. The challenge paper was still structured the same as before, but the combination of objects was changed based on feedback from the previous user test. According to the feedback the experience would be more fun and engaging if the challenges were harder to solve. Therefore, a larger number of objects were added and the combinations of objects for the challenges were closer in size than previously. Now some level of thinking and discussion might be necessary compared to immediately knowing which objects to place where on the podiums.

4.4.1 User testing two

Two groups of a grade 9 class participated in the user tests conducted on this day. The sessions were carried out differently for each group. The first groups testing will be described below and the second groups testing will be explained in section 4.4.2.

The first group was given an introduced to the station; how to initiate and how to proceed. According to their teachers they have learned no space related subjects since 3rd grade, making it approximately six years since they learned about, for example, the planets in our solar system. Although, they do have more experience in other scientific subjects, such as chemistry and physics, compared to the first user test group of grade 5 students.

The biggest problem during this user test was that the students were sent to the installation in very large groups, five to eight people in each group. Due to this, some of the groups decided among themselves to split into 2 groups and perform two challenge papers at once. Just like user test one, this caused the installation to be harder to use as people covered each others view, needed to use the same models simultaneously or accidentally nocking over and breaking models.

The fun facts were not notices as much during this user test. However, the ones that did notice the fun facts expressed that they were fun to read, but did not help them complete the task.

By the time three groups of students had used the installation, the challenge and solution papers were misplaced between the magazine collectors two compartments.

Some things that stayed consistent between the first and second user test was that the groups talked among themselves about the task at hand.

4.4.2 User testing two and a half

The second group received no introduction and was instead allowed to explore the prototype independently. This was done to simulate a natural interaction rather than a test scenario. The easy difficulty level was also removed during this session, as feedback from previous user tests indicated that these missions were too easy. To avoid unnecessary time spent on trivial tasks, the researchers decided to remove them.

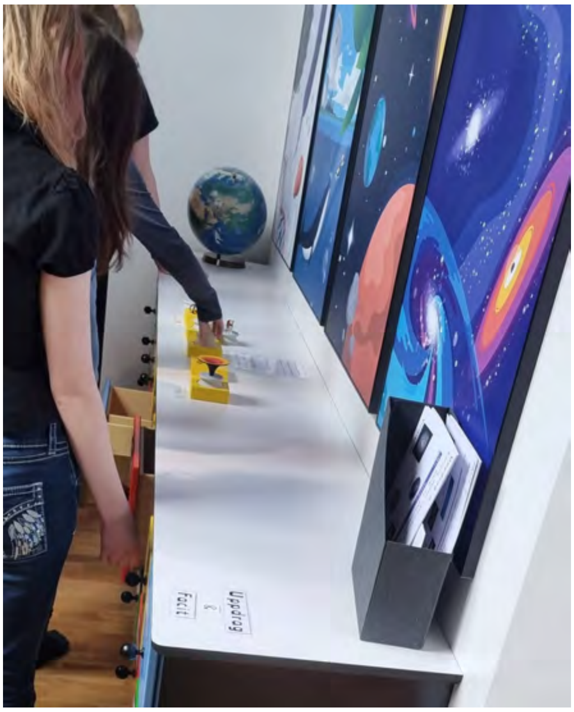


Figure 4.8: The participants opening the dressers without a visible mission card.

The majority of the groups did not notice or ignored the mission stand, shown on the right in Figure 4.8. This made the experience slower, as participants struggled to understand how the installation was intended to be used. Initially, all groups began by opening the dressers and placing the objects in order of magnitude. Interestingly, several participants in each group looked at the mission stand, labelled “Uppdrag & Facit”, but did not inform the rest of the group and instead continued following the group’s initial approach. Although, once the mission cards were discovered, the interaction progressed more quickly and participants began solving their respective missions. Because of this, one participant suggested adding a large arrow pointing toward the mission cards, as locating them was perceived as the most challenging aspect.

During their mission, all groups remained focused on their assigned missions and discussed possible solutions. Some participants looked at the posters (visible in Fig. 1.4.1), but did not connect them to their missions. All of them recognised that the mission card numbers corresponded to the cheat sheet numbers. However, the unit sheet was not used by any of the groups. Thus why some participants believed they had completed the task incorrectly when starting with mission 6. They assumed they had to calculate something with the unit sheet after placing the models on the the holders.

All participants proceeded to new missions after completing the previous ones, until they had to leave the station. Approximately half of the groups returned the models to the dressers between missions. Although, between the groups, the mission cards and cheat sheets became mixed, which made it more difficult for subsequent groups to locate the cheat sheets used for verifying their answers. The attempt of separating the mission cards and cheat sheets can be seen in Figure 4.9.

Figure 4.9: The magazine collector with a makeshift paper divider in the middle.

Feedback: Did not understand the unit sheet. The fun facts were fun and interesting even if they did not help with the missions. Some of the missions were difficult, but some of the guesses were easier and could be excluded, leading to easier hypothesis of the rest on the mission. Reasonable level difficulty for them. We should have put a large arrow leading to the mission cards, since that was the most difficult according to one of the participants.

Specific problems: Thought the did it wrong since they started with mission 6. Some misunderstanding the size to distance. When they looked at the unit list they became confused if they were to figure out how large the models were. Most of the participants did not make note of the sizes on the mission cards (see Fig. 4.5(c)). Models are not scaled properly, except for the planets.

4.5 Prototype Three

In this prototype, several elements were modified based on findings from the previous user tests. The feedback mechanism was redesigned. The previous version relied on a printed cheat sheet that required participants to manually verify accuracy. In the updated version, a digital display was introduced to provide automated feedback. The display functions both as an initial instruction screen and as a real-time correcting indicator during task execution. This was inspired by the two installations *Nördlig* and *Sifferjakten* at Universum, read more about them in section 1.4.3, as they both provide users with colour coded feedback which includes the colours red as incorrect and green as correct.

Figure 4.10: How the feedback was relayed through the digital display.

As this iteration introduced the digital display, the prototype did not yet include fully implemented automated feedback. Instead, a Wizard-of-Oz setup was used, in which one of the researchers manually controlled the feedback while remaining visible to the participants, which can be read more of at 2.4. This could impact the feedback from the participants, but was not measured in this user test. The screen was a Figma with prototype animations combined with components that were controlled by different keys on the wizards computer keyboard. The keys were marked to make it easier to remember what keys affected what on the screen. This can be seen in Figure 4.12(a).

The design of the missions and their holders was also revised. Additional objects and models were introduced, allowing the missions to be structured differently compared to earlier iterations. To create a clearer distinction between difficulty levels, the mission cards were redesigned with coloured borders instead of text labels (see Fig. 4.13). The holders were redone into five blue, one red and one black, corresponding to the amount of models required from the missions. The colours were chosen based off of the difficulty colours for skiing slopes, which are the standards in Europe (Bobone and Garcia, 2017). However, removing the text might make it more difficult for colour-blind participants to distinguish between difficulty levels, an issue that was overlooked during the design process. In the next iteration, the difficulty indicators will be redesigned to support colour-blind accessibility.

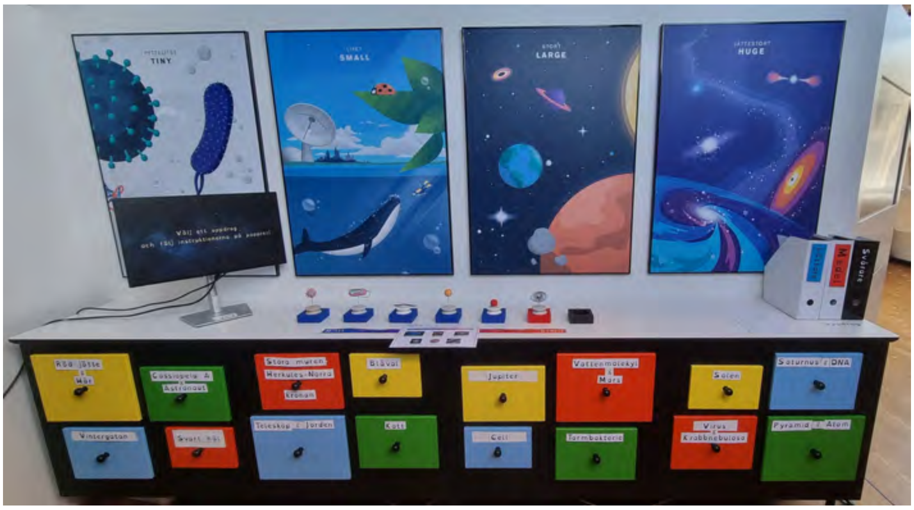
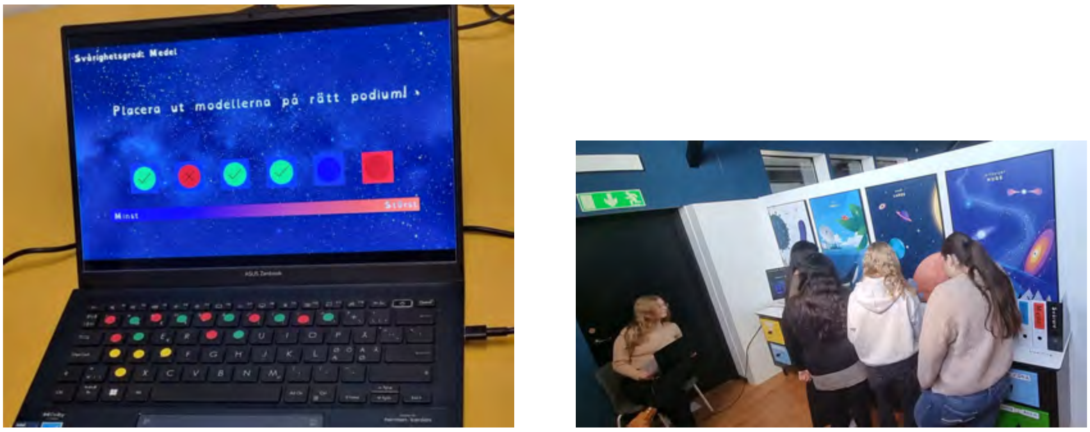


Figure 4.11: Prototype 3



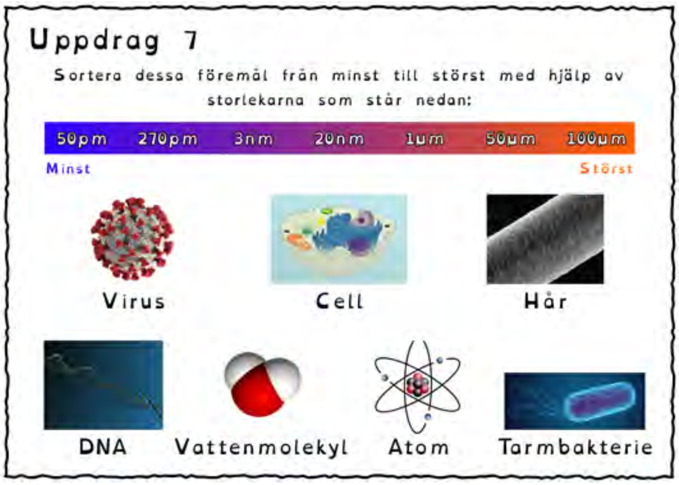
((a)) Computer setup

((b)) The Wizard-of-Oz during testing.

Figure 4.12: Wizard-of-Oz setup

((a)) Easy

((b)) Medium



((c)) Hard

Figure 4.13: The mission cards in their respective border colours.

4.5.1 User testing three

The user group this session was a grade 8 class. The introduction of the digital display changed how participants interacted with the prototype. Four groups participated in this session; three groups consisted of four participants, and one group consisted of five participants. Compared to earlier user tests, three out of four groups instantly understood how to begin from the initiation information on the display. One group, however, started opening the dressers without reading the instruction or looking for additional cues. As a result, they selected objects based on their knowledge of size, placing them on the holders from smallest to largest. Only when two latecomers arrived and noticed their group had not chosen a mission card did they begin following the intended mission. The researchers consider this behaviour unlikely to be completely eliminated within the scope of their study and, as such, regard the current initiation process as acceptable.

Three out of four groups chose a medium-difficulty mission to start, and the fourth chose an easy mission. Despite this initial variation, all groups advanced to a hard-difficulty mission.

Figure 4.14: In the midst of a user test with Mission 5, medium-difficulty.

Most participants waited for the automated feedback after placing their models on their guessed holders. When incorrect results were shown, participants often rearranged their models, suggesting that the display encouraged immediate retry behaviour.

Almost all participants interacted positively with the prototype and described it as enjoyable to use. Most of them did not believe they learned something, but that these sizes were put into perspective. Putting them against each other made them realise how big och small some things in space and on Earth are compared to each other. Although it was expected that the new colours and the number of holders per colour could confuse participants, no confusion was observed during the user tests. However, this session's participants did not engage with the fun facts placed inside the dressers. Many participants also expressed uncertainty regarding models that were unfamiliar to them, such as the Crab Nebula and Hercules-Corona Borealis Great Wall.

4.5.2 User testing three and a half

The setup for this user test was identical to that of User Test three, except for the placement of the screen. The screen was positioned behind the podium to improve its visibility (see Fig. 4.16).

Two groups participated in this user testing, and a third group had a brief look and hands-on interaction before being directed elsewhere due to time constraints.

In this round, all participants began by opening the dressers without checking the screen, despite it being positioned directly in front of them. Often, one or two in the groups would read the screen and direct their group to finding a mission. One group stepped back to observe the entire installation, yet proceeded to open the dressers before understanding how the installation was intended to be used.

Overall, participants showed limited engagement with the installation, including during discussion about the mission. Participants also did not refer to the sizes indicated on the missions, nor did the look at the unit sheet.

Figure 4.15: Participants opening the dresser during the user test, note the lack of a mission card.

Figure 4.16: Change of screen position.

4.6 Prototype Four

This version of the prototype was developed to eliminate any misplacements of mission cards and cheat sheets. Therefore, the design is entirely screen-based, but without touch interaction, as tangible elements are still preferred. As shown in Figure 4.17, a start screen and a difficulty selection screen initiate the experience.

((a)) Start screen.

((b)) Difficulty level.

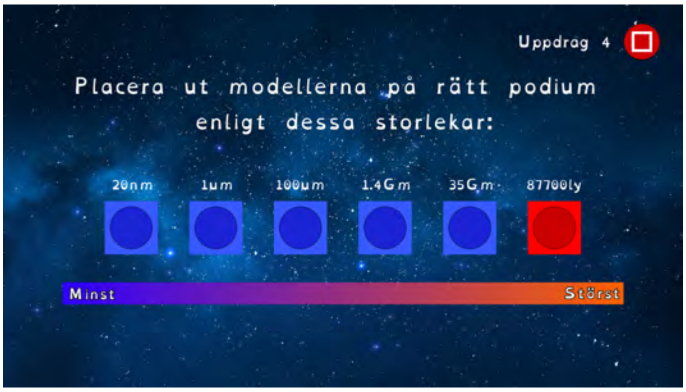
Figure 4.17: Prototype 4 Figma initiating screens.

The buttons on the screens are not touch-based but instead corresponds to physical buttons. Three buttons are present on the physical installation, representing the options displayed on the screen. The initial sketch of how the screen and buttons should look can be seen in Figure 4.18. However, following the realisation of issues related colour blindness, as discussed in Section 4.5, the colour scheme based on ski slopes was chosen to also be used for the buttons with an addition of correlating ski slope difficulties, such as black diamond. Each button has therefore also been given a distinct shape to further differentiate the difficulty levels beyond colour alone and to help differentiate the buttons if the colours were to clash for a user. The inspiration to use these physical buttons mainly can from the installation *Sifferjakten* at Universeum, see Section 1.4.3, and the use of physical buttons at multiple of OSO's visitor centres installations.

Figure 4.18: Sketch of physical button functionality.

The missions have been significantly redesigned compared to the previous paper-based mission cards. As mentioned above, the buttons include not only different colours but also different shapes to represent the difficulty levels. Each mission is associated with a corresponding button, indicating its level, along with visual information about which models should be used. An digital version of the dresser is also provided to show where these models are located, as seen in Figure 4.19. For this prototype, no real sensors will be added to the buttons or podiums. The screen will be controlled by the facilitator using the Wizard of OZ method. As the users interact with a button, the facilitator will relocated them to the screen corresponding with that button being pressed. On the screen in Figure 4.19(a) there is no option to press any button to proceed. Therefore, the nest screen will be revealed by the facilitator when the users have successfully collected all the models for the mission. The next screen, seen in Figure 4.19(b), displays the mission, including instructions on what to do, where to place the models, and how to complete the task.

((a)) Mission 4.



((b)) Medium difficulty.

Figure 4.19: Prototype 4 Figma mission screens.

When all correct placements have been made, the screen updates to Figure 4.20. At this point, users can choose to either continue with another mission or end their interaction with the installation.

Figure 4.20: End screen.

4.6.1 User testing four

The first round of testing on prototype four was conducted during the city of Gothenburg's annual science festival. This was a unusual user testing as OSO was open for the general public. Therefore, we could not predict who would turn up to the visitor centre. Due to this, a minimal part of the visitors were a part of the projects focus age. The most common interaction that occurred during the event was younger children playing with the models. Some were trying to perform the task with a lot of support and supervision by their parents. However, even if the users for this test were not the usually visitors there were some very useful takeaways from this experience. When users go from the mission screen, seen in Figure 4.19(a), to the podium screen, in Figure 4.19(b), you can no longer see which models were supposed to be used for the mission. This caused a problem for users who did not put back models from previous missions, as they mix up the relevant models with the irrelevant ones.

The new interface visually presenting which models should be used and where they are located in the dresser with the goal to make it easier for users to find them was mostly misunderstood. As the users stand vert close to the dresser when looking at the screen, they do not have both the digital dresser and the drawers visible to them simultaneously. However, during this user test the screen was moved to the left side of the dresser due to a short cable which caused the screen to be off centre and not angled parallel to the dresser. This could have had an impact on the misinterpretation of the model location information.

Both senior citizens and younger children had a harder time understanding the task presented to them to to either bad sight or limited reading capabilities. However, the visitors within the projects age range were fully capable of understanding and performing the task without outside help. Showing that the installation has achieved a good difficulty level for OSO's visitor centres main audience.

Some other problem that were identified during the user testing was for example the language barrier. The current prototype only exists in swedish, excluding users who does not not know the language. A concern to keep in mind is that the buttons controls the screen might confuse younger children, as they are used to touch-screen play. Although, the children that tried to touch the screen might have been too short to see the buttons on the high dresser counter.

4.6.2 User testing four and a half

The second test conducted on the fourth prototype was on a group of year nine students who were at OSO for a special work experience program aimed at introducing science to children in economically disadvantaged areas. The main feedback from this user test was that the installation is fun and engaging, but finding the models is the biggest hassle of the task. The digital dresser still does not convey model locations clearly to the users. A suggestion was to sort the models in alphabetical order make it easier to find.

4.7 Implementation week

This section presents the implementation and the user evaluations of the final design of the prototype. The focus was on developing a final, more technical, version that reflects a potential product, while supporting interaction through WOz. The sketch that the new design was based on can be seen below, in Figure 4.21.

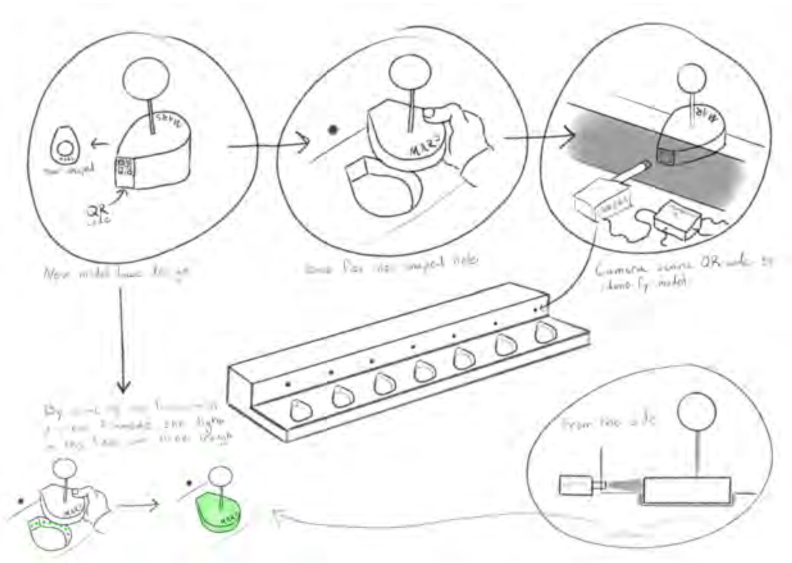


Figure 4.21: The newest sketch for the last iteration of the prototype.

The major differences between the previous iteration and this version are the redesigned podium and the addition of technical components, specifically cameras, to support a more independent installation. Incorporating cameras would eliminate the need of a wizard if connected to a system that scanned the models placed at the podiums with QR-codes. However, this was not recommended during consultation with a technical supervisor, and was therefore not fully implemented in this version. As the focus of this phase was on building and implementation with a time constraint, a new technical approach was therefore not pursued.

Excluding the camera implementation, a new design was created, focusing on the implementation of LED ring lights positioned beneath each base on the podium and also include the buttons to be connected to the same built. The box was built in wood and laser cut plywood and can be seen in Figure 4.22. Compared to previous iterations, this version featured a single podium supporting all stands, rather than multiple with each supporting a single base.

Figure 4.22: Final prototype installed at OSO visitor centre.

A newly shaped base for the models was also constructed in transparent 3D filament to make the models light up when placed on the new podiums. The new podium holes were done in the same shape as the new model bases water droplet shape to make sure they could only be placed down one way. This was done to complement the cameras and QR-codes for easier scanning. This shape was still included in the final design as the bases were printed before the decision of not incorporating the cameras was made. An exmaple image of how the LEDs light up the models can be seen in figure 4.23. A protective layer of transparent filament was added between the LED and where the podium is placed to prevent people from being able to reach into and touch the light and cables.

Figure 4.23: Models lit up by LED-lights.

The technology required to make this prototype work was an Arduino connected to 5 circular LED lights soldered to their respective cables. A part of the wiring can be seen in Figure 4.24 How the light colour change was based on written code where the original colour was yellow and each circular light changed colour to either green or red depending on which button the computer was pressed, just as the Figma animation works. The Arduino, therefore, needed to be connected to a computer for the controls to change the colour of the lights to work. Originally, the plan was to control the Arduino and Figma simultaneously from the same computer. However, both programs required the computer to have them open as the main program, which can not be done at the same time. Therefore, two computers had to be utilised to perform this WOZ.

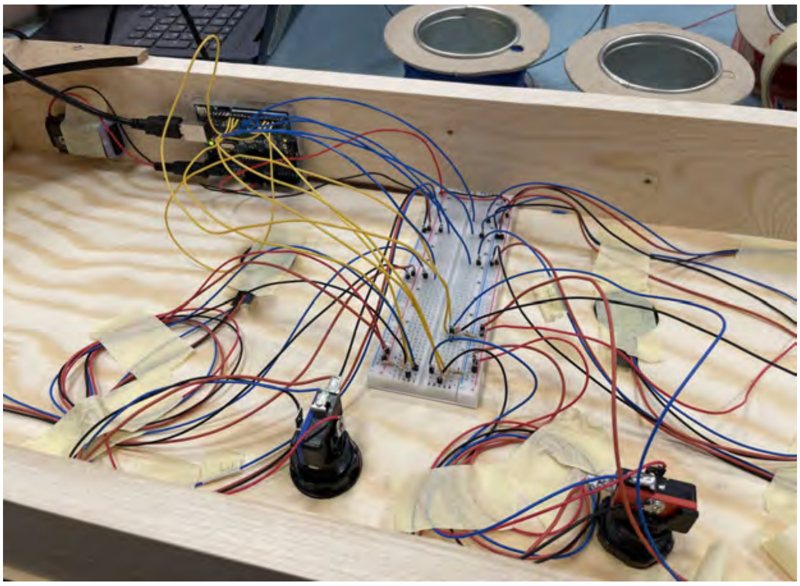


Figure 4.24: Final prototype wiring.

The Figma was changed based on feedback from prototype test four, which can be read in section 4.6.1 and 4.6.2. The digital dresser was not changed much, except the colour of the drawers that showed where an item was located. Previously it was green, which we do not know was a reason for the confusion, but it might have been. Therefore, the colour of the digital dressers drawers was made to correlate with the colours of the actual drawers. Either yellow, red, blue or green. In Figure 4.25 a comparison between the real dresser and the digital dressers with new colours can be seen. The models have also been changed to be sorted in alphabetical order in the drawers to try if it can help users find the models more easily. The new location of each model can be seen in Figure 4.25. As some drawers contain more than one model, the additional models in a drawer can be seen in the lower digital dresser in the image. Another change is that the tasks have been made into 3 task from each difficulty level, equivalent to 9 tasks in total. The amount of models per task has also been changed, from different amounts per difficult level, to five, regardless of the tasks difficulty level. The task were therefore remade to fit both the new amount and the model relocation in the drawers. A button press has also been added as a requirement to take the user from the screen where they find the models to the screen where they are asked to place them in order according to size. Previously, this was done by the facilitator manually changing the screen when they saw the users had collected all the necessary models.

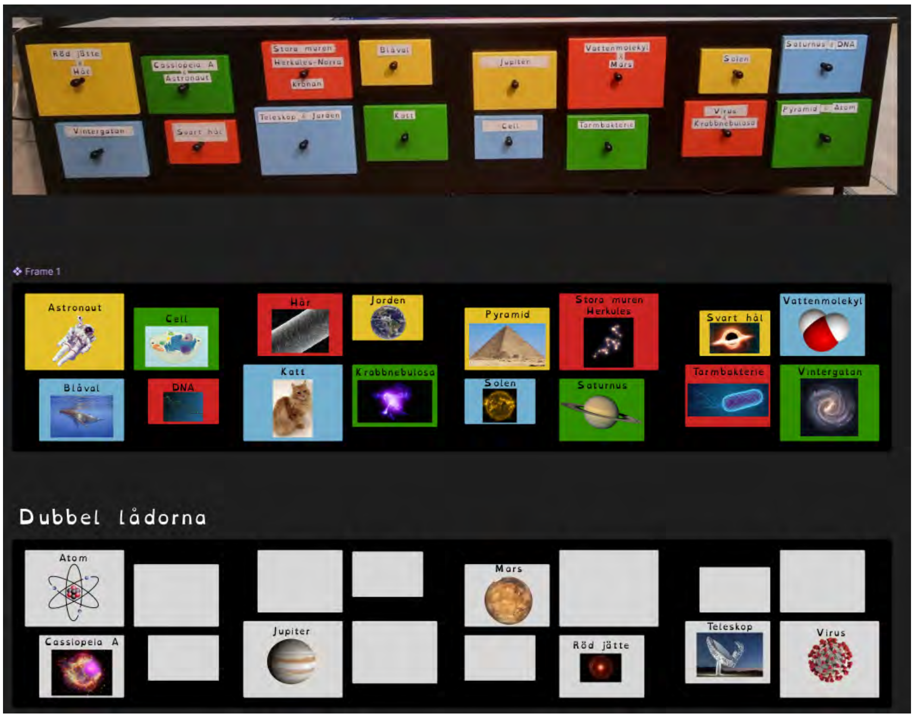


Figure 4.25: New colours for digital dresser and new location of models.

As the previous colourful podiums were removed and replaced with the wooden box for this prototype, the Figma changed the podium screen into only showing five round yellow circles, as shown in Figure 4.26(a). Previously the line going from the first podium to the last was a line with a blue-to-orange gradient. Due to risk of confusion among users, as the colour blue is already used to represent the easier difficulty level, this was changed to a simple white line with arrows at both ends. The final change to the Figma was to include the solution visually in the final screen with the correct sizes. Previously, the sizes were included above each podium in the mission screen, but users did not seem to either notice or user them to solve the task.

((a)) The newest edition of a mission.

((b)) The final screen has been modified from user tests.

Figure 4.26: The new changes made to the graphics.

4.7.1 User testing of last version

Two rounds of user testing were made to the last prototype of this project. The first user test was conducted on a year 9 class. A majority of the groups were very enthusiastic about participating and finishing the task at hand. In their excitement they hit the physical buttons with quite a lot of force. Vocal celebrations were made when each task was finished correctly, showing great collaboration. Most of the groups were also quick on pressing the buttons, which caused them to miss vital information on the previous screen they skipped over. As there were no "return" button implemented into the Figma, the students did not know how to move forward and the game had to be manually reset to the starting screen by the facilitator. Even when the groups are provided with screens that contain the information they need to perform the task, they seem to ignore the text and try to understand the task without reading the text.

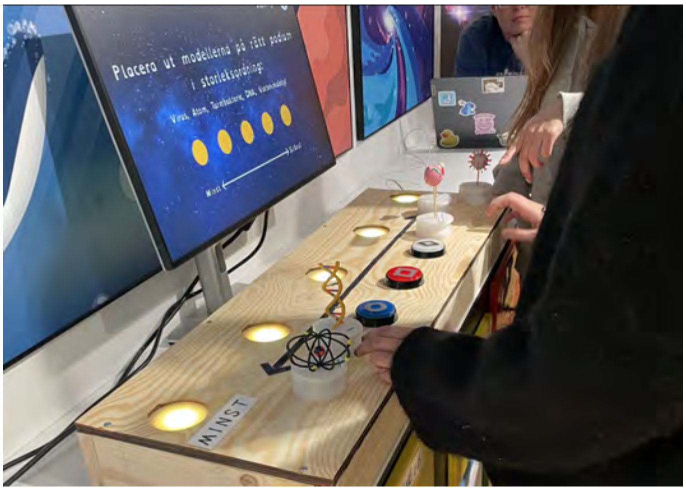


Figure 4.27: Year 9 students using the final prototype.

Based on the findings that the users were quite eager to press the "go to the next step"-button with no way to get back to the previous screen, a return button was added with the intention to make it easier for users to change mission, go back to see where the models were located if they missed one or return for any other reason.

((a)) Digital dresser screen with return button.

((b)) Mission screen with return button.

Figure 4.28: The newly added return button.

The second round of user tests were conducted on a year 5 class. This was an important moment for the project, as it was the first time since the initial user test of the first prototype that testing was conducted with a group of year 5 students. The usual age range for year 5 is around 11 years old, which puts them in the lower range of the projects focus group. As the prototypes had been developed iteratively based on feedback collected primarily from users in the higher age range, such as 14- and 15-year-old's, there was a concern that the final prototype may have evolved in a direction less suited to a younger audience. However, the results showed that the current prototype worked great with the younger children as well. During this session, at least one teacher was present at the installation, which might have caused the children to behave in a certain manner due to the teacher telling them what to do. Although, we did not stop this from happening as this might be what would happen even if we were not there. We also believe that the installation would be comprehensible for the students even if the teachers were not present. All groups thought the information provided to them was enough to solve the tasks. The harder difficulty level was doable even for this age group. One group heavily relied on the images in the digital dresser to interpret which models were larger or smaller than the other. None of the groups tried to touch the screen instead of the buttons on the counter, showing that even children who are used to touch screen technology understand that the buttons are the main interactive component. The most common comment was that they thought it was a fun exercise, that it was exciting to see the objects real sizes at the end and that they wanted to do more. No groups needed to use the newly implemented return button.

By observing both the year 5 and year 9 students we could arrive at the judgment that the new colours on the digital dresser helped the users find the models quicker. Even if it was easier to find the models, some users expressed that it was hard to find where to put them back when the task was over.

5

Results

This chapter presents the result of the final iteration together with the insights gained throughout the design process. Furthermore, the findings are discussed in relation to the research questions: *"How to design a tangible interactive installation to support adolescents', 10-15 year old's, engagement with scientific scale?"* and *"Which interaction design and tangible interaction principles used during this project are the most helpful for communicating scientific scale in a science centre context?"*.

5.1 Final prototype

Throughout the iterative process several updates was made to the prototype, which concluded to this version (see Fig. 5.1).

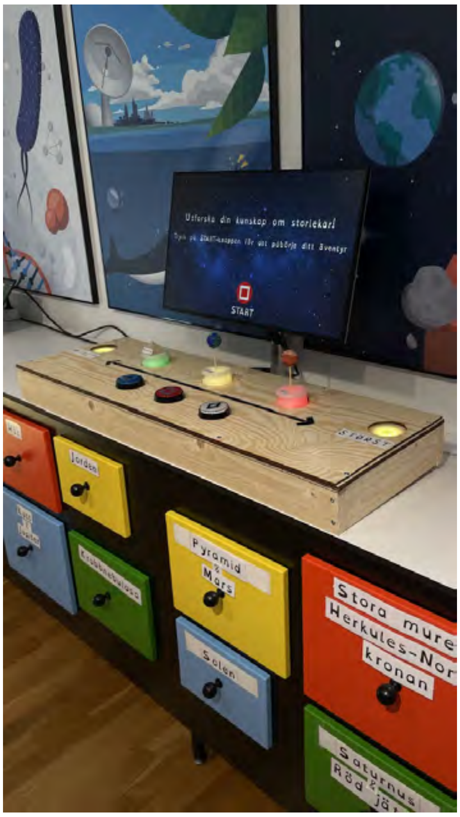


Figure 5.1: The final prototype in the science centre at OSO.

A 3D-model based installation was made, which was developed early on in the process. A screen along with buttons, in the form of a wooden podium, was added later, which elevated the stand-alone design. This wooden podium holds all the electronics within to hide it from sight.

The drawers were sorted alphabetically, and holds up to two models along with a fun fact for each entity. They are matched with a size in either centimetre (cm), meter (m), kilometre (km) and light year (LY). They are easily spotted with a huge name on the front of the drawers, the participants also get a map over where and which models to pick out from the dresser, as can be seen in Figure 5.1.

5.2 Findings from User Interaction

The feedback collected during the user evaluations primarily consisted of open-ended group discussions conducted after participants had completed the interaction. Because the feedback was in a group setting, responses were often brief and driven by consensus. However, in several groups, an individual would elaborate and give direct feedback and contributed to more detailed reflections as well as suggestions for improvements of the installation.

Several interaction elements were positively received throughout the testing sessions. The red button, which stands for continue or for the difficulty level medium was was noticed by participants and was noted to be "the red button" (i.e. usually symbolises a warning button) but proceeded to use it as it was intriguing. Participants showed little difficulty in finding the models needed for the missions, suggesting that the visual organisation and categorisation of the objects supported navigation within the installation.

Many participants commented that they had never previously compared scientific entities of such different scales side by side. By physically placing them next to one another, participants expressed a better understanding of the dimensional contrast between the scientific objects. This indicates that the tangible comparison of scale contributed to a more concrete understanding of an otherwise abstract concept.

Some usability issues remained during the user evaluation of the final iteration of the prototype. Several participants placed the models incorrectly in the podium slot, leading to the models being left in an awkward position. Additionally, the drawers were alphabetically organised to re-place the models in their original drawer after finishing the mission. However, this structure was left unnoticed by the participants, only a teacher identified this during this user test session. This made it unclear whether the alphabetical system was sufficient or intuitive for the participants themselves, as the older age range of the user group has tested this new system.

Similarly, the fun facts included in each drawer were largely overlooked, with no participants commenting on them during the later tests. This suggests that they were not perceived as a central part of the interaction, indicating limited engagement with secondary informational elements. A similar pattern was observed regarding the representation of scientific measuring units, which also changed during the iteration process. Earlier prototypes relied on a wider range of scientific units, to elevate the difficulty level, however, frequently resulted in misunderstanding or confusion. As a result, in the final prototype the units were reduced to only cm, m, km and ly. The lesser amount of units proved to be more understandable, less confusing, and created fewer interruptions during interaction.

5.3 Helpful Design Approaches

Several design approaches emerged as particularly helpful throughout the iterative process. The use of tangible interaction supported understanding of, otherwise abstract concepts, by allowing them being manipulable and directly comparable. As an alternative to relying solely on textual or visual explanations, participants can interact with the content through physical exploration and collaborative discussions.

Introducing progressive difficulty levels sustained engagement, meaning that the applied levels of Easier, Medium and Harder (coloured blue, red and black) supported longer engagement with the installation. Moreover, it initiated curiosity and collaborative problem-solving between the group members. It encouraged them to continue exploring beyond a single mission and promoted competitiveness towards being successful on all difficulty levels.

The immediate feedback proved to reduce confusion, according to the evaluations. The feedback provided by the podium was highly appreciated, as it reduced uncertainty about whether the answers were correct after leaving the visitor centre. This also resulted in users interacting with the installation for a longer than one round. The participants also frequently relied on colour coding and visual indicators to navigate the installation independently.

From the earlier prototype, it was evident that hidden information reduced usability. It took them longer to get started with the installation, as well as uncertainty that stayed longer during the initiation phase, compared to the final prototype. Participants asked the authors more questions regarding how to initiate the installation in earlier iterations, whereas users interacting with the final version were able to begin significantly faster.

Overall, the helpful design approaches identified in this study shared a common characteristic: they reduced cognitive barriers while encouraging active participation. Tangible interaction made abstract content more accessible, progressive difficulty levels sustained engagement, immediate feedback supported understanding and confidence, and clear visual communication improved usability. Combined, these approaches supported an interactive experience that encouraged exploration, collaboration, and prolonged engagement with the installation.

5.4 Accessibility and Inclusivity Findings

Several findings related to inclusivity and accessibility emerged during the iterative design process. During the development of the physical mission cards, the initial reliance on colour-coded difficulty levels highlighted a potential accessibility issue regarding colour blindness. To address this, additional shapes were introduced alongside the colour coding in later iterations. However, because participants were not screened for colour vision deficiencies during user evaluations, the effectiveness of these adaptions could not be empirically evaluated.

The installation was also designed to support collaborative interaction. Observations from user evaluations indicated that the installation functioned well in groups of approximately five participants. In larger groups, however, participants who were less engaged with the topic were more likely to disengage from the activity or leave the interaction entirely.

Many of the participants found it difficult to understand scientific units and representations of scale. Difference between the age groups became evident throughout the user evaluations. Younger participants showed marginally more difficulty identifying scientific objects, interpreting abbreviations such as "LY", but more difficulty understanding certain tasks instructions without assistance. In contrast, participants closer to the upper end of the age span were more confident when interacting with the installation and were slightly more likely to discuss possible solutions using prior scientific knowledge. However, all participants remained engaged when the interaction relied on tangible exploration and collaborative problem-solving rather than factual recall alone.

The provided unit sheet was overlooked or misunderstood, where some became very uncertain and thought calculations was required with the sheet. Some confusion emerged between representation of size and distance, which had participants attempt to connect model dimension to scientific measurements. What was concluded from the user evaluation was that unit based information was less intuitive than tangible and visual representations through the installation.

5.5 Summary of key findings

In summary, the result indicated that tangible interaction was helpful. The buttons as well as the models were highly effective in both entertaining the users and keeping them engaged with the installation. The buttons worked especially well with the intended age group of the project, however when in the user tests which included all ages, younger children presented difficulty in using the buttons which was interpreted as them being too short to see them. They also seemed more eager to press the screen instead of the tangible buttons, which is a fine line in this age group.

Participants generally found that the models and their placements were intuitive to use, which findings from the user tests provided. The participants could start their missions before proceeding from the starting screen to the mission screen, which is a sign of positive intuitiveness. Comparing to earlier iterations of the installation, narrowing down the amount of models from 7 to 5 also proved to be more intuitive and less confusing. Although, the participants seems to easier understand where to place the models, the current version still causes some minor confusion of the placement rotation.

The difficulty levels were appreciated by the participants as they typically started with the easier level and then proceeded to medium and hard level, while still entertained based on comments directly from users. It was also noted that the fun facts became less noticed with each user test. The unit sheet, as well as the size information presented during the correction step, was frequently overlooked during earlier iterations. However, during the final user evaluations, participants increasingly noticed and discussed the displayed sizes during the interaction.

Before the final iteration, resetting the installation was inefficient and disrupted the interaction flow. The on-screen map supported participants in locating the correct models efficiently, and together with the colour-coded drawers in the final iteration, created the clearest navigation system throughout the design process. Although feedback about difficulty in relocation was presented, it is considerably easier at this current version.

In conclusion, the results from the user evaluations and the iterative design process several findings help answer the research questions. Adolescents can be engaged through experiential learning at science centres by combining tangible interaction with intuitive navigation, physical exploration and progressively challenging tasks. The use of 3D-printed models and tangible arcade buttons sparked curiosity, encouraged engagement and entertainment. In addition to the different difficulty levels, which fostered continued participation and exploration, the intuitive manipulation and placement of the models, supported learning through hands-on interaction and comparison of scientific scales. Together, these findings contribute to answering the main research question, *"How to design a tangible interactive installation to support adolescents', 10-15 year old's, engagement with scientific scale?"*.

The second research question, *"Which interaction design and tangible interaction principles used during this project are the most helpful for communicating scientific scale in a science centre context?"*, can be answered through the use of tangible interfaces, immediate visual and physical feedback, intuitive navigation systems, and straightforward interaction. The colour-coded drawers, the on-screen map reflecting the physical layout of the installation, and reduced number of models per task improved usability and reduced confusion during interaction. Furthermore, simplifying the scientific measuring units and refining the interaction flow contributed to a more understandable and accessible experience for the participants. There might be more helpful principles to be used, but they have not been tested during this project and will therefore not be a part of this analysis.

6
Discussion

This chapter discusses the findings presented in Chapter 5. The discussion covers a range of varied aspects, including the findings of results, design relations in previous research to design implications and methodological reflections.

6.1 Interpretation of findings and its relation to previous research

Through interactive and collaborative engagement with scientific concepts, the current improved installation encouraged curiosity and the possibility to gain a personal interest to want to learn more. Compared to the original Scaling Dresser, the final version developed during this project has reached a much better experiential learning standard than before. Tangible interaction was the correct choice for this project based on the previous research that experiential learning is a good way to get children to learn and gain a better understanding of concepts through real life examples, such as the 3D models. Peer collaboration and social interaction is also a big part of learning among children. The collaboration part of the installation worked well in smaller groups of 5 users or less, any larger and the dresser became too crowded. This caused some participants to either not see the instructions or not being able to reach any drawers with people in front of them, which most often resulted in them being left out or leaving voluntarily. The CTI framework highlight the importance of "Space for Friends" and "Space for Action" where physical manipulation and peer collaboration support children's cognitive engagement, which the final prototype fulfils. As the visitors actively participate in interacting with the installation, the science capital is increased, which aligns with findings of Gathings and Peterman (2021), that informal STEM environments can contribute to increased science capital.

The visual feedback implemented to improve the user experience showed great response compared to the original dresser. Users can now know what to do without the need of a facilitator if they read the instructions provided on the different pages of the screen. Previously there was no identification of what any of the images portrayed or any way to know if an image was placed in the correct drawer. Even if the visitors remembered the images, they would have no information to go on if trying to search for the objects online after the visit. If a user wanted to learn more about the models used in the final prototype from this project, they would have both the name of the object and its size which was displayed at the end of each mission. They also have an evaluation system that visually displays which models were placed correct or not. Thanks to all of these visual improvements the cognitive effort to participate is reduced, and it directs user attention toward relevant information. For example, in the earlier paper-based mission iteration, participants frequently missed the mission stand until clearer visual guidance was introduced. This suggests that placement and visibility are critical design factors in informal learning environments.

The game aspect of the installation was a big change from the original dresser that user responded positively to. The challenge based structure and difficulty levels seemed to engage the users in the later versions of the prototypes, as the missions were made increasingly harder. The early feedback pointed to having easier missions would not create the need for deeper thinking and discussion among peers, as well as the more difficult missions do. These findings relates to educational game research by Hwang and Kang (2023), who argue that gamified learning environments increase motivation and immersion. The results also connect to Csikszentmihalyi (1990) concept of flow in an optimal experience, where engagement occurs when a task is challenging but still achievable.

Most of the participants had learnt astronomy in school in year three, which meant that the upper age group might not have studied it as recent as the younger group. However, the findings indicated differences between age groups in how participants approached the installation. Younger participants relied heavily on visual cues such as images in the Figma and the posters on the walls, whereas older participants engaged more in collaborative reasoning and discussion around scale relationships. This partially supports Piaget's developmental theory discussed by Kolb (2014), suggesting that children of different ages approach problem-solving differently rather than simply possessing more or less knowledge. The findings also support Wideström et al. (2023), who identified variations in collaborative behaviour between primary and secondary school students in science centre environments.

6.2 Design implications

The onboarding cues should be highly visible, as this supports an intuitive installation process. Participants began with their assigned mission before proceeding to the mission page, which indicates a generally intuitive flow. However, an overly informative and explanatory guide, when combined with an already intuitive interface, may temporarily disrupt the interaction flow. In this case, this did not appear to be of significant issue, however, it entails further testing.

Another disruptor would be the slot and model shapes. The participants were struggling to place the models correctly into their slots on the podium, which not only left the installation look awkward, but the participants were also slightly uncertain of the situation. Instead of designing a platform with models to fit in one way, it would be more beneficial to design a forgiving placement to encourage users instead of confusing them.

Through the evaluations of the prototype, it was demonstrated that tangible interaction supports experiential and collaborative learning. Nevertheless, physical interaction should be directly linked to learning goals, in this case understanding the scales and magnitudes of astronomical sizes, to get a cohesive learning yet playful experience.

It was apparent that the challenge levels mattered for sustained engagement. An appropriate level for the general age group should be found, along with at least an easier and a more difficult level, which should be sufficient for maintaining involvement. However, the effectiveness of this approach depends on clear feedback indicators, which may reduce reliance on facilitators. Without self-directed engagement, the continuity of the installation might not provide the anticipated learning outcome.

6.3 Methodological reflection

Using the WOz method has several limitations, as described earlier. The visible 'wizard' may have influenced participant behaviour, for example by increasing reliance on the facilitator or inducing performance anxiety. Although this was not directly measured in this study, it can only be speculated, based on the behaviours observed. As multiple elements were tested, it is difficult to fully isolate their individual effects which could affect the consistency of the different elements. Consequently, the results cannot be considered fully controlled or directly comparable across iterations. Instead, each iteration should ideally be isolated and test a single element. Subsequently, separate testing phases could evaluate combinations of different iteration versions to assess their combined effects.

The non-random participant selection could be limiting to evaluating different aspects, such as accessibility, age range and so on. This restricts the evaluation and application of accessibility on this installation, however is not forgotten while designing. However, this could possibly catalyse observer bias, which could potentially affect the objectivity of the findings of this particular aspect.

There was also a limitation in the amount of qualitative data collected, as the evaluations sample was skewed toward participants in the upper age group rather than being evenly distributed across the intended age range. This limits the ability to make meaningful comparisons between the age groups and reduces the extent to which age-related differences in interaction behaviour can be identified. Consequently, the qualitative findings reflects the experiences of older participants and should be considered as that. A more balanced distribution across age groups would likely have improved the ability to compare results and understand differences more clearly.

6.4 Limitation

The main limitations throughout this project have been the small sample size of the user evaluations. Due to the remote location of OSO, it can be difficult to find school classes in our preferred age group. Additionally, the user tests were tied to time-limited programmes in which participants also visited other installations at the centre. Therefore, the actual duration of the tests were very short per group in combination with the small amount of students, which resulted in a small amount of collected data that compared to a longer duration which preferably would have provided more data.

Related to the researchers coming into the field as interaction designers, without any prior education within childcare or pedagogy, was difficult concerning gathering the data desired. It is possible that a lack of pedagogical knowledge and experience in engaging with young children influenced the researchers' interactions with participants, thereby affecting the data collection process.

The absence of Year 4–7 participants, combined with a predominance of Year 8 and 9 users in the testing, resulted in data biased toward the upper end of the age spectrum. Due to the lack of a diverse user testing group, there was no way of validating the accessible design choices with the participants. Additionally, collecting unbiased data from the user tests involving the WOz method proved difficult due to the limited physical space. Considering that there was no way of hiding the wizards, nor setting up a proper WOz environment, the data would not be considered complete. Participants may have relied too heavily on the authors during the tests.

Focusing on the actual process of prototyping, the project relied on machines such as 3D-printers. Due to unpredictable printing success, faulty prints could increased production time and need for more material.

Regarding the technological aspects, it is noted in the Delimitation section (Section 1.2) that frequency constraints were one of the reasons why the prototype could not be fully functional. Prior to this insight, it was assumed that different types of scanners could be used to enable an automated verification process. However, the inability to apply frequency-based techniques meant that this part of the project had to be discontinued due to time constraints.

6.5 Future work

Several ideas for future development emerged throughout the iterations of the installation. One of the ambitions of this project was to create an automated feedback system. During the user tests conducted with the WOz-system, which provided automated feedback to the users' experience, participants appeared to enjoy the feedback and were amazed by the "automatic" responses.

The idea of an adaptive difficulty system emerged when we realised that participants mainly wanted to continue interacting with the harder difficulty levels. Therefore, having an adaptive system that can identify entities that have not been used before and generate even more difficult levels could improve the experience for users wanting to challenge themselves further.

We were not able to find users with accessibility needs, which made the installation impossible to adjust accordingly. Therefore, future work should investigate designing and creating a more accessible version of the installation would be ideal.

While testing children and adolescents, it can be difficult to evaluate certain aspects, especially without established methods for evaluation. One of these aspects is their retained understanding of scientific scale, as this is important from the perspective of a science centre. Hence, future evaluations could investigate participants' perceived understanding of scientific scale. However, the interpretation of this result is context-dependent and should be guided by that intended outcome. Science centres are often satisfied if visitors leave with an increased awareness of the importance of science, or greater interest in science than they did prior to visiting.

Although this might not be an actual problem, but rather an intention, it would be interesting to test how users could more easily find the models after finishing an interaction. Why this might not be a problem is that it could encourage more open exploration of the installation. They have continuously received directives to find specific entities, but have not had the opportunity to explore independently. This could give them the opportunity to discover what other entities are present in the installation and therefore encourage them to explore further. However, this interpretation remains speculative and is worth mentioning as a possible area for future work.

As the project was conducted within the scope of a student thesis, the exploration of advanced technical solutions was limited. This could have affected the technological ideas for the installation, which is why not many advanced technical solutions were tested. Thus, it is relevant to include this in future work, since the technology will most likely affect both the interaction and the appearance of the installation.

A few other interactive aspects, such as implementing a read-aloud function instead of relying solely on text-based interaction, creating a more visually engaging screen saver to attract participants to the installation, and further testing and revising the current fun facts, are also relevant for areas for future development.

7 Conclusion

The purpose of this project was to investigate how an existing interactive installation at Onsala Space Observatory visitor centre could be redesigned to better support adolescents aged 10 to 15 in engaging with and understanding scientific scales through tangible interaction. Through an iterative design process including prototyping and user testing, the study explored how interaction design and tangible interaction can improve visitor experiences in informal science learning environments.

The main research question, *"How to design a tangible interactive installation to support adolescents', 10–15 year old's, engagement with scientific scale?"*, can be answered through tangible interaction, intuitive navigation, physical exploration, and progressive challenge, which together supported engagement and encouraged hands-on exploration.

The second research question, *"Which interaction design and tangible interaction principles used during this project are the most helpful for communicating scientific scale in a science centre context?"*, can be answered through tangible interfaces, immediate feedback, intuitive navigation, and clear visual communication, which improved usability, reduced uncertainty, and made the installation more accessible and understandable.

The findings from user tests showed increased engagement when the installation provided clear goals, visual instructions, collaborative opportunities, and hands-on participation. The physical 3D models in each drawer encouraged exploration and discussion among peers, while tasks with different difficulty levels increased motivation and sustained participation throughout the process. The results also highlighted the importance of visual communication, as missing instructions created confusion in the original version of the installation.

Based on the feedback and evaluation data, the study suggests that experiential learning can be strengthened through interaction designs that combine tangible interaction, social collaboration, and structured guidance. Design approaches such as gamification, tangible user interfaces, and clear affordances were found to support engagement and usability among adolescent visitors.

This project demonstrates that designing interactive scientific installations extends beyond communicating scientific facts. It also involves shaping meaningful, exploratory experiences that encourage young visitors to engage with science actively, collaboratively, and on their own terms.

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